Accountability Audit of Natural Resource, Government Environmental Regulation and Pollution Abatement：An Empirical Study Based on Difference-in-Differences Model

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Abstract: For many years, the lack of environmental supervision by local governments has been a challenge for China's environmental governance. In the process of promoting green development, the system of accountability audit of natural resource (AANR for short), which has a supervisory role, is an innovative policy attempt with Chinese characteristics, and pollution emissions are a key factor in assessing the effectiveness of the policy. Based on 2012-2017 panel data from 30 provincial regions, this research empirically investigates the effectiveness of AANR in treating pollution and improving air quality using the difference-in-difference model using the AANR pilot project launched in 2015. The results show that AANR can significantly reduce industrial wastewater and sulfur dioxide emissions and improve air quality in the long term. Meanwhile, AANR can improve the environmental regulating behaviour of local governments, which serves in part as an intermediate. This study recommends enhancing the necessary evaluation standards, promoting the standardisation and institutionalisation of AANR, and implementing big data audit techniques to further boost the promotion effect of AANR on pollution reduction. This research innovatively incorporates natural resource asset separation audits, government environmental regulation and pollution abatement into the same research system, providing theoretical and practical references for achieving green development and building a high-quality modern economic system.

Keywords: Accountability Audit of Natural Resource; pollution reduction; local government environmental regulatory behaviour

1.Introduction

China's fast economic growth since the reform and opening up has come at a great cost in terms of both resources and the environment. For example, after discounting the cost of resource use and environmental losses, GDP growth in many Chinese regions was nearly zero or negative (Feng et al., 2019). In addition, the increase in energy consumption also puts enormous pressure on the environment to reduce emissions (Li et al., 2022). Energy consumption and

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pollution emissions are not only environmental and economic issues, but political and public management issues, which are closely tied to local officials' environmental regulations (Hassan et al., 2022; Okafor et al., 2022). The separation of environmental powers between the central and local governments means that environmental policies of the central government are not strictly enforced at the local level, but are adapted to the actual situation (Zeng et al., 2022). As implementers of central environmental policies, local governments act as "middlemen" between the central government and enterprises. Under the traditional "GDP tournament" model, local officials have been known to relax environmental regulations to pursue financial gain and personal advancement, and this has sometimes led to local officials allowing excessive emissions by local enterprises, especially when sacrificing the environment can promote economic growth (Huang and Xie, 2022; Li and Zhang, 2018; Yu, 2019). To curb the deterioration of this trend, Accountability Audit of Natural Resource (AANR for short) has emerged, which is the focus of this paper.

In 2013, the "decision of the Communist Party of China Central Committee on Comprehensively Deepening the Reform of Some Major Issues" first introduced AANR and officially incorporated environmental and ecological protection into the evaluation system of government institutions. In 2015, the General Office of the CPC Central Committee and the General Office of the State Council jointly launched the Pilot Program on Conducting AANR of Leading Cadres, marking the large-scale pilot period of AANR in China. The implementation of AANR improves ecological monitoring mechanisms for local officials responsible for natural resource management, holds specific leading cadres accountable for environmental pollution management problems, and uses audit results for performance assessment and accountability, thereby addressing the lack of consideration of environmental pollution in the accountability mechanism (Liu and Wang, 2017; Liu et al., 2022; Xiong et al., 2022). Implementing AANR strengthens local governments' responsibility for environmental governance, and local governments will prefer environmentally friendly strategies in their choice of strategies (Liu and Wang, 2017). However, can AANR truly contribute to pollution reduction? What role does government regulation play in this? These questions deserve deeper investigation.

The emission of pollutants not only affects air quality, but also seriously affects individual subjective well-being, and physical health of individuals (Peters et al., 2001; Zhang et al., 2022). Since the implementation of the ecological civilisation construction strategy, China's environmental quality has improved, but the results are not solid and the long-term mechanism has not been established, which makes the pollution prevention and control enter a more difficult period of attack (Chen et al., 2022; Zhang et al., 2023). The reduction of pollutant emissions faces three major challenges: First, how to switch production and life to a green development track (Zhang et al., 2020)? Second, how to scientifically protect and reasonably use the mountains, forests, fields and lakes (Shi et al., 2021)? Third, how to build a long-term mechanism for pollution prevention and control (Chu et al., 2021)? AANR is an innovative system in China to solve the above problems, which can play an important role as a strategic support and institutional guarantee to help reduce pollutant emissions. Therefore, in the subsequent empirical evidence of this paper, we will test the time effect of AANR in pollution reduction to determine whether it plays a long-term mechanism.

AANR is a unique audit policy in China. However, in recent years, there has been growing international interest in this new audit regulation. Governments have also taken action one after another. For example, the US Environmental Protection Agency has the power to conduct direct

audits of companies suspected of falsification in the natural ecology sector; the European Union requires manufacturing companies registered under its eco-audit scheme to conduct audits of natural resource assets and provide audit reports to their 'competent authorities'; the UK Environmental Audit Committee is a specialised body in the UK responsible for conducting The UK Environmental Audit Committee is the administrative body responsible for conducting performance audits of government departments and non-government public bodies, and reporting on these audits to Parliament. In the face of environmental degradation, governments are expected to take responsibility for environmental governance and sustainable development (Betsill et al., 2022). For developing countries, problems of corruption, accountability and poor governance have contributed to the natural resource 'curse' (Adams et al., 2019). If the policy of discharging responsibility for natural resource assets can work in China to curb environmental pollution and protect the environment, then countries such as India, Brazil, and South Africa, which are rich in natural resources, can learn from China's experience and develop sound and effective resource management policies to achieve green development.

Investigating whether AANR has contributed to better environmental quality before and after its implementation is the primary focus of this study, which is being conducted primarily from the standpoint of pollution abatement. Accordingly, a difference-differences model is adopted in this paper to evaluate the impact of AANR pilot as an exogenous shock on pollution abatement and conducts an impact mechanism analysis based on this. The empirical results confirm that the audit pilot has a considerable beneficial policy effect on pollution emission reduction, and it still holds after a one-system robustness test. The pressure for promotion and the environmental responsibility of government officials makes them strengthen their environmental regulation, and it is through influencing government regulation that AANR achieves pollution abatement.

Typically, the difference-in-differences method is used to figure out how well a policy is being put into place (Liu et al., 2022). The application of the model cannot be separated from the AANR policy pilot implementation. Policy pilots, which are summed up in China's gradual reforms, are a set of methodologies that foster policy innovation while simultaneously advancing economic development and social progress (Yang et al., 2022). In fact, the process of promoting a policy pilot is the gradual refinement and development of a new policy and the reforms that go along with it. According to the national unified arrangement, the pilot phase for the leading cadres of AANR was from 2015 to 2017, the nationwide promotion began in 2018, and the AANR system will be more complete by 2020. The phased and step-by-step piloting of AANR offers a unique "natural experiment" condition for the empirical design of this paper, which helps to form a more objective causal judgment of the policy effect.

The contribution of this paper is three-fold. Firstly, institutional economics is used to illustrate the possible policy effects of AANR in terms of pollution reduction. At present, research on AANR has focused more on problem exploration and countermeasure research (Li, 2022; Liu et al., 2020). However, there are few empirical studies on its policy effects. Theoretical analysis alone cannot confirm the effectiveness of the implementation of AANR. Therefore, whether AANR help reduce pollution emissions needs to be tested empirically using a standardised micro-econometric approach. Second, a difference-in-differences model is developed to visualise the pollution abatement effects of AANR different types of pollution emission indicators. The model can reduce the estimation bias and avoid the endogeneity problem brought by the reverse causality problem (Yu et al., 2022), making it easier to figure out what the real effect of AANR is and helping to improve the theoretical system of exit audits.

Third, we attempt to investigate the mechanism of AANR's function in pollution reduction by inserting the mediating variable of local government's environmental regulating behaviour. Since pollution control is a public benefit with negative externalities, the traditional evaluation system and incentive structures that simply prioritise economic growth would inevitably result in inadequate oversight on the part of the government (Khan et al., 2020). With this perspective, this study finds that local government environmental regulatory behaviour plays a part in mediating the pollution abatement effect of AANR and anticipates the long-term effects, further enriching and expanding the literature on government regulation and pollution abatement.

The rest of the article is structured as follows. The second section reviews the previous literature and presents research hypotheses. The third section presents research methods. The results are presented in section four. The full text is discussed and summarised in the final section, with policy recommendations.

2. Literature review and hypothesis development

2.1 Policy effects of Accountability Audit of Natural Resource

Natural resource consumption is rising along with socio-economic growth, and the capacity of those resources to replenish themselves cannot keep up with the rising demands of human society (Almulhim and Cobbinah, 2022). To solve this contradiction between supply and demand, human beings gradually put labour into natural resources, which makes natural resources have labour attributes and scarcity, and thus have value. It is required to account for natural resource assets when combined with the notion of natural resource asset value, and the value of AANR arises at this moment. According to the theory of public fiduciary responsibility, the public has entrusted government agencies and leading officials with the care of natural resource assets, and this trust comes with fiduciary duties, including the need to report on the assets' use and management (Huang, 2022). However, due to information asymmetry in reality, government agencies and leading cadres who hold the right to manage and operate natural resource assets tend to abuse their power and over-exploit and utilise natural resources by taking advantage of their absolute information advantage in order to maximise their own interests (Zhan, 2017). The public is in a disadvantaged position in terms of information, so it is not only difficult to monitor and control the government's actions, but also difficult to take responsibility for the risks because they are too fragmented. However, according to the "Deep Pocket" theory, the risks borne by the public should be appropriately transferred and dispersed. The government agencies and leading cadres as the "Deep Pockets" party should take the initiative to take responsibility and achieve risk transfer. The AANR is such a special monitoring mechanism, taking the role of an independent third party as an information risk reducer and insurer, thus effectively advancing the government's fiduciary obligation for natural resource assets while maximising and optimising the interests of all stakeholders. Its specific logical relationship is shown in Figure 1.

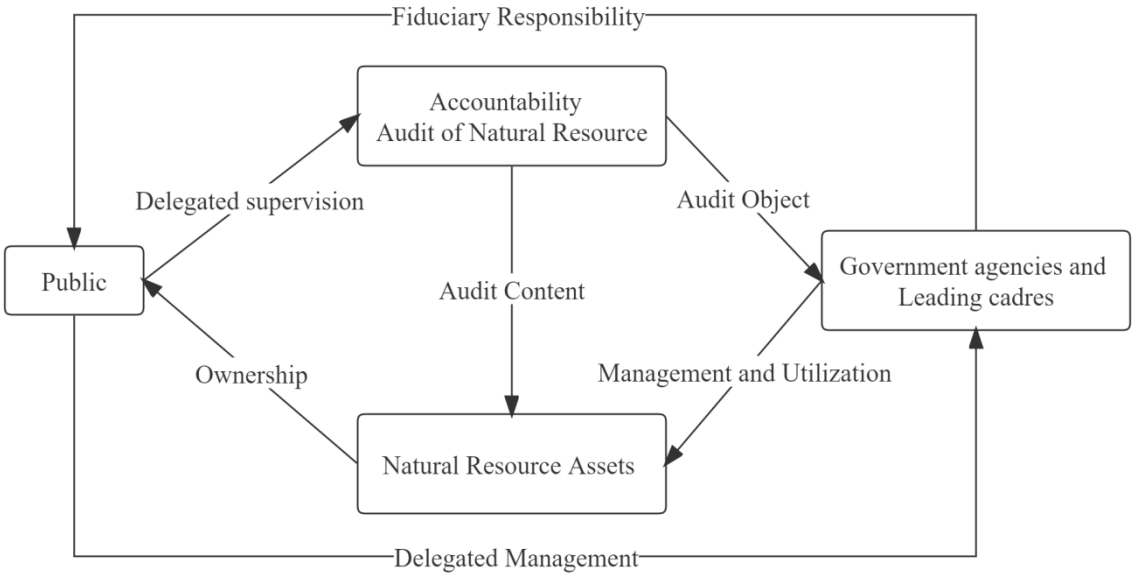

Figure 1：Internal mechanism of Accountability Audit of Natural Resource

AANR is a process in which the auditing department supervises and evaluates the effectiveness of local leading cadres' utilisation of local resource and environmental protection during their tenure according to relevant laws and regulations and evaluates and appraises their performance of duties in resource and environmental management activities. According to institutional economics, institutions can restrict people's options through a variety of rules, thereby reducing interpersonal interactions, giving market economy participants incentives and restraints, preventing rent-seeking in public affairs activities, and lowering environmental uncertainty (Chu, 2019). The object of AANR is the leading cadres, and the implementation of the system will have an incentive and restraint effect on the leading cadres and influence their environmental supervision (Yan et al., 2022). Additionally, institutional economics holds that the secret to development and progress rests with the correspondingly effective institutions, which have the potential to contribute to prosperity and raise welfare. The audit's focus is on how well leadership cadres performed their environmental and resource management responsibilities, which are particularly evident in the results of resource development, exploitation, and environmental protection. The implementation of AANR will have an impact on regional resources and environment, promote pollution reduction and increase social and environmental welfare. Leading cadres are the direct subjects exercising the power of resource and environment management, and their behaviour will inevitably have an impact on the results of the resource and environment. Often stricter environmental regulation will result in less pollution emissions. To sum up, the policy effects of AANR can be divided into two aspects: first, the impact on local environmental regulatory behaviour; second, the impact on pollution emission reduction.

2.2 Natural resources assets discharge audit and pollution reduction

Academic study and policy discussions have centred on finding a balance between ecological limits on economic expansion and environmental protection (Zhang et al., 2020). The Third Plenary Session of the 18th Party put forward "exploring the implementation of the ruling cadres' system of ecological civilisation" as a significant system for balancing economic

and environmental relations, the number of relevant studies has gradually increased, which can be mainly divided into two parts: theoretical studies and policy implementation effects. In terms of theoretical studies, the existing literature mainly focuses on theoretical foundations, audit elements, audit framework, shortcomings in design and policy recommendations (Cai and Bi, 2014; Chen, 2015; Lei and Wang, 2020; Liu and Sun, 2016). In terms of policy implementation effect, existing studies not only consider the influence of AANR on air pollution control and fiscal environmental protection input from the regional level, but also explain its influence on corporate decision-making from the perspectives of tax evasion and equity capital cost (Huang et al., 2019; Jiang and Sun, 2019; Quan et al., 2018).

Specifically, relevant studies have shown that AANR can promote pollution reduction and bring environmental dividends. Implementing this new audit policy does not make economic development give way to environmental dividends but will produce a double dividend effect (Zheng et al., 2022). It can also support high-quality economic development and enable local government cadres and leaders successfully carry out their responsibilities for resources and the environment (Sun and Sun, 2020). On the topic of "pollution", studies have been conducted mainly on water pollution and air pollution. On the one hand, AANR can promote water pollution prevention (Gu, 2019). In particular, the impact of the audit pilot on the prevention of water pollution is more evident in areas where the audit authority attaches high importance, the government has strict regulations of the water environment, and officials have strong incentives for promotion (Li et al., 2022). Not only that, AANR can also improve the quality of water resources over time while having a cumulative effect (Ma et al., 2021). It also shows that the government isn't just trying to improve the environment in the short term but is also starting to investigate whether long-term changes are possible.

On the other hand, AANR has helped cut down on pollution in the air in some ways besides ozone (Feng et al., 2021). AANR can reduce carbon dioxide emissions by improving capacity utilisation in pilot areas (Li and Guo, 2022). Compared to non-pilot areas, it was also able to significantly reduce PM10 (PM2.5) emission concentrations and cut peak emissions of production-sensitive pollutants such as SO2, but air quality did not improve overall (Huang et al., 2019). This suggests that, due to the inertia of the traditional promotion assessment mechanism, leading cadres have adopted the strategy of "environmental qualification race" in air pollution prevention and control. Meanwhile, another study demonstrates that AANR not only reduces haze pollution in pilot cities but also has a subtle spatial spillover effect on haze pollution in nearby cities (Guo et al., 2022). Although there are no studies in the existing literature on the pollution abatement effects of AANR, this paper proposes hypothesis 1 based on the above studies.

Hypothesis 1: The implementation of AANR can promote pollution reduction in pilot areas.

2.3 Analysis of the intermediary effect of government environmental regulation

AANR provides a new means for evaluating the performance of leading cadres in environmental governance. AANR clarifies the environmental governance responsibilities of leading cadres and provides a comprehensive evaluation of the environmental and economic fiduciary responsibilities of leading cadres (Yan et al., 2022). Therefore, the "government-enterprise collaboration" motivated by economic interests will cease to exist when environmental indicators are employed as a significant foundation for the promotion assessment

of government officials (Tang et al., 2021). This new audit model is based on relevant resource and environmental monitoring data and identifies the pollution reduction performance of leading cadres through the assessment of the administration of natural resource assets and ecological and environmental changes in the territory of leading cadres.

AANR has three functions of prevention, revealing, and defence. The preventive function is mainly reflected in the early warning of incipient environmental problems and the deterrence of behaviours that endanger the environment. The revealing function uses government supervision to investigate and correct errors, mainly in understanding the resource management and ecological protection of the audited area and revealing the government input and supervision needed to improve the resource environment at an overall level. The defensive function is mainly reflected in audit recommendations, follow-up audits, and punitive measures (Tang et al., 2019). If these three things are in place, local governments will be more likely to carry out their obligations in the areas of resource management and environmental protection, which will help cut down on pollution and boost the quality of the environment.

Implementing AANR is the start of a system in China that will hold people responsible for ecological and environmental damage for the rest of their lives (Zhang and Wu, 2022). The lifelong accountability for environmental responsibility will prompt local governments to change from "inactive" regulation to "active" regulation in environmental supervision. To a certain extent, local governments' inadequate supervision of polluting enterprises is the root cause of resource and environmental problems (Li et al., 2021). According to the theory of government failure, when the government provides public and environmental resources, it does not supervise and control the enterprises enough or even ignores their illegal behaviours, which will lead to resource depletion and environmental pollution and cause external diseconomies to the whole society. The irresponsibility of enterprises towards the environment can lead to global warming, frequent natural disasters, and increased water, air, and soil pollution, ultimately affecting the ecological balance (Utomo et al., 2020). To address the phenomenon of government failure, the implementation of AANR is to break through the interest relationship between polluting enterprises and local governments, to motivate local government leaders to take action to prevent and control environmental risks, to strengthen environmental regulatory behaviour, to supervise the illegal behaviour of enterprises in their jurisdictions, and to motivate enterprises to actively combat pollution and reduce resource depletion. AANR serve two purposes. First, it prompts local governments to directly supervise enterprises' excessive consumption of resources and environmental pollution. Second, enterprises' opportunistic behaviour in environmental pollution is effectively curbed. Therefore, after the implementation of AANR, local government leaders and cadres, under the deterrence of AANR, will improve environmental oversight of local businesses and prompt them to reduce pollution. In summary, AANR is conducive to strengthening local governments' environmental regulatory behaviour and promoting pollution reduction. Hypotheses 2 and 3 are thus proposed.

Hypothesis 2: The implementation of AANR strengthens the environmental regulatory behaviour of local governments.

Hypothesis 3: Local government environmental regulatory behaviour plays a mediating role in the relationship between AANR and pollution abatement.

3. Study Design

3.1 Sample selection and data sources

We aim to evaluate the impact of the implementation of AANR on pollution reduction. On the one hand, we explore the differences between pilot and non-pilot areas of the policy. On the other hand, we explore the differences between the pilot areas before and after the pilot. Therefore, the study interval includes both the pre-pilot period (we chose 2012 and 2013) and the post-pilot period (we chose 2014 to 2017). 2018 saw the full roll-out of AANR, which changed from a phased audit to a regular audit, and the end of the pilot. Therefore, the data after 2018 no longer satisfy the conditional qualification of the difference-in-differences model (DID). The research interval of this paper is from 2012 to 2017. Due to a severe lack of data, information from Tibet was not used. As a result, 30 provinces, municipalities, and autonomous regions were chosen as the research samples to analyse the influence of the implementation of AANR on pollutant emission reduction.

The following lists the data sources used in this analysis. The pilot information of each region to carry out AANR is derived from the China Audit Yearbook, the National Audit Office, and relevant provincial audit offices. The China Environmental Statistics Yearbook is where the information for the pollution reduction indicators is taken from. Data on local government environmental regulatory behaviour indicators are captured from the Statistical Yearbooks of each region and the China Stock Market & Accounting Research Database (CSMAR). The CSMAR database and the EPS Global Data Analysis Platform are where the data for the control variables are found.

3.2 Model construction and variable definition

This paper employs a multiperiodic DID method (Huang et al., 2019). According to whether they are impacted by the policy, the sample is split into two groups using the DID method: those who are impacted by the policy are the treatment group, and those who are not impacted by the policy are the control group. The DID method then compares the difference between the treatment and control groups before and after policy implementation to determine the effect of policy implementation. Following (Wen et al., 2004) and (Zhang and Li, 2021), we use the DID method to construct Models 1 and 2 based on hypothesis 1 and hypothesis 2 to investigate the effects of AANR on the explanatory and mediating variables. Model 3 was constructed based on hypothesis 3.

$$\mathrm{en}_{\mathrm{it}} = \alpha_0 + \alpha_1 \mathrm{treat} \times \mathrm{time} + \sum_{\mathrm{i}=1}^{\mathrm{N}} \alpha_{\mathrm{j}} \mathrm{X}_{\mathrm{it}} + \alpha_{\mathrm{i}} + \alpha_{\mathrm{t}} + \varepsilon_{\mathrm{it}} \quad (1)$$

$$supervise = \beta_0 + \beta_1 treat \times time + \sum_{i=1}^{N} \beta_j X_{it} + \beta_i + \beta_t + \varepsilon_{it} \quad (2)$$

$$\mathrm{en}_{\mathrm{it}} = \gamma_0 + \gamma_1 \mathrm{treat} \times \mathrm{time} + \gamma_2 supervise + \sum_{\mathrm{i}=1}^{\mathrm{N}} \gamma_{\mathrm{j}} \mathrm{X}_{\mathrm{it}} + \gamma_{\mathrm{i}} + \gamma_{\mathrm{t}} + \varepsilon_{\mathrm{it}} \quad (3)$$

In Models 1 and 3, en is the explanatory variable, which includes industrial wastewater emissions of 10,000 Yuan GDP (hereafter referred to as 'industrial wastewater emissions'), sulfur dioxide emissions of 10,000 Yuan GDP (hereafter referred to as 'sulfur dioxide emissions') and Air Quality Index (AQI). The subscript i denotes individual variable (i.e., region) and t denotes time series (i.e., year). In Model 2, $supervise$ represents local government environmental regulatory behavior. treat represents the regional dummy variable, time represents the time dummy variable, $\mathrm{treat} \times \mathrm{time}$ represents the multiplicative difference term (i.e., DID). The coefficient of the multiplicative difference term calculates the

net effect of AANR on pollution reduction. X_{it} is the control variable, including gross domestic product (GDP), urbanisation rate (urban), industrial structure (industry), and central environmental protection inspector (hbdc). α_i represents the regional fixed effect, which is used to control for inherent differences across regions. α_t represents the time fixed effect and ε_{it} the error term.

3.2.1 Explained variables

Based on the green development index system released by China, this paper selects three basic indicators to measure pollution reduction. In terms of water pollution, the explained variable selected is industrial wastewater discharge. This is because industrial enterprises have more serious pollution issues than other industries (Li et al., 2022). Since exhaust emissions and air quality are selected as the focus of the AANR review, the explained variables selected are sulfur dioxide emissions and AQI.

3.2.2 Explanatory variables

Explanatory variables in this paper include time dummy variable, region dummy variable, and interaction term DID. The time dummy variable (time) is assigned a value of 1 if the region has conducted AANR in the year, and 0 otherwise. The estimated coefficient of this value measures the difference before and after the pilot in the treatment group. The regional dummy variable (treat) is assigned a value of 1 if the region has performed AANR and 0 otherwise. The estimated coefficient of this value measures the difference between the treatment group and the control group. The estimated coefficients of DID measure the impact of AANR on pollution reduction. In addition, dummy variables did1, did2, did3, and did4 are defined in this paper to test the temporal effects of implementing AANR, with a value of 1 when the pilot area is in the pilot year, the second year, the third year, and the fourth year, respectively, and 0 otherwise.

3.2.3 Mediating variables

An essential way to gauge how local governments are behaving in terms of environmental regulation is through environmental monitoring, which includes monitoring of air quality, water quality, and soil quality (Gong and Qi, 2014). We thus use environmental monitoring expenditure (supervise) to measure the environmental regulatory behaviour of local governments and standardise it with industrial value added.

3.2.4 Control variables

When determining control variables, such as GDP, urbanisation rate (urban), and industrial structure (industry), we also add controlling yearly fixed effects and regional fixed effects to control additional potential effects on pollution abatement. Environmental protection inspectors (hbdc) are used to control economic and social characteristics. The physical geographic characteristics are controlled by the annual precipitation (rain), forest cover (forest), annual average temperature (tem), and annual sunshine hours (sun). A summary of study variables is displayed in in Table 1.

Table 1. Definition and description of study variables

Variable Category	Variable Name	Variables Symbol	Variable Description

Explained variables	Industrial wastewater emissions of 10,000 Yuan GDP		water	Total industrial wastewater discharge /GDP
	Sulfur dioxide emissions from		SO2	Industrial sulfur dioxide emissions
	Air quality index		AQI	Number of days with air quality at level 2 or higher /365
Explanatory variables	Time dummy variable		time	The treatment group was taken as 0 before the pilot and 1 after the pilot
	Regional dummy variables		treat	The treatment group was taken as 1 and the control group was taken as 0
	Audit Pilot		DID	DID=time*treat
	Audit pilot year		did1	Audit pilot year take 1, otherwise 0
	Second year of audit pilot		did2	Take 1 for the second year of the audit pilot, otherwise 0
	Third year of audit pilot		did3	Take 1 for the third year of the audit pilot, otherwise 0
	Fourth year of audit pilot		did4	Take 1 for the fourth year of the audit pilot, otherwise 0
Intermediate variables	Environmental monitoring funds		supervise	Environmental monitoring funds / Industrial value added
Control variables	Economic and social characteristics	Gross Domestic Product	GDP	GDP is taken as logarithm
		Urbanisation rate	urban	Urban population / Year-end resident population
		Industry Structure	industry	Industrial value added/GDP
		Central Environmental Protection Inspectors	hbdc	A number of 1 is given to the province that conducted environmental protection inspection during the current year, and a value of 0 otherwise.
	Physical Geographical Features	Annual precipitation	rain	Total annual precipitation
		Forest cover	forest	Forest area/land area
		Average annual temperature	tem	Arithmetic mean of monthly average temperature month by month
		Annual sunshine hours	sun	The sum of the actual hours of sunlight in a year

3.3 Data analysis procedure

The following steps were taken in the data analysis process. For each variable, a t-test and descriptive statistics were first run. Second, correlation analysis was conducted for the relationship between different variables. Third, basic regression analysis was conducted using DID models. Fourth, robustness tests and mediating effects tests were conducted to make the empirical findings of this research more persuasive.

4. Findings

4.1 Descriptive statistics

Table 2 presents the descriptive statistics for the study variables, as well as the T-test findings for the variables before and after the pilot (Fegade et al., 2013). The table shows that the mean value of industrial wastewater emissions in the pilot year is 1.468, lower than 2.517 in the non-pilot year. The mean value of sulfur dioxide emissions in the pilot year is 14.881, lower than 39.369 in the non-pilot year. T-test results reveal major differences between the mean values of the above two indicators at the 0.01 significance level ($p<0.01$) (Allua and Thompson, 2009). The mean value of AQI in the pilot year is 0.719, higher than 0.634 in the non-pilot year ($p<0.01$). This result indicates that, following the implementation of AANR, the level of pollution abatement in the pilot areas improved to varying degrees. This result preliminarily supports Hypothesis 1.

Considering local government environmental regulatory behaviour, the mean value of environmental monitoring expenditure (supervise) in the pilot year is 0.288, higher than 0.085 in the non-pilot year ($p<0.01$). This result shows that after AANR was put into place, local governments tightened their regulations about the environment. This expected result preliminarily supports Hypothesis 2.

Table 2. Descriptive statistics and T-test results for different time samples

Variable Name	VARIABLES	（1） Time=0（Pre-pilot）		（2） Time=1（Post-pilot）		（3） T-test
		N	mean	N	mean	
Explained variables	water	98	2.517	82	1.468	1.049***
	SO_2	98	39.369	82	14.881	24.488***
	AQI	98	0.634	82	0.719	-0.085***
Intermediate variables	supervise	98	0.085	82	0.288	-0.203***
Control variables	GDP	98	9.638	82	10.100	-0.463***
	industry	98	44.291	82	41.894	2.398**
	urban	98	57.678	82	58.856	-1.178
	hbdc	98	0.020	82	0.317	-0.297***

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ reveal significance level of the regression coefficients. Robustness standard errors are in parentheses.

4.2 Correlation analysis

The Pearson correlation coefficients for the explained, explanatory, mediating, and control variables are presented in Table 3. DID and industrial wastewater emissions are negatively correlated ($r=-0.23$, $p<0.01$), indicating that the intensity of wastewater emissions decreased after the implementation of AANR. DID and sulfur dioxide emissions are negatively correlated

(r=-0.318, p<0.01). DID and AQI is positively associated (r=0.224, p<0.01), demonstrating that the intensity of air pollutant emissions decreased, and air quality improved in areas where AANR has been implemented. This result supports Hypothesis 1.

DID and environmental monitoring funding (supervise) are positively correlated (r=0.543, p<0.01). This result suggests that the regions that underwent AANR saw an increase in environmental monitoring funding, and local governments strengthened their environmental regulatory practice. This result supports Hypothesis 2. Finally, considering the magnitude of the correlation coefficients, the absolute values of the variables' correlation coefficients are less than 0.70. This indicates no multicollinearity issues among the study variables.

Table 3. Correlation Analysis

	DID	water	SO_2	AQI	supervise	GDP	industry	urban	hbdc
DID	1								
water	-0.230***	1							
SO2	-0.318***	0.352***	1						
AQI	0.224***	-0.203***	-0.094	1					
supervise	0.543***	-0.201***	-0.399***	0.041	1				
GDP	0.339***	0.110	-0.558***	-0.273***	0.550***	1			
industry	0.008	0.574***	0.284***	-0.309***	-0.073	0.132*	1		
urban	-0.034	-0.262***	-0.486***	-0.053	0.106	0.332***	-0.364***	1	
hbdc	0.163**	-0.303***	-0.233***	0.134*	0.253***	0.070	-0.174**	0.092	1

Note: * p < 0.05, ** p < 0.01, *** p < 0.001 reveal significance level of the regression coefficients. Robustness standard errors are in parentheses.

4.3 Regression analysis

A multiple linear regression was performed on the correlation between AANR and pollution abatement (Schroeder et al., 2016). Table 4 reports the average effect of pollution abatement from AANR after controlling for the fixed effects of the year and province. Models 1, 3, and 5 report the average effects of AANR on industrial wastewater emissions, sulfur dioxide emissions, and AQI without considering control variables. The interaction term coefficients of water and SO2 are significantly negative (p<0.01), and the interaction term coefficients of AQI are significantly positive (p<0.01). Models 2, 4, and 6 include control variables. The coefficient of determination (r2_w) rises after introducing control variables, indicating that the model fit has improved. The regression coefficients of DID are -0.66, -7.55 and 0.08, and their significance, positivity and negativity do not change significantly. This result indicates that the implementation of AANR helped reduce industrial wastewater and sulfur dioxide emissions while improving the AQI rate. Hypothesis 1 is thus supported.

Table 4. AANR and Pollution Abatement (average effect)

	（1）	（2）	（3）	（4）	（5）	（6）
	water	water	SO_2	SO_2	AQI	AQI
DID	-1.22***	-0.66***	-18.55***	-7.55***	0.12***	0.08***
	(-7.80)	(-4.79)	(-5.31)	(-3.01)	(8.80)	(5.16)
GDP		-0.13		-21.80***		0.00

		(-0.61)		(-4.63)		(0.04)
industry		0.09***		1.53***		-0.01***
		(6.31)		(5.04)		(-6.91)
urban		-0.04***		-1.17***		0.00
		(-2.65)		(-3.43)		(0.16)
hbdc		-0.42***		-6.38**		-0.00
		(-3.23)		(-2.29)		(-0.13)
_cons	2.43***	2.15	34.19***	246.36***	0.63***	1.09***
	(14.00)	(1.09)	(7.93)	(5.60)	(21.08)	(3.72)
YEAR	YES	YES	YES	YES	YES	YES
PROVINCE	YES	YES	YES	YES	YES	YES
N	180	180	180	180	180	180
r2_w	0.33	0.63	0.15	0.58	0.34	0.55

Note: * p < 0.05, ** p < 0.01, *** p < 0.001 reveal significance level of the regression coefficients. Robustness standard errors are in parentheses.

Drawing on the studies of (Qian et al., 2018) and (Mao and Zhang, 2021), this paper further assesses the time effects of AANR, as shown in Table 5. Models 1, 3, and 5 report the time effects of each year of the AANR pilot on industrial wastewater emissions, SO_2 emissions, and AQI, respectively. The regression results for each year of the audit pilot are seen to be largely consistent with those in Table 4, demonstrating the robustness of the model. Among them, the estimated coefficients of did1, did2, did3 and did4 for water are all negative, and each year is significantly negative at the 1% level. The estimated coefficients of did1, did2, did3 and did4 for SO2 were all significantly negative at the 1% level. The coefficients of did1, did2, did3 and did4 on AQI are all significantly positive at the 1% level. The absolute values of all three coefficients show an increasing trend, indicating that AANR is a long-term mechanism for reducing pollution. After adding control variables to Models 1, 3 and 5, the coefficient of determination (r2_w) has increased to some extent, indicating that the model's explanatory power has improved. Their significance, positivity and negativity did not change significantly.

Table 5. AANR and Pollution Abatement (Time Effect)

	（1）	（2）	（3）	（4）	（5）	（6）
	water2	water2	SO2	SO2	AQI	AQI
did1	-0.91***	-0.62***	-17.85***	-8.06***	0.08***	0.05***
	(-7.45)	(-4.89)	(-6.08)	(-2.79)	(5.91)	(3.58)
did2	-1.35***	-0.99***	-25.24***	-12.22***	0.09***	0.06***
	(-10.26)	(-7.07)	(-7.99)	(-3.80)	(6.26)	(3.30)
did3	-1.70***	-1.17***	-25.77***	-7.17*	0.12***	0.08***
	(-10.16)	(-6.16)	(-6.43)	(-1.64)	(6.36)	(3.25)
did4	-1.96***	-1.37***	-34.84***	-12.80**	0.14***	0.08***
	(-9.41)	(-5.98)	(-6.95)	(-2.42)	(5.71)	(2.98)
GDP		0.16		-16.38***		-0.01
		(0.78)		(-3.57)		(-0.21)
industry		0.06***		1.11***		-0.01***

		(4.70)		(3.60)		(-6.01)
urban		-0.03**		-1.08***		-0.00
		(-2.48)		(-3.33)		(-0.03)
hbdc		-0.11		-4.06		-0.02
		(-0.85)		(-1.38)		(-1.37)
_cons	2.65***	0.27	39.06***	209.91***	0.63***	1.17***
	(15.14)	(0.15)	(9.15)	(4.94)	(20.49)	(3.70)
YEAR	YES	YES	YES	YES	YES	YES
PROVINCE	YES	YES	YES	YES	YES	YES
N	180	180	180	180	180	180
r2_w	0.61	0.68	0.45	0.59	0.38	0.52

Note: * p < 0.05, ** p < 0.01, *** p < 0.001 reveal significance level of the regression coefficients. Robustness standard errors are in parentheses.

4.4 Robustness tests

4.4.1 Parallel trend test

The DID model assumes that the time trend between the treatment and control groups is fixed in the absence of treatment. Drawing on (Li et al., 2016), the explained variables remain unchanged, the explanatory variables are selected as window variables BT1, BT2, BT3, BT4, and BT5 for the 1-5 years before to the introduction of the AANR. Table 6 displays the regression results. Models 1, 2, and 3 all demonstrate that none of the explanatory variable regression coefficients are statistically significant, indicating that the level of pollution abatement in the two groups of regions is essentially the same in the first five years of the AANR pilot. Furthermore, we also choose the differential value of pollution abatement level as the explained variable and whether to treat group (treat) as the explanatory variable. The treatment regression coefficients in Models 4, 5, and 6 are not significant, implying that the difference in pollution abatement between the two groups maintained the same trend prior to the implementation of the AANR policy. This supports the parallel trend hypothesis in the DID model.

Table 6. Parallel trend test

	（1）	（2）	（3）	（4）	（5）	（6）
	water	SO2	AQI	D.water	D.SO2	D.AQI
BT1	1.38	-18.36	-0.00			
	(1.20)	(-0.93)	(-0.09)			
BT2	1.01	-19.64	0.04			
	(0.87)	(-0.99)	(1.15)			
BT3	1.74	-23.25	0.05			

	(1.59)	(-1.17)	(1.26)			
BT4	1.14	-16.52	0.05			
	(0.99)	(-0.83)	(1.23)			
BT5	1.23	-19.46	0.06			
	(1.07)	(-0.98)	(1.61)			
treat				0.04	0.27	-0.02
				(0.10)	(0.08)	(-1.16)
YEAR	YES	YES	YES	YES	YES	YES
PROVINCE	YES	YES	YES	YES	YES	YES
N	150	150	150	120	120	120
r2_w	0.29	0.56	0.81	0.06	0.33	0.79

Note: * p < 0.05, ** p < 0.01, *** p < 0.001 reveal significance level of the regression coefficients. Robustness standard errors are in parentheses.

4.4.2 Propensity score matching (PSM)

For the policy effect study, the distinction about the treatment and control groups is likely to be overlooked. We rematch the data using the PSM method to assess the contribution of AANR to pollution reduction, ensuring the results are solid and trustworthy. Figure 2 shows the distribution of the standardised deviations after matching, showing that the standardised deviations of the samples were significantly different before matching, and the standardised deviations of the samples were reduced to different degrees after matching, and their standardised deviations met the matching requirements. There is no statistically significant difference in the traits of the treatment and control groups, according to the findings of the four covariate t-tests, which all had p-values greater than 0.1 (Biau et al., 2010).

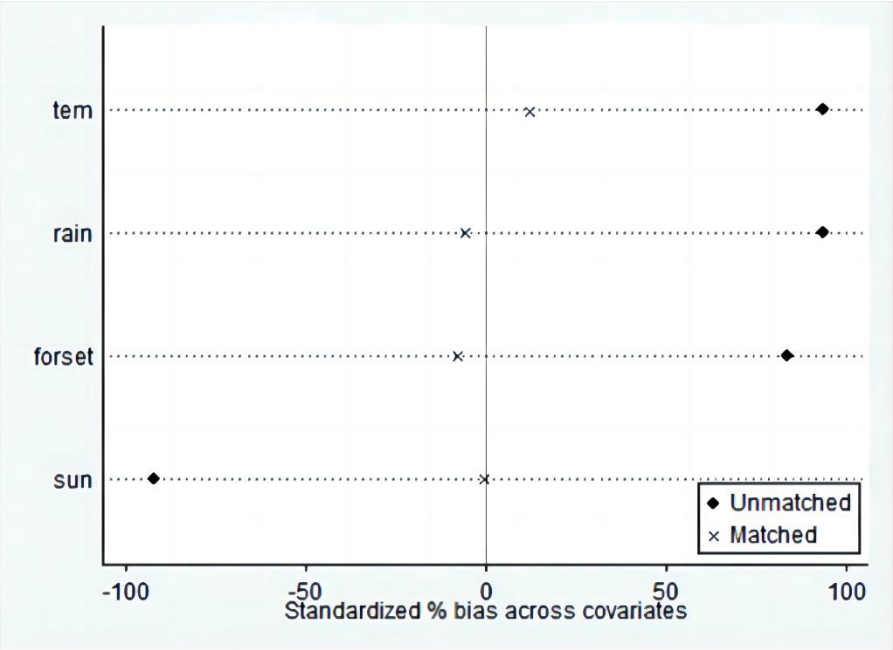

Figure 2. Product Life Cycle Loop

After completing the step of PSM, the DID model was used to run the regression analysis once again. The regression's findings are displayed in Table 7. The findings demonstrate that the implementation of AANR has a pronounced effect on the reduction in environmental contaminants. The findings are in line with those of the basic regression analysis in terms of positivity, negativity, and significance, firmly establishing the validity of this paper's conclusions.

Table 7. Propensity Score Matching (PSM) Regression Results

	（1）	（2）	（3）	（4）	（5）	（6）
	water	water	SO2	SO2	AQI	AQI
DID	-1.31***	-0.62***	-19.52***	-6.33**	0.14***	0.08***
	(-7.60)	(-4.22)	(-6.10)	(-2.49)	(8.32)	(4.71)
GDP		-0.52**		-27.07***		0.02
		(-2.21)		(-5.08)		(0.49)
industry		0.09***		1.40***		-0.01***
		(6.41)		(5.09)		(-6.24)
urban		-0.03**		-1.14***		0.00
		(-2.26)		(-3.20)		(0.07)
hbdc		-0.39***		-3.21		0.04
		(-2.75)		(-1.29)		(0.32)
_cons	2.59***	5.54***	33.55***	304.08***	0.62***	0.92***
	(13.48)	(2.60)	(6.30)	(6.18)	(19.59)	(2.70)
YEAR	YES	YES	YES	YES	YES	YES
PROVINCE	YES	YES	YES	YES	YES	YES
N	147	147	147	147	147	147
r2_w	0.33	0.66	0.23	0.65	0.38	0.58

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ reveal significance level of the regression coefficients. Robustness standard errors are in parentheses.

4.4.3 Counterfactual test

Referring to Fan and Tian (2013), we perform a counterfactual test by modifying the dummy time when the policy works, i.e., artificially setting the time of the AANR pilot and testing it. This is done by advancing the time of the audit pilot in the treatment group by one year in all cases and re-running the DID estimation, whose regression results are presented in Models 1, 2, and 3 in Table 8. The DID coefficients of all three models are not significant, indicating that pollution reduction is not caused by the influence of time trends, further verifying that AANR has a pollution reduction effect.

4.4.4 Delete part of the sample

From 2013, when the concept of AANR was first proposed, to 2014, when the pilot was successively launched, and then to 2015, when the program was promulgated, this phase of AANR was piloted on a small scale in China. Therefore, the auditors in the pilot region were still in the policy mapping stage in 2014. As a result, the sample from the year of the 2014 policy shock was removed and re-regressed in this study to confirm the reliability of the conclusions of the above analysis. The results are shown in Models 5, 6, and 7 in Table 8, and their significance and positivity are consistent with the benchmark test, further verifying the stability of the results.

Table 8. Counterfactual test with partial sample deletion

	（1）	（2）	（3）	（4）	（5）	（6）
	SO2	AQI	water1	water2	SO2	AQI
DID	0.45	0.03	-6.34	-0.84***	-8.27***	0.09***
	(0.14)	(1.38)	(-1.45)	(-5.47)	(-2.83)	(5.77)
GDP	-22.51***	0.00	-55.67***	-0.03	-20.23***	0.01
	(-4.77)	(0.03)	(-3.68)	(-0.16)	(-4.38)	(0.18)
industry	1.57***	-0.01***	-0.05	0.09***	1.65***	-0.01***
	(5.24)	(-7.09)	(-0.09)	(6.30)	(5.20)	(-6.69)
urban	-1.17***	0.01	-4.22***	-0.03**	-0.96***	0.00
	(-3.42)	(0.49)	(-3.91)	(-2.11)	(-2.87)	(0.26)
hbdc	-6.44**	0.00	-1.63	-0.32**	-4.80	-0.01
	(-2.31)	(0.16)	(-0.40)	(-2.40)	(-1.63)	(-0.09)
_cons	250.61***	1.04***	900.73***	0.56	212.45***	0.99***
	(5.72)	(3.58)	(6.88)	(0.29)	(4.90)	(3.39)
YEAR	YES	YES	YES	YES	YES	YES
PROVINCE	YES	YES	YES	YES	YES	YES
N	180	180	150	150	150	150
r2_w	0.59	0.59	0.52	0.66	0.61	0.65

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ reveal significance level of the regression coefficients. Robustness standard errors are in parentheses.

4.5 Intermediation effect test

The regression analysis results show a significant influence of the explanatory variables on the explained variables, so the mediating variables do not fully mediate between the two (Allen, 2004). The test of mediating effect mainly explores whether the mediating variable plays a partial mediating role. Therefore, this paper successively tested the effect of explanatory variables on mediating variables and mediating variables on explained variables. Table 9 displays the test results.

According to Model 1, the coefficients of AANR and environmental monitoring funds are significantly positive at the 1% level, indicating that after the implementation of AANR in the pilot areas, local government leaders and cadres implemented stricter environmental regulation and strengthened local government environmental regulatory behaviour, which verifies hypothesis 2. Model 2 presents the findings after including the control variables, and we can see that the introduction of the goodness-of-fit adjustment (r2 w) increases, denoting that the model is more convincing. The results are fully consistent with the positive, negative, and significant compared with Model 1, further verifying the stability of the results. Model 3 presents the time effect of AANR on environmental regulatory behaviour. The results show that all the coefficients are statistically significant at the 1% level and are on the rise, indicating that AANR plays a long-term mechanism for local governments to strengthen environmental regulatory behaviour. Model 4 presents the regression results with the inclusion of control variables, which are overall consistent with Model 3.

Models 5, 6, and 7 show that the contribution effects of environmental monitoring funding on industrial wastewater emissions, SO_2 emissions, and AQI are all significant at the 1% level. In addition, the coefficients of DID also meet the significance requirements, indicating that environmental monitoring funds play a partly mediating role, which verifies hypothesis 3. Models 5, 6, and 7 show that the contribution effects of environmental monitoring funding on industrial wastewater emissions, SO_2 emissions, and AQI are all significant at the 1% level. In addition, the coefficients of DID also meet the significance requirements, indicating that environmental monitoring funds plays a partly mediating role, which verifies hypothesis 3.

Table 9. Intermediation effect test

	（1）	（2）	（3）	（4）	（5）	（6）	（7）
	supervise	supervise	supervise	supervise	water2	SO2	AQI
DID	0.23***	0.16***			-0.69***	-8.58**	0.09***
	(9.29)	(6.50)			(-3.92)	(-2.10)	(5.41)
did1			0.09***	0.07***			
			(3.91)	(2.58)			
did2			0.21***	0.17***			
			(8.16)	(6.11)			
did3			0.30***	0.25***			
			(9.53)	(6.85)			
did4			0.32***	0.25***			
			(7.94)	(5.68)			
GDP		0.12***		0.11***			
		(5.29)		(4.88)			
industry		-0.01***		-0.00**			
		(-2.98)		(-2.05)			
urban		-0.00		-0.00			
		(-1.03)		(-1.18)			
hbdc		0.06**		-0.01			
		(2.41)		(-0.23)			
supervise					-2.35***	-42.04***	0.14***
					(-5.49)	(-4.21)	(3.36)

_cons	0.10***	-0.71***	0.09***	-0.67***	2.68***	38.44***	0.62***
	(4.64)	(-3.38)	(3.91)	(-3.31)	(14.97)	(8.90)	(20.77)
YEAR	YES	YES	YES	YES	YES	YES	YES
PROVINCE	YES	YES	YES	YES	YES	YES	YES
N	180	180	180	180	180	180	180
r2_w	0.34	0.46	0.50	0.53	0.47	0.23	0.40

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ reveal significance level of the regression coefficients. Robustness standard errors are in parentheses.

5. Discussion and implications

The goals of AANR are to strengthen the government's environmental oversight, improve the assessment and accountability system for ecological civilisation performance, and make sure that senior cadres carry out their duties for natural resource asset management and environmental protection. By doing this, the environment will be improved, and the green development will be encouraged. Based on a theoretical analysis of AANR, we propose three hypotheses that AANR promote pollution reduction and its mechanism of action and conduct an empirical analysis using panel data from 30 provincial regions from 2012-2017 through a DID model to obtain the following conclusions.

First, the implementation of AANR can significantly reduce industrial wastewater and sulfur dioxide emissions and improve air quality. Air pollution is a critical environmental issue that draws public attention and is measured by indicators such as AQI and emissions of polluting gases; therefore, local governments are more motivated to combat air pollution (Huang et al., 2019). AANR has forced local officials to pay attention to local air quality and take prompt action to address excessive emissions of pollutants such as SO2, CO2 and PM2.5 (Feng et al., 2021; Guo et al., 2022; Li and Guo, 2022). In addition to air pollution, water pollution has a direct impact on public health and is also a key area of focus for AANR, whose effects on water pollution are mainly reflected in the improvement of indicators such as dissolved oxygen and chemical oxygen demand (Li et al., 2022; Ma et al., 2021). Our study builds on previous research by integrating water pollution and air pollution in a unified research system, confirming that AANR can have a dampening effect on different types of pollutants and accelerate the process of green development in China.

Second, the results of the assessment of the time effect reveal a developing trend in the pollution reduction effect of AANR, suggesting that it functions as a long-term mechanism for pollution reduction and air quality improvement. The solution to environmental problems is a long-term process, and the contradiction between environmental protection and economic growth cannot be fundamentally solved if environmental performance is improved in the short term only through campaign-style enforcement (Zeng et al., 2022). On the one hand, "leaving office without accountability" is the reason AANR can be a long-term mechanism. Local authorities will be held responsible for ecological and environmental pollution issues discovered by the audit for the rest of their lives under AANR, a system of ongoing responsibility (Chen et al., 2023). On the other hand, during the pilot stage, government agencies' experience was insufficient. China's eco-environmental supervision mechanism is moving forward in exploration. After absorbing the lessons learned over a long time, the system of AANR has been continuously improved in practice.

Third, the intermediary effect test shows that AANR strengthens the environmental regulatory acts of local governments, which in turn promotes pollution abatement. Local government environmental regulatory actions play a partially intermediary role. The main reason for this finding is that the accountability mechanism of AANR has worked. On the one hand, the auditing authority monitors the power operation of the leading cadres in resource management and environmental protection, and if it finds any power operation irregularities, it needs to hold the leading cadres accountable for resource and environmental management, even if the leading cadres have left their jobs (Xiong et al., 2022; Zeng et al., 2022). On the other hand, timely information on the performance of leading cadres in resource and environmental management ought to be delivered to the relevant departments, as this will serve as a significant basis for promotion, appraisal, reward, and punishment of leading cadres(Huang and Xie, 2022). The implementation of AANR will disclose information about environmental governance of leading cadres, and the ensuing promotion incentives and accountability will increase the importance of environmental issues for leading cadres. Leadership cadres will strengthen local governments' environmental regulatory actions, conduct stricter monitoring of environmental indicators, and restrain the behaviour of environmental polluters from preventing further deterioration of the ecological environment.

Three policy suggestions are offered based on the findings of the study. First, the criteria that are used to judge how well leading cadres make decisions and keep an eye on things like resources and the environment need to be changed. Based on the above findings, we found that after including pollution emission as an evaluation indicator, AANR did play a role in curbing pollution emission. Therefore, to play a greater role in AANR, consideration should be given to including the implementation of the major deployments of the Party Central Committee, such as natural resources protection, ecological protection red line, arable land protection red line, river and lake long system, among the evaluation indicators. Scientifically set the evaluation index weights and scoring methods to strengthen the constraints on resources and environment, led by important environmental indicators such as the physical quantity of natural resources assets and ecological environment quality.

Second, promote the standardisation and institutionalisation of AANR. The above study shows that the effect of conducting AANR on the government's environmental regulation is beginning to show. The next step should be to continue to improve the design of the system and make it more effective. The current problems faced by AANR are that due to the lack of relevant auditing standards in China, in different regions, the audits are carried out differently, the audit content varies widely, and the audit standards are not uniform (Guo et al., 2022). Therefore, China should develop audit standards related to this as soon as possible. From the root to standardise the work of AANR, so that each region can reasonably determine the audit content, evaluation criteria, etc. according to regional characteristics.

Third, carry out big data audits to improve the efficiency of AANR. Our study finds that government environmental regulation plays a partial mediating role in the pollution reduction effect of AANR. If the efficiency of government regulation can be further improved, then pollution emission will be curbed to a greater extent. In practice, the objects of outgoing audits are various natural resource assets such as land, water, minerals, forests and oceans, which are diverse and widely distributed (Yang et al., 2021). If the audit assessment is conducted only through human tactics and traditional audit methods, huge human and material resources are required. In recent years, big data has been increasingly crucial in economic and social development. Big data technology can be used by party governments to manage natural

resources and the ecological environment, such as using GIS data to manage land and forests and databases to manage online monitoring data.

This study explores in depth the relationship among AANR, government environmental regulation and pollution reduction. However, due to the limitation of research data and the number of indicators, future studies can be optimised in the following aspects. The variables selected in this paper mainly measure the effect of pollution control, but with the introduction of the "Double Carbon" target, future research can explore the environmental performance from the perspective of climate governance and add the environmental indicator of carbon dioxide as the explanatory variable. Moreover, in the analysis of the pathway of the impact of AANR on pollution reduction, this paper only considers the government as the main body, without considering other social bodies. Therefore, future research can also analyse the impact of this policy on the behaviour of enterprises to enrich the research on the pathways of action.

6. Conclusion

In conclusion, this paper empirically investigates the effectiveness of AANR in treating pollution and improving air quality using the difference-in-difference model based on the AANR pilot project launched in 2015. The novelty of the paper is that it incorporates natural resource asset separation audits, government environmental regulation, and pollution abatement into the same research system, providing theoretical and practical references for achieving green development and building a high-quality modern economic system. The results show that AANR can significantly reduce industrial wastewater and sulfur dioxide emissions and improve air quality in the long term. Additionally, AANR can improve the environmental regulatory behaviour of local governments, serving in part as an intermediate.

This paper contributes to the literature by providing empirical evidence on whether AANR helps reduce pollution emissions using a standardised micro-econometric approach. The paper enriches the literature on government regulation and pollution abatement by highlighting the role of local government environmental regulatory behaviour in mediating the pollution abatement effect of AANR. Based on the findings, we recommend enhancing the necessary evaluation standards, promoting the standardisation and institutionalisation of AANR, and implementing big data audit techniques to further boost the promotion effect of AANR on pollution reduction.

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.

Data availability

The authors do not have permission to share data.

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Author contribution statement

Yalian Zhang: Writing original draft, Writing review & editing, Funding acquisition, Supervision. **Qihang Zhang:** Writing original draft, Formal analysis. **Hexiao Hu：** Writing original draft. **Cao Wang:** Writing original draft, Data curation, Software. **Xin Guo:** Writing review & editing, proof reading and validation.

References

Adams, D., Adams, K., Ullah, S., Ullah, F., 2019. Globalisation, governance, accountability and the natural resource 'curse': Implications for socio-economic growth of oil-rich developing countries. Resources Policy 61, 128-140.
Allen, M.P., 2004. Understanding regression analysis. Springer Science & Business Media.
Allua, S., Thompson, C.B., 2009. Hypothesis testing. Air medical journal 28(3), 108-153.
Almulhim, A.I., Cobbinah, P.B., 2022. Urbanisation-environment conundrum: an invitation to sustainable development in Saudi Arabian cities. International Journal of Sustainable Development & World Ecology, 1-15.
Betsill, M.M., Enrici, A., Le Cornu, E., Gruby, R.L., 2022. Philanthropic foundations as agents of environmental governance: a research agenda. Environmental Politics 31(4), 684-705.
Biau, D.J., Jolles, B.M., Porcher, R., 2010. P value and the theory of hypothesis testing: an explanation for new researchers. Clinical Orthopaedics and Related Research® 468, 885-892.
Cai, C., Bi, M., 2014. Theoretical thinking about accountability audit of natural resource. Audit Res 5, 3-9.
Chen, B., 2015. Auditing of Natural Resources Assets before the Leading Cadres Leave Their Post Based on the Protection of Property Rights. Journal of Audit & Economics 30(05), 15-23.
Chen, H., Xu, J., Zhang, K., Guo, S., Lv, X., Mu, X., Yang, L., Song, Y., Hu, X., Ma, Y., 2022. New insights into the DPSIR model: Revealing the dynamic feedback mechanism and efficiency of ecological civilisation construction in China. Journal of Cleaner Production 348, 131377.
Chen, X., Ou, J., Tang, X., Yang, Q., 2023. The Impact of Officials' Off-Office Accountability Audit of Natural Resource Assets on Firms' Green Innovation Strategies: A Quasi-Natural Experiment in China. Sustainability 15(3), 2640.
Chu, E., 2019. Analysis of "full coverage" of audit supervision based on institutional economics. Finance and Accounting Monthly (15), 96-99.
Chu, Z., Bian, C., Yang, J., 2021. Joint prevention and control mechanism for air pollution regulations in China: A policy simulation approach with evolutionary game. Environmental Impact Assessment Review 91, 106668.
Fegade, S.L., Tande, B.M., Cho, H., Seames, W.S., Sakodynskaya, I., Muggli, D.S., Kozliak, E.I., 2013. Aromatisation of propylene over Hzsm-5: A design of experiments (DOE) approach. Chemical Engineering Communications 200(8), 1039-1056.

Feng, Y., Wang, X., Du, W., Wu, H., Wang, J., 2019. Effects of environmental regulation and FDI on urban innovation in China: A spatial Durbin econometric analysis. Journal of Cleaner Production 235, 210-224.
Feng, Y., Wang, X., Hu, S., 2021. Accountability audit of natural resource, air pollution reduction and political promotion in China: Empirical evidence from a quasi-natural experiment. Journal of Cleaner Production 287, 125002.
Gong, M., Qi, Y., 2014. A Behavior Analysis of Local Government's Environmental Governance from Perspective of Information Structure: On Case of Pollutants Emission Reduction during the “Eleventh Five-Year Plan” Period. Journal of Nanjing University of Technology(Social Science Edition) 13(01), 39-46.
Gu, Y., 2019. Study on Policy Effect of Outgoing Audit of Natural Resources Assets Promoting Water Pollution Prevention and Control Nanjing Audit University.
Guo, Q., Wei, Y., Wan, R., 2022. Leading officials’ accountability audit of natural resources and haze pollution: Evidence from China. Environmental Science and Pollution Research, 1-17.
Hassan, T., Khan, Y., He, C., Chen, J., Alsagr, N., Song, H., 2022. Environmental regulations, political risk and consumption-based carbon emissions: Evidence from OECD economies. Journal of Environmental Management 320, 115893.
Huang, R., 2022. Auditing the environmental accountability of local officials and the corporate green response: evidence from China. Applied Economics, 1-21.
Huang, R., Xie, X., 2022. Can Accountability Audit of Natural Resources Improve the Implementation Ability of Local Government's Environmental Governance? Journal of Audit & Economics 37(04), 9-20.
Huang, R., Zhao, Q., Wang, L., 2019. Accountability audit of natural resource and air pollution control: Harmony tournament or environmental protection qualification tournament. China Industrial Economics 10, 23-41.
Jiang, Q., Sun, F., 2019. Leading Officials' Natural Resources Accountability Audit and Corporate Tax Avoidance——A study based on natural experiment of government leaders' promotion system. Auditing Research(03), 35-43.
Khan, S.A.R., Zhang, Y., Kumar, A., Zavadskas, E., Streimikiene, D., 2020. Measuring the impact of renewable energy, public health expenditure, logistics, and environmental performance on sustainable economic growth. Sustainable development 28(4), 833-843.
Lei, J., Wang, Z., 2020. Supply-side reforms of natural resource assets auditing system. China Population,Resources and Environment 30(01), 12-21.
Li, B., 2022. Exploring the issue of natural resources assets exit audit. Communication of Finance and Accounting(17), 118-122.
Li, B., Zhang, X., 2018. Theoretical and empirical analysis of environmental pollution transfer in China from the perspective of collusion between government and enterprises. Journal of Central University of Finance and Economics 5, 72-81.
Li, P., Lu, Y., Wang, J., 2016. Does flattening government improve economic performance? Evidence from China. Journal of Development Economics 123, 18-37.
Li, T., Li, X., Liao, G., 2022. Business cycles and energy intensity. Evidence from emerging economies. Borsa Istanbul Review 22(3), 560-570.
Li, Y., Li, L., Zhai, H., 2022. Discharge audits of natural resource assets and water pollution prevention and control: empirical data based on water quality monitoring in major river basins in China. Jiangxi Social Sciences 42(05), 90-100.

Li, Z., Guo, L., 2022. Can Off-office Auditing of Natural Resource Assets of Leading Cadres Promote Energy Conservation and Emission Reduction? Journal of Nanjing Audit University 19(03), 31-39.
Li, Z., Zou, F., Mo, B., 2022. Does mandatory CSR disclosure affect enterprise total factor productivity? Economic Research-Ekonomska Istraživanja 35(1), 4902-4921.
Li, Z., Zou, F., Tan, Y., Zhu, J., 2021. Does financial excess support land urbanisation—an empirical study of cities in China. Land 10(6), 635.
Liu, H., Wang, C., Zhang, M., Wang, S., 2022. Evaluating the effects of air pollution control policies in China using a difference-in-differences approach. Science of the Total Environment 845, 157333.
Liu, M., Sun, J., 2016. Research on Elements of Accountability Audit of Natural Resources Assets for Leading Carders. Journal of Audit & Economics 31(04), 12-20.
Liu, R., Wang, H., 2017. Analysis of Audit of Outgoing Leading Officials' Natural Resources Accountability. Auditing Research(04), 32-38.
Liu, S., Geng, J., Lv, X., 2020. Research on Natural Resources Asset Accounting and Management: Taking Practice on Land Resource in County A as an Example. Fudan Journal(Social Sciences Edition) 62(06), 165-173.
Liu, Y., She, Y., Liu, S., Tang, H., 2022. Can the Leading Officials' Accountability Audit of Natural Resources policy stimulate Chinese heavy-polluting enterprises' green behavior? Environmental Science and Pollution Research 29(31), 47772-47799.
Ma, X., Shahbaz, M., Song, M., 2021. Off-office audit of natural resource assets and water pollution: a quasi-natural experiment in China. Journal of Enterprise Information Management.
Mao, L., Zhang, Y., 2021. Robust optimal excess-of-loss reinsurance and investment problem with p-thinning dependent risks under CEV model. Quantitative Finance and Economics 5(1), 134-162.
Okafor, S.O., Izueke, E.M., Nzekwe, I., Okezi, O., Isah, A., 2022. Urban Settlement and Behavioural Exchange towards Environmental Policy among Urban Settlers in Southeast Nigeria: Implications for Environmental Policy Administration and Sustainability. Public Policy and Administration 21(1).
Peters, A., Dockery, D.W., Muller, J.E., Mittleman, M.A., 2001. Increased particulate air pollution and the triggering of myocardial infarction. Circulation 103(23), 2810-2815.
Qian, X., Kang, J., Tang, Y., Cao, X., 2018. Industrial policy, efficiency of capital allocation and firm's total factor productivity—Evidence from a natural experiment in China. China Industrial Economics 8, 42-59.
Quan, J., Liu, W., Xie, B., 2018. Leading officials' accountability audit of natural resources political connection and the cost of equity capital. Audit Res 2, 46-54.
Schroeder, L.D., Sjoquist, D.L., Stephan, P.E., 2016. Understanding regression analysis: An introductory guide. Sage Publications.
Shi, X., Zhou, F., Wang, Z., 2021. Research on optimisation of ecological service function and planning control of land resources planning based on ecological protection and restoration. Environmental Technology & Innovation 24, 101904.
Sun, W., Sun, Y., 2020. An Empirical Study on the Impact of Resource-Environment Audit on High-Quality Economic Development:A Pilot Study on the Audit of Natural Resources Assets of Leading Cadres as an Example. Ecological Economy 36(01), 166-171.
Tang, P., Feng, Y., Li, M., Zhang, Y., 2021. Can the performance evaluation change from

central government suppress illegal land use in local governments? A new interpretation of Chinese decentralisation. Land Use Policy 108, 105578.
Tang, S., Shi, W., Sun, A., 2019. Environmental Pollution and Firm Value: Theory and Empirical Evidence. Journal of Financial Research(08), 133-150.
Utomo, M.N., Rahayu, S., Kaujan, K., Irwandi, S.A., 2020. Environmental performance, environmental disclosure, and firm value: empirical study of non-financial companies at Indonesia Stock Exchange. Green Finance 2(1), 100-113.
Wen, Z., Lei, C., Kit-Tai, H., Hongyun, L., 2004. Testing and application of the mediating effects. Acta Psychologica Sinica.
Xiong, H., Li, Y., He, J., 2022. Construction and Application of the Evaluation System of Natural Resources Asset Accountability Audit of Officials: A Case Study of Jiangxi, China. Sustainability 14(1), 528.
Yan, Y., Cheng, Q., Huang, M., Lin, Q., Lin, W., 2022. Government Environmental Regulation and Corporate ESG Performance: Evidence from Natural Resource Accountability Audits in China. International Journal of Environmental Research and Public Health 20(1), 447.
Yang, S., Wang, W., Feng, D., Lu, J., 2022. Impact of pilot environmental policy on urban eco-innovation. Journal of Cleaner Production 341, 130858.
Yang, Y., Jia, Y., Ling, S., Yao, C., 2021. Urban natural resource accounting based on the system of environmental economic accounting in Northwest China: A case study of Xi'an. Ecosystem Services 47, 101233.
Yu, M., 2019. Technological and Political Logic and Its Interaction of Meticulous Environmental Governance Tianjin Social Sciences(06), 75-79+97.
Yu, Y., Dai, C., Wei, Y., Ren, H., Zhou, J., 2022. Air pollution prevention and control action plan substantially reduced PM2. 5 concentration in China. Energy Economics 113, 106206.
Zeng, H., Li, X., Zhou, Q., Wang, L., 2022. Local government environmental regulatory pressures and corporate environmental strategies: Evidence from natural resource accountability audits in China. Business Strategy and the Environment 31(7), 3060-3082.
Zhan, J.V., 2017. Do natural resources breed corruption? Evidence from China. Environmental and Resource Economics 66(2), 237-259.
Zhang, D., Xu, J., Zhang, Y., Wang, J., He, S., Zhou, X., 2020. Study on sustainable urbanisation literature based on Web of Science, scopus, and China national knowledge infrastructure: A scientometric analysis in CiteSpace. Journal of cleaner production 264, 121537.
Zhang, G., Ren, Y., Yu, Y., Zhang, L., 2022. The impact of air pollution on individual subjective well-being: evidence from China. Journal of Cleaner Production 336, 130413.
Zhang, H., Geng, Z., Yin, R., Zhang, W., 2020. Regional differences and convergence tendency of green development competitiveness in China. Journal of Cleaner Production 254, 119922.
Zhang, P., Wu, H., 2022. Does the Exit Audit of Natural Resource Assets of Leading Cadres Promote the Fulfillment of Corporate Environmental Responsibility? Journal of Audit & Economics 37(02), 24-33.
Zhang, Q., Zhang, Y., Liao, Q., Guo, X., 2023. Effect of green taxation on pollution emissions under ESG concept. Environmental Science and Pollution Research, 1-16.
Zhang, Y., Li, X., 2021. Environmental Law Enforcement Supervision and Air Quality:Quasi-natural Experimental Evidence from Central Environmental Protection Inspectorate. Journal

of Technology Economics 40(11), 112-121.
Zheng, P., Wang, X., Zhao, L., 2022. Study on the Double Dividend Effect of Discharge Audit of Natural Resource Assets: The Case of Marine Fisheries in Chinese Coastal Cities. Friends of Accounting(14), 92-98.