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GOVERNMENT ENVIRONMENTAL AUDITS AND POLLUTION CONTROL PERFORMANCE: A COMPARATIVE ANALYSIS OF HEBEI, GUANGDONG, AND ZHEJIANG

Abstract: Government environmental audits play a critical role in strengthening ecological governance and supporting China's "dual-carbon" objectives. This study evaluates the pollution control performance of Hebei, Guangdong, and Zhejiang Provinces from 2013 to 2022 through the lens of government environmental auditing. Based on the PSR (Pressure-State-Response) framework, an audit-oriented evaluation index system was constructed and weighted using the analytic hierarchy process (AHP). Grey relational analysis (GRA) was then employed to calculate provincial performance scores and examine temporal trends. The results show that all three provinces exhibit an overall upward trend in pollution prevention and control performance, although with clear regional disparities. Zhejiang performs consistently well, achieving "excellent" ratings after 2020, while Guangdong shows steady improvement with periodic fluctuations. Hebei, despite high investment in pollution-control funding, demonstrates limited progress and remains under the greatest environmental pressure. These findings reveal that environmental governance performance is not strictly proportional to financial input, and that administrative capacity, industrial structure, and policy implementation intensity play decisive roles. The study contributes new comparative evidence on regional differences in the effectiveness of government environmental audits and offers policy implications for enhancing pollution control and achieving low-carbon development goals.

Keywords: government environmental audit, environmental pollution prevention and control, performance audit evaluation, grey correlation degree

Introduction

Protecting the ecological environment has become a central component of China's high-quality development strategy, particularly under the national commitments of achieving "carbon peaking by 2030 and carbon neutrality by 2060". As ecological degradation and resource depletion intensify, environmental governance has risen to the forefront of national policy agendas. Over the past four decades, China's economic growth has produced remarkable achievements, but it has also generated severe environmental pressures, highlighting the need for more effective monitoring, regulation, and policy implementation. In this context, government environmental auditing has emerged as an indispensable instrument for safeguarding ecological security and promoting sustainable development.

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As a vital part of the national governance system, auditing serves as the "immune system" of the economy, providing independent, authoritative, and comprehensive supervision [1, 2]. With growing national emphasis on ecological civilisation, the government has explicitly called for strengthening the role of audit oversight in environmental protection, including full audit coverage of major pollution control initiatives, natural resource management, and ecological restoration programs. Although environmental auditing originated in the United States in the 1950s and later expanded to countries such as Japan and Canada, China's systematic research on environmental performance audits began relatively late. Nonetheless, significant progress has been made. Existing studies have shown that environmental audits can help advance industrial transformation, improve environmental performance [3], help to improve carbon disclosure quality [4] act as a mitigation tool for post-socio-environmental disaster relief [5], and stimulate innovation among heavily polluting enterprises. However, scholars have also noted strong regional differences in how environmental audits influence environmental governance outcomes, suggesting heterogeneous implementation capacity and diverse local policy environments [6-8].

Against this backdrop, evaluating pollution prevention and control performance from the perspective of environmental auditing is both theoretically meaningful and practically necessary. China's vast territorial span and differentiated industrial structures lead to significant variation in environmental challenges and governance capabilities. For instance, economically developed coastal provinces, such as Guangdong and Zhejiang, have made notable progress in ecological governance, whereas heavily industrialised northern provinces like Hebei continue to face substantial pollution pressures. Understanding the performance gaps among these regions is essential for advancing evidence-based policy design and improving environmental governance effectiveness.

This study therefore, focuses on the ten-year period from 2013 to 2022 and compares the performance of environmental pollution prevention and control in Hebei, Guangdong, and Zhejiang Provinces through the analytical lens of government environmental auditing. By constructing an evaluation index system grounded in the PSR (Pressure-State-Response) framework and determining indicator weights via the Analytic Hierarchy Process (AHP), the study leverages grey relational analysis to quantitatively assess provincial environmental performance. This comparative approach directly addresses the academic debate concerning regional heterogeneity in the effectiveness of environmental audits. It enriches empirical research on environmental governance by providing differentiated evidence from three regions with distinct economic, industrial, and ecological characteristics.

The contributions of this study are threefold. First, it supplements the literature by introducing a regional comparison that highlights how audit effectiveness varies by local context, thereby responding to ongoing academic discussions on the spatial heterogeneity of environmental audit outcomes. Second, it develops a scientifically grounded and operable evaluation toolkit by integrating the PSR model, AHP, and grey relational analysis, addressing limitations in previous studies that rely on single-method or fragmented indicator systems. Third, the findings offer practical references for local governments by identifying performance gaps, revealing the non-linear relationship between funding investment and governance outcomes, and providing direction for optimising pollution control strategies in pursuit of China's "dual-carbon" goals.

In summary, through systematic comparative analysis and a robust methodological framework, this study seeks to deepen the understanding of how government environmental audits influence pollution control performance in different provincial contexts, and to offer actionable insights for improving environmental governance capacity in China.

Literature review

In the 1950s, the United States began environmental audit evaluation, and in the 1960s, American scholars initially explained the meaning of environmental performance evaluation. In 1969, the United States Audit Office conducted a special audit of water pollution control projects and provided a basis for the government to carry out water pollution control. Subsequently, countries such as Japan and Canada began environmental audit evaluation work and proposed some evaluation indicators for environmental auditing. After the 1990s, environmental performance auditing received increasing attention and gradually developed with the development of the economy. British accountant Grey proposed from the perspective of information disclosure that environmental performance should include the following content: company environmental management and governance policies, proposed and implemented environmental protection measures, environmental expenditure and income, ongoing environmental governance activities, and content related to environmental prevention and protection. Wu et al. [9] empirically examined the mechanism by which environmental regulation and policy complexity affect the efficiency of technological innovation applied in defence industrial enterprises, providing theoretical and empirical support for the development of related industries. Scholars proposed the meaning of corporate environmental performance, explaining the impact of environmental production and management activities, which is reflected in both the objective effects on the ecological environment and the subtle effects on systems and culture. Prajogo et al. [10] pointed out that one of the important roles of environmental performance audit evaluation indicators is that each aspect involved can be measured and transformed into comparable results for detection, and the detected results can also be analysed. Chabane et al. [11] took Biskra, Algeria as the research subject, combined meteorological elements with air pollution factors such as CO, O_3, and NO_2, fitted experimental data to establish a relevant dataset, and constructed a precise mathematical model for temperature estimation. By using certain methods, the importance and risk level of the indicators can be identified. Grey pointed out that the accounting system should be modified, and revenue and expenditure related to the environment should be separately recognised and measured. With the rapid development of the economy, there are many unreasonable exploitation situations of environmental resources, and the quality of resources and environment continues to decline. In this case, some scholars have studied how to govern resource and environmental issues from an audit perspective. The 2018 Environmental Performance Index Report is jointly released by multiple organisations including the World Economic Forum, Yale University, and Columbia University [12]. The report mainly analyses the environmental performance of 180 countries and regions participating in the ranking from 2007 to 2016. It constructs an evaluation index system consisting of two primary dimensions of ecosystem vitality and environmental health, ten secondary dimensions of policy areas, and 24 variable indicators, which is quite influential [12]. American scholars explore U.S. water audit practices, analysing their challenges, achievements and development opportunities with datasets from five regions and AWWA methodologies. They emphasise accurate leakage tracking as the core, point out regional disparities in audit data and leakage rates, and confirm that third-party support can improve audit quality and data accuracy [13]. This study takes Kaliningrad Oblast as a case to explore environmental audits in anthropogenically disturbed territories, identifies core problems in audit practices, clarifies key growth points for such audits, and provides targeted insights for optimising environmental audit practices in disturbed areas [14]. Empirical research on environmental auditing also indicates that environmental management plans can indeed improve corporate environmental performance [15]. In addition, many foreign experts have demonstrated various influencing factors of the ecological environment from different perspectives [16, 17].

In 1992, Ge Jiashu, a renowned accountant, and his student Li Ruoshan introduced the theory of green accounting, which incorporated the advancements in Western environmental accounting theory. This sparked domestic reflection on environmental accounting, and subsequently, scholars began to pay increasing attention to environmental auditing. With the increasingly serious phenomenon of ecological environment damage, some scholars are paying more attention to the research of environmental performance auditing. However, compared with western developed countries, China’s research on environmental performance audit is late, with single indicators, unscientific model construction and incomplete system. Nevertheless, through the unremitting efforts of scholars, certain achievements have also been made. Scholars believes that environmental performance audit evaluation is an independent supervisory behaviour and should establish its own audit evaluation system. Liang et al. [18] introduced the Environmental Excellence Model to conduct an environmental performance audit evaluation of the “three wastes” treatment in Beijing. Wang and Li [19] conducted a study specifically on the environmental performance audit evaluation of multinational corporations. He stood from the perspective of the global value chain, adopted stakeholder theory, and constructed an evaluation index system. Hyunseo et al. [20] conducted a systematic review on environmental audit tools for evaluating the quality of ecological green spaces in mental health research. Ravichandran et al. [21] explore the application of machine learning in CSR and ESG assessment, and promote the transformation of assessment from committee mode to climate dimension. Kee and Junghwan [22] explored the Application and Practical Value of Multimodal Large Language Models as Built Environment Audit Tools. Comprehensive and systematic governance measures are the key to solving this problem. Tan et al. [23] analysed how government environmental audits can promote green innovation in enterprises. Feng [24] provides scientific support for urban ecological planning by constructing an ecological assessment model and establishing a specialised decision support system. Some experts have proposed using microwave and aerobic technologies to reduce microbial pollution in aquatic environments [25]. Explored the role of internal audit in environmental, social, and governance (ESG) practices and risks, based on the concerns of stakeholders as well as the perspectives of audit committees and chief executive officers [26]. This paper employs a difference-in-differences model to confirm that the departure audit of natural resource assets can strengthen environmental regulation and promote pollution reduction, providing empirical support for official accountability in environmental protection [27]. In particular, some scholars have proposed practical methods for environmental and social impact assessments, which have contributed to environmental auditing [28]. Using Beijing-Tianjin-Hebei as a case study, this paper constructs a government performance evaluation model for air pollution control, analyses existing issues, and proposes targeted optimisation measures, providing practical references for regional pollution control performance evaluation [29].

Based on the above, scholars at home and abroad have abundant preliminary research literature, which can provide good reference and a solid theoretical foundation for the smooth development of this study. However, the defect is that there is no indicator system that meets the development requirements of “ecological civilisation construction” in the new era, in terms of evaluation criteria and evaluation levels. At present, the evaluation standards and evaluation levels for environmental performance auditing are not perfect enough, and even lacking, with no unified quantitative standards, resulting in poor comparability and hindering the effective implementation of environmental governance performance auditing and evaluation work.

Research method

Construction and weight determination of evaluation index system for the impact of government environmental audit on environmental pollution prevention and control

(*i*) *Logical mechanism of PSR framework*

The PSR model [30] answers three fundamental questions about sustainable development of the ecological environment: what problems have occurred, why they have occurred, and how we should solve them. As a result, three types of indicators have been formed, namely pressure indicators: indicating “why they have occurred” and reflecting the burden of human activities on the environment; Status indicator: describes “what has happened” and identifies the status of environmental quality, natural resources, and ecosystems; Response indicator: Answer “How should we do it”, the countermeasures and measures taken by humans in response to environmental change. At present, many domestic and foreign scholars advocate the PSR framework and widely apply it to the research of regional ecological environment sustainable development indicator system.

The PSR model reveals the interaction mechanism between P-S-R: if human economic and social activities reduce the load on the environment or if humans increase their response to environmental changes and take timely and effective measures, the environmental quality status will be improved. The formula is shown as: $P\downarrow + R\uparrow = S$ or $S\uparrow$.

On the contrary, if human economic and social activities increase the environmental burden without timely response, and the implementation of environmental pollution prevention and control policies is weak, the environmental quality will degrade and even cause serious harm. Similarly, it can be expressed by the formula: $P\uparrow + R\downarrow = S\downarrow$.

(*ii*) *Construction of evaluation index system and determination of weights*

The construction of indicator system is the key to the evaluation of government environmental audit. Based on the perspective of ecological civilisation in the context of the new era and the logical structure of “Pressure (Abbreviated as P, the same below) - State (S) - Response (R)” under the framework of PSR, this paper adopts a variety of methods such as theoretical deduction, expert meeting, questionnaire survey and other methods, and combines them with the actual situation to design the criterion layer indicators in three dimensions: pressure indicator (i.e. P dimension), state indicator (i.e. S dimension), and response indicator (i.e. R dimension). (i.e. P-frame), state indicator (i.e. S-frame) and response indicator (i.e. R-frame), and at the same time, the seven selected variable layer indicators are analysed by principal component determination method and exploratory factor analysis to determine the corresponding variable layer indicators belonging to the criterion layer of the indicator system, which constitutes the environmental pollution prevention and control performance auditing and evaluation indicator system. At the same time, according to the characteristics of this study, AHP hierarchical analysis was used to assign weights to the indicators at the criterion level and variable level, respectively, from an objective point of view. The specific indicator system and weights are shown in Table 1.

Table 1
Observation indicators and weights for evaluating the impact of government environmental audits on the performance of environmental pollution prevention and control

Level 1 Indicators and weights	Indicator code and weights	Observations indicators	Operation define
Environmental pollution prevention pressure indicators for environmental pollution prevention (P = 0.396)	P1 = 0.150	Chemical Oxygen Demand (COD) emissions per unit of industry	Industrial COD emissions/ gross domestic product (GDP)
	P2 = 0.141	Emissions per unit of sulphur dioxide	Industrial sulphur dioxide emissions / gross domestic product (GDP)
	P3 = 0.105	Unit of general industrial solid waste production	General industrial solid waste production / gross domestic product (GDP)
environmental pollution prevention status indicators for environmental pollution prevention (S = 0.261)	S1 = 0.140	Urban sewage treatment rate	Sewage treatment capacity ÷ Total sewage discharge· 100 %
	S2 = 0.121	Rate of harmless treatment of municipal domestic waste	Amount of domestic waste disposed of in an environmentally sound manner÷Domestic waste generation· 100 %
Environmental pollution prevention indicators of response to environmental pollution control (R = 0.343)	R1 = 0.187	Investment in industrial pollution control as GDP	Investment in industrial pollution control completed / gross domestic product (GDP)· 100 %
	R2 = 0.156	Greening coverage in built-up areas	Vertical projection of all vegetation in built-up areas / Built-up area· 100 %

Note: In view of space constraints, the process of selecting audit evaluation indicators and calculating weights using the AHP hierarchical analysis method is omitted

The evaluation method and evaluation level of the impact of government environmental audit on the performance of environmental pollution prevention and control

(*i*) *Grey correlation analysis*

Grey Relational Analysis (GRA) is a multi-factor statistical analysis method proposed by scholar Deng Julong in 1982, belonging to the grey system theory. It quantifies the close relationship between variables by calculating the correlation between reference sequences and comparison sequences, in order to analyse the degree of correlation between various factors in uncertain systems with partially known information and partially unknown information [31]. This method first constructs an eigenvalue matrix; Next, determine the reference data column for the sample; Non dimensionalisation of the third pair of data; The fourth difference sequence; Fifth, calculate the maximum and minimum difference between the two levels; Sixth, calculate the correlation coefficient of each evaluation indicator; Finally, calculate the comprehensive evaluation index score for each comparison year. Calculate the composite evaluation index score for each comparison year. A linear weighting model is used to obtain the comprehensive evaluation index score, *Z*, of the environmental pollution control performance audit for each evaluation year:

$$Z = \sum_{i=1}^{n} W_i R_{ij}$$

where W_i is the weight of the i-th evaluation indicator; R_{ij} to represent the correlation coefficient between the *i*-th evaluation indicator factor in the *j*-th year and the optimal reference sample.

(*ii*) *Establishment of criteria for evaluating and grading environmental pollution control performance audits*

Table 2

Evaluation criteria and grading of the impact of government environmental audits on the performance of environmental pollution prevention and control

Audit evaluation level	**excellent (I)**	**good (II)**	**general (III)**	**poor (IV)**	**very poor (V)**
Index evaluation criteria	$1 \geq Z \geq 0.70$	$0.70 > Z \geq 0.60$	$0.60 > Z \geq 0.50$	$0.50 > Z \geq 0.40$	$0.40 > Z \geq 0$
Descriptive	Governments at all levels have attached great importance to the prevention and control of environmental pollution, strictly enforced the requirements of the system, taken various measures to prevent and control pollution, and performed excellently in the prevention and control of environmental pollution and stabilised the ecosystem	Governments at all levels attach great importance to the prevention and control of environmental pollution, have stricter enforcement systems, are able to take a variety of measures to prevent and control pollution, perform well in environmental pollution prevention and control, and have more stable ecosystems	Governments at all levels attach importance to various aspects of environmental pollution prevention and control, but the implementation of the system is average, pollution prevention and control measures are problematic, the ecosystem is not very stable, and environmental performance is average	Governments at all levels have not paid sufficient attention to the prevention and control of environmental pollution, and the measures taken have been inadequate, with unstable ecosystems and poor environmental performance	There is a serious lack of attention to environmental pollution prevention and control at all levels of government, poor implementation of regulations, serious inadequacies in measures, highly unstable ecosystems and very poor environmental performance

In order to make the performance audit evaluation of environmental pollution prevention and control referable, assessable, comparable, scientific and objective, it is necessary to formulate unified quantitative evaluation standards and to compare and assess the results of the evaluation, so it is necessary to classify the evaluation results into grades. Based on the above steps, this study formulated the evaluation criteria and evaluation level of governmental environmental pollution prevention and control performance audit based on the research results of other experts and scholars based on the calculation of how many scores of the comprehensive evaluation indexes in each comparison year. The status of the environmental pollution control performance audit evaluation level is divided into five grades, including "excellent", "good", "medium", "poor" and "bad", based on the comprehensive score, and the specific division criteria and grades are shown in Table 2.

Results and discussion

The evaluation index attribute and data source of the impact of government environmental audit on the performance of environmental pollution prevention and control

(*i*) *Attribute of government environmental audit evaluation indicators*

The battle against environmental pollution prevention and control is currently one of the three major battles in China, and pollution prevention and control work is being carried out in full swing throughout the country. However, the performance of environmental pollution prevention and control needs to be tested and evaluated in order to know. Especially, the central government has explicitly proposed to audit the environmental resources and comprehensive environmental governance, achieve full coverage of major pollution prevention and control projects, and play a unique role in auditing in China’s ecological civilisation construction. Therefore, in order to examine the effectiveness of the governments at all levels in Hebei Province, Guangdong Province, and Zhejiang Province in fulfilling their responsibilities for environmental pollution prevention and control, and to fully play the role of economic supervision, with the unique authority, independence, professionalism, comprehensiveness, and sensitivity of auditing, while conducting regular "economic examinations", we will conduct in-depth audits and evaluations of the performance of environmental pollution prevention and control in the three provinces.

Table 3

Dimensions and attributes of evaluation indicators for the impact of government environmental audits on environmental pollution prevention and control performance

Overall indicators	**Primary indicators**	**Secondary indicators**	**Observation indicator dimension**	**Observation indicator attributes**
A	P	P1	t*/100 million yuan GDP	Negative indicator
		P2	t/100 million yuan GDP	Negative indicator
		P3	t/100 million yuan GDP	Negative indicator
	S	S1	%	Positive indicators
		S2	%	Positive indicators
	R	R1	%	Positive indicators
		R2	%	Positive indicators

* [t] - tonne = 10^6 g = Mg, the same below

This project belongs to practical application research, and the research objective is to audit and evaluate the performance of government environmental pollution prevention and control. Therefore, the evaluation indicators constructed by this research institute mainly come from the State Council’s "Thirteenth Five Year Plan for Ecological Environment Protection", "Thirteenth Five Year Plan", and "Opinions on Strengthening Ecological

Environment Protection and Fighting Pollution Prevention and Control", which have strong policy, applicability, and operability characteristics. The specific evaluation indicators are shown in Table 3.

(*ii*) *Data sources*

This paper analyses and evaluates the performance level of environmental pollution prevention and control in the three provinces of Guangdong, Hebei, and Zhejiang provinces over a total time span of 10 years from 2013 to 2022. Specific data from the Guangdong Provincial Statistical Yearbook, Zhejiang Provincial Statistical Yearbook, Hebei Provincial Statistical Yearbook, National Economic and Social Development Bulletin, China Statistical Yearbook, and each province's Department of Ecology and Environment, Department of Finance, Department of Audit and other relevant governmental websites, as well as research and interviews with the data obtained during the interviews, etc. for individual years of indicators missing data using interpolation method for the calculation. The optimal reference value uses the value of the most optimal state indicator in each comparison year as the reference value. SPSS25 and EXCEL software were also applied for quantitative statistics and empirical analysis.

Empirical process of overall evaluation of the impact of government environmental audit on environmental pollution prevention and control performance

Based on the constructed grey correlation analysis model and calculation steps, Calculate the score values of the comprehensive evaluation index for environmental pollution prevention and control performance of government environmental audits from 2013 to 2022 (limited by space, cumbersome calculation process, brief), as shown in Tables 4 and 5.

(*i*) *Calculate the comprehensive evaluation index scores for each comparative year*

Table 4

Comprehensive index score values of national and three provincial government environmental pollution prevention and control performance comparison years

Indicator code	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
QP1	0.054	0.055	0.056	0.057	0.057	0.073	0.078	0.083	0.062	0.060
HP1	0.054	0.054	0.055	0.055	0.056	0.077	0.076	0.071	0.057	0.057
ZP1	0.059	0.061	0.063	0.065	0.069	0.092	0.107	0.133	0.150	0.110
GP1	0.056	0.057	0.058	0.059	0.061	0.079	0.082	0.089	0.069	0.071
QP2	0.047	0.047	0.047	0.047	0.047	0.048	0.049	0.049	0.050	0.056
HP2	0.047	0.047	0.047	0.047	0.047	0.048	0.048	0.048	0.049	0.053
ZP2	0.047	0.047	0.047	0.048	0.048	0.051	0.054	0.055	0.065	0.141
GP2	0.047	0.047	0.048	0.048	0.048	0.052	0.055	0.059	0.065	0.093
QP3	0.037	0.037	0.037	0.038	0.038	0.038	0.039	0.039	0.039	0.039
HP3	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
ZP3	0.049	0.051	0.054	0.054	0.058	0.061	0.063	0.075	0.064	0.084
GP3	0.055	0.057	0.061	0.069	0.075	0.087	0.085	0.090	0.076	0.105
QS1	0.098	0.099	0.100	0.106	0.111	0.115	0.121	0.123	0.129	0.133
HS1	0.110	0.115	0.118	0.124	0.126	0.129	0.132	0.133	0.137	0.138
ZS1	0.110	0.115	0.119	0.122	0.125	0.130	0.132	0.134	0.138	0.140
GS1	0.098	0.116	0.125	0.123	0.128	0.130	0.131	0.131	0.137	0.140

Indicator code	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
QS2	0.086	0.092	0.099	0.104	0.108	0.113	0.116	0.119	0.119	0.120
HS2	0.078	0.088	0.090	0.095	0.112	0.116	0.121	0.121	0.120	0.121
ZS2	0.113	0.119	0.120	0.121	0.119	0.121	0.121	0.121	0.121	0.121
GS2	0.094	0.084	0.091	0.094	0.103	0.112	0.116	0.121	0.121	0.121
QR1	0.077	0.078	0.090	0.094	0.082	0.081	0.075	0.072	0.071	0.068
HR1	0.079	0.077	0.103	0.187	0.103	0.075	0.077	0.081	0.081	0.067
ZR1	0.069	0.074	0.093	0.098	0.087	0.085	0.077	0.071	0.069	0.074
GR1	0.065	0.068	0.068	0.069	0.067	0.065	0.066	0.067	0.065	0.063
QR2	0.128	0.130	0.130	0.133	0.132	0.133	0.136	0.138	0.140	0.143
HR2	0.143	0.137	0.138	0.142	0.138	0.136	0.142	0.141	0.145	0.149
ZR2	0.123	0.131	0.133	0.136	0.134	0.137	0.133	0.138	0.140	0.144
GR2	0.139	0.138	0.139	0.139	0.139	0.145	0.152	0.156	0.151	0.152
whole country	0.526	0.538	0.560	0.577	0.576	0.602	0.613	0.623	0.610	0.620
Hebei Province	0.546	0.554	0.587	0.687	0.618	0.616	0.630	0.629	0.625	0.620
Zhejiang Province	0.571	0.597	0.628	0.643	0.639	0.676	0.688	0.727	0.747	0.813
Guangdong Province	0.553	0.566	0.590	0.601	0.622	0.669	0.687	0.713	0.683	0.745

Note: 1. QP1 represents the national unit industrial chemical oxygen demand emissions, HP1 represents the unit industrial chemical oxygen demand emissions in Hebei Province, ZP1 represents the unit industrial chemical oxygen demand emissions in Zhejiang Province, and GP1 represents the unit industrial chemical oxygen demand emissions in Guangdong Province; similarly for other indicators in the government's environmental pollution prevention and control performance audit evaluation. 2. The above data are dimensionless. 3. The same applies to the next tables

(*ii*) *Calculate the score values of the factor evaluation index at each level in each comparative year*

Table 5

Score values of various factor indices for comparison of environmental pollution prevention and control performance across the country and three provinces in different years

Indicator code	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
QP1	0.054	0.055	0.056	0.057	0.057	0.073	0.078	0.083	0.062	0.060
QP2	0.047	0.047	0.047	0.047	0.047	0.048	0.049	0.049	0.050	0.056
QP3	0.037	0.037	0.037	0.038	0.038	0.038	0.039	0.039	0.039	0.039
QP	**0.138**	**0.139**	**0.140**	**0.141**	**0.143**	**0.160**	**0.165**	**0.172**	**0.151**	**0.155**
QS1	0.098	0.099	0.100	0.106	0.111	0.115	0.121	0.123	0.129	0.133
QS2	0.086	0.092	0.099	0.104	0.108	0.113	0.116	0.119	0.119	0.120
QS	**0.184**	**0.192**	**0.199**	**0.209**	**0.219**	**0.228**	**0.237**	**0.242**	**0.248**	**0.253**
QR1	0.077	0.078	0.090	0.094	0.082	0.081	0.075	0.072	0.071	0.068
QR2	0.128	0.130	0.130	0.133	0.132	0.133	0.136	0.138	0.140	0.143
QR	**0.205**	**0.207**	**0.220**	**0.226**	**0.214**	**0.215**	**0.212**	**0.210**	**0.211**	**0.212**
Whole country	**0.526**	**0.538**	**0.560**	**0.577**	**0.576**	**0.602**	**0.613**	**0.623**	**0.610**	**0.620**
HP1	0.054	0.054	0.055	0.055	0.056	0.077	0.076	0.071	0.057	0.057
HP2	0.047	0.047	0.047	0.047	0.047	0.048	0.048	0.048	0.049	0.053
HP3	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
HP	**0.136**	**0.137**	**0.138**	**0.138**	**0.139**	**0.160**	**0.160**	**0.155**	**0.143**	**0.146**
HS1	0.110	0.115	0.118	0.124	0.126	0.129	0.132	0.133	0.137	0.138
HS2	0.078	0.088	0.090	0.095	0.112	0.116	0.121	0.121	0.120	0.121
HS	**0.187**	**0.203**	**0.209**	**0.219**	**0.238**	**0.245**	**0.252**	**0.253**	**0.257**	**0.259**

HR1	0.079	0.077	0.103	0.187	0.103	0.075	0.077	0.081	0.081	0.067
HR2	0.143	0.137	0.138	0.142	0.138	0.136	0.142	0.141	0.145	0.149
HR	**0.223**	**0.214**	**0.241**	**0.329**	**0.242**	**0.211**	**0.218**	**0.221**	**0.226**	**0.216**
Hebei Province	**0.546**	**0.554**	**0.587**	**0.687**	**0.618**	**0.616**	**0.630**	**0.629**	**0.625**	**0.620**
ZP1	0.059	0.061	0.063	0.065	0.069	0.092	0.107	0.133	0.150	0.110
ZP2	0.047	0.047	0.047	0.048	0.048	0.051	0.054	0.055	0.065	0.141
ZP3	0.049	0.051	0.054	0.054	0.058	0.061	0.063	0.075	0.064	0.084
ZP	**0.155**	**0.159**	**0.164**	**0.167**	**0.174**	**0.204**	**0.224**	**0.263**	**0.279**	**0.335**
ZS1	0.110	0.115	0.119	0.122	0.125	0.130	0.132	0.134	0.138	0.140
ZS2	0.113	0.119	0.120	0.121	0.119	0.121	0.121	0.121	0.121	0.121
ZS	**0.223**	**0.234**	**0.238**	**0.243**	**0.244**	**0.251**	**0.253**	**0.255**	**0.259**	**0.261**
ZR1	0.069	0.074	0.093	0.098	0.087	0.085	0.077	0.071	0.069	0.074
ZR2	0.123	0.131	0.133	0.136	0.134	0.137	0.133	0.138	0.140	0.144
ZR	**0.193**	**0.205**	**0.226**	**0.233**	**0.221**	**0.222**	**0.210**	**0.209**	**0.209**	**0.217**
Zhejiang Province	**0.571**	**0.597**	**0.628**	**0.643**	**0.639**	**0.676**	**0.688**	**0.727**	**0.747**	**0.813**
GP1	0.056	0.057	0.058	0.059	0.061	0.079	0.082	0.089	0.069	0.071
GP2	0.047	0.047	0.048	0.048	0.048	0.052	0.055	0.059	0.065	0.093
GP3	0.055	0.057	0.061	0.069	0.075	0.087	0.085	0.090	0.076	0.105
GP	**0.158**	**0.161**	**0.167**	**0.176**	**0.185**	**0.218**	**0.222**	**0.239**	**0.210**	**0.269**
GS1	0.098	0.116	0.125	0.123	0.128	0.130	0.131	0.131	0.137	0.140
GS2	0.094	0.084	0.091	0.094	0.103	0.112	0.116	0.121	0.121	0.121
GS	**0.192**	**0.200**	**0.216**	**0.217**	**0.231**	**0.242**	**0.247**	**0.252**	**0.258**	**0.261**
GR1	0.065	0.068	0.068	0.069	0.067	0.065	0.066	0.067	0.065	0.063
GR2	0.139	0.138	0.139	0.139	0.139	0.145	0.152	0.156	0.151	0.152
GR	**0.204**	**0.205**	**0.208**	**0.208**	**0.206**	**0.210**	**0.218**	**0.223**	**0.215**	**0.216**
Guangdong Province	**0.553**	**0.566**	**0.590**	**0.601**	**0.622**	**0.669**	**0.687**	**0.713**	**0.683**	**0.745**

Evaluation results of the impact of government environmental audit on the performance of environmental pollution prevention and control

(i) Overall evaluation results of environmental pollution prevention and control performance

According to the composite index of the national and Hebei, Guangdong and Zhejiang provincial governments' environmental pollution prevention and control performance comparison years listed in Table 7, and in accordance with the environmental pollution prevention and control performance audit evaluation criteria and grade division shown in Table 2, it can be concluded that they belong to the grades of the comprehensive evaluation of the environmental pollution prevention and control performance audits in different years, which is specifically shown in Table 9.

As can be seen from Table 6 and Figure 1, environmental pollution prevention and control at the national level and in the three provinces have achieved better performance, with an upward trend in the overall performance status, Among them: the comprehensive score value of the National Environmental Pollution Management Performance Evaluation increased by 17.74 % from 0.5264 in 2013 to 0.6198 in 2022, rising from medium to good grade; Hebei Province increased by 13.57 % from 0.5462 in 2013 to 0.6203 in 2022, rising from medium to good grade; Zhejiang Province increased from 0.5709 in 2013 to 0.8131 in 2022, an increase of 42.42 %, from medium to excellent grade; and Guangdong Province from 0.5529 in 2013 to 0.7452 in 2022, an increase of 34.78 %, also from medium to excellent grade. However, from the perspective of each province, Zhejiang Province, environmental pollution prevention and control performance is the best, has been in an even upward trend, and from 2015 onwards in a good grade, to 2020 after it is a continuous excellent grade.

Table 6

Ranks belonging to the comprehensive evaluation of environmental pollution prevention and control performance audits in the country and the three provinces

Year	Whole country		Hebei Province		Zhejiang Province		Guangdong Province	
	Compre-hensive evaluation score	Audit evaluation level	Compre-hensive evaluation score	Audit evaluation level	Compre-hensive evaluation score	Audit evaluation level	Compre-hensive evaluation score	Audit evaluation level
2013	0.5264	general	0.5462	general	0.5709	general	0.5529	general
2014	0.5376	general	0.5536	general	0.5973	general	0.5658	general
2015	0.5596	general	0.5870	general	0.6279	good	0.5903	general
2016	0.5771	general	0.6866	good	0.6429	good	0.6009	good
2017	0.5757	general	0.6181	good	0.6394	good	0.6215	good
2018	0.6023	good	0.6156	good	0.6756	good	0.6692	good
2019	0.6133	good	0.6296	good	0.6875	good	0.6870	good
2020	0.6233	good	0.6293	good	0.7270	excellent	0.7131	excellent
2021	0.6103	good	0.6245	good	0.7465	excellent	0.6831	good
2022	0.6198	good	0.6203	good	0.8131	excellent	0.7452	excellent

Note: The data in this table has no unit of measurement [-]

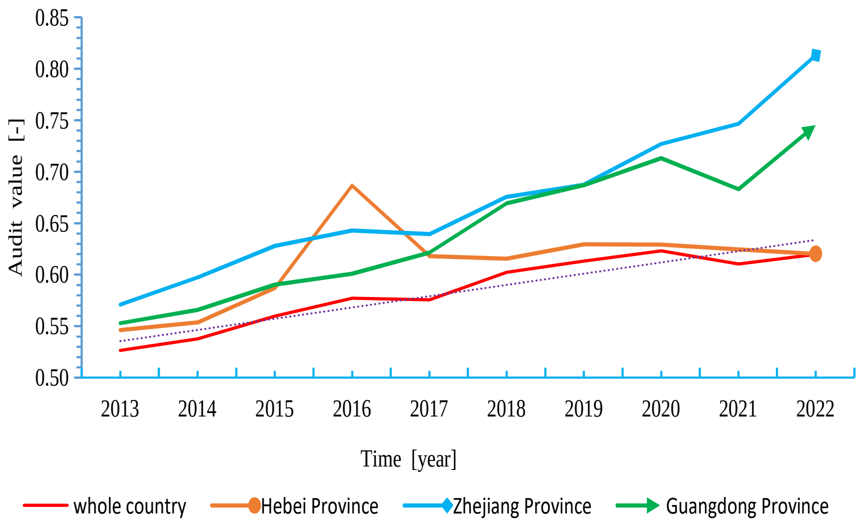

Fig. 1. Trend of the rank belonging to the comprehensive evaluation of environmental pollution prevention and control performance audit in the whole country and Hebei, Guangdong and Jiangsu provinces

Guangdong Province, although also in an upward trend, but there are ups and downs, in 2016 to obtain a good grade, to 2020 to obtain an excellent grade, in 2021 and is a good grade In the three provinces, Hebei Province is the worst, with the performance of environmental pollution prevention and control from 2013 to 2015 always at a medium level, and in 2016, it took a leap when it increased the investment of pollution control funds. In 2016, there was a leap in increasing the investment of funds in pollution control, and it began to reach the good level, although it was within the good score range, but it began to show a downward trend, and it did not reach the excellent level in any of the years. Looking at the performance trend of environmental pollution control in the country and the three provinces, it can be seen that after 2017, i.e. the years after the beginning of 2018, the overall performance of environmental pollution prevention and control is good, which is mainly due to the fact that the period from 2018 to 2022 is in the middle to late stage of the "13th Five-Year Plan" and the "14th Five-Year Plan", China attaches great importance to the protection of the ecological environment and the concept of the famous "two mountains" is better penetrated into the hearts of the people, and the ecological environmental protection and control has been sublimated.

(*ii*) *Evaluation results and trend analysis of environmental performance factors*

The comprehensive score value of environmental pollution prevention and control performance audit evaluation in Hebei Province, Zhejiang Province, and Guangdong Province is calculated by summarising the scores of three PSR factors, namely environmental pollution prevention and control pressure (P), environmental pollution prevention and control status (S), and environmental pollution prevention and control response (R), based on their weights. The development trend of the three factors of PSR ultimately affects the comprehensive score trend of environmental pollution prevention and control performance audit evaluation. From Table 7 and Figure 2, it can be seen that the pressure indicators for environmental pollution prevention and control in Hebei Province, Zhejiang Province, and Guangdong Province (i.e. P factor, which is composed of industrial "three wastes" emissions) have shown an overall upward trend after audit evaluation. However, the upward trend in Hebei Province is not obvious, and it is almost a parallel forward trend. The specific P factor performance audit evaluation comprehensive score values for these indicators are as follows, Hebei Province has increased from 0.1363 in 2013 to 0.1461 in 2022, with only a 7.19 % increase over the past 10 years; Zhejiang Province increased from 0.1552 in 2013 to 0.3348 in 2022, an increase of 115.72 % over the past 10 years; Guangdong Province increased from 0.1576 in 2013 to 0.2689 in 2022, an increase of 70.62 % over the past 10 years. This indicates that Hebei Province has not achieved significant results in controlling and treating industrial "three wastes" emissions, while Zhejiang Province and Guangdong Province have achieved significant performance, especially in a steady upward trend.

Table 7

Score values of pressure factor index for environmental pollution prevention and control in three provinces

Indicator code	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Hebei Province	0.1363	0.1370	0.1377	0.1383	0.1390	0.1604	0.1595	0.1552	0.1425	0.1461
Zhejiang Province	0.1552	0.1586	0.1642	0.1671	0.1744	0.2036	0.2242	0.2630	0.2791	0.3348
Guangdong Province	0.1576	0.1607	0.1668	0.1760	0.1846	0.2176	0.2220	0.2387	0.2096	0.2689

Note: The data in this table has no unit of measurement [-]

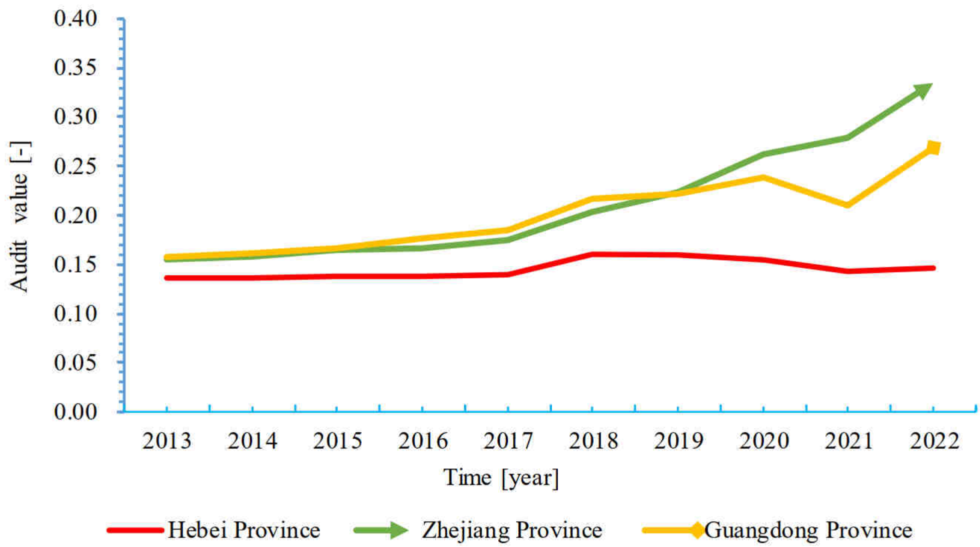

Fig. 2. Score values of pressure indicators for environmental pollution prevention and control

From Table 8 and Figure 3, it can be seen that the environmental pollution prevention and control status indicators (i.e. S factor, which is composed of urban sewage treatment rate and harmless treatment rate of urban household waste) in Hebei Province, Zhejiang Province, and Guangdong Province have good comprehensive score values after audit evaluation. The overall trend of the three provinces is on the rise, with Zhejiang Province being the best. However, the upward trend in Hebei Province and Guangdong Province has been more obvious since 2017. Their specific S-factor performance audit evaluation comprehensive score value has increased from 0.1873 in 2013 to 0.2587 in 2022 in Hebei Province, an increase of 38.12 % over the past 10 years; Zhejiang Province has increased from 0.2230 in 2013 to 0.2610 in 2022, an increase of 17.04 % over the past 10 years; Guangdong Province has increased from 0.1918 in 2013 to 0.2607 in 2022, an increase of 35.92 % over the past 10 years. This indicates that the three provinces have achieved significant results in the treatment of urban sewage and harmless treatment of urban household waste, with Hebei and Guangdong provinces achieving particularly significant results.

Table 8

Score values of environmental pollution prevention and control status factor index in three provinces

Indicator code	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Hebei Province	0.1873	0.2027	0.2085	0.2191	0.2376	0.2447	0.2520	0.2531	0.2565	0.2587
Zhejiang Province	0.2230	0.2336	0.2382	0.2428	0.2438	0.2505	0.2534	0.2554	0.2588	0.2610
Guangdong Province	0.1918	0.1998	0.2161	0.2173	0.2307	0.2417	0.2468	0.2517	0.2581	0.2607

Note: The data in the table has no unit of measurement [-]

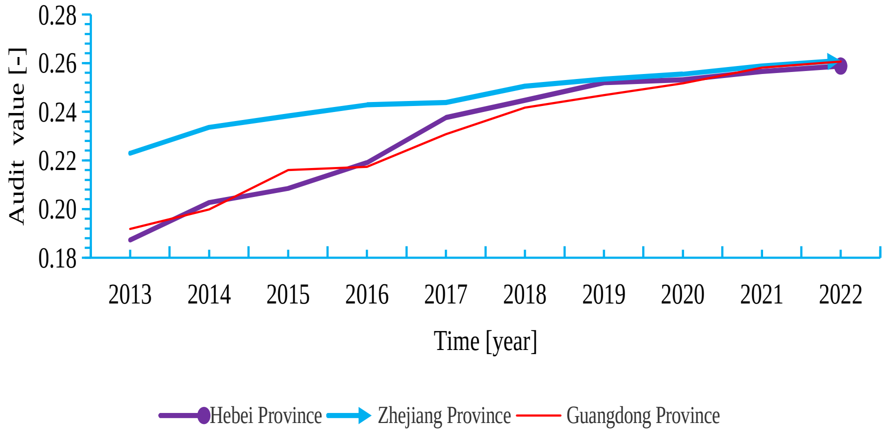

Fig. 3. Score values of environmental pollution prevention and control status indicators

From Table 9 and Figure 4, it can be seen that the environmental pollution prevention and control response indicators in Hebei Province, Zhejiang Province, and Guangdong Province (i.e. the S factor, which is composed of the proportion of industrial pollution control investment to GDP and the green coverage rate of built-up areas). After auditing and evaluating the comprehensive score of this factor, the overall upward trend of the three provinces is not significant, especially in Hebei Province, which has also shown a decline and a significant jump in 2016. The comprehensive score value of their specific S-factor performance audit evaluation has increased from 0.2226 in 2013 to 0.2155 in 2022 in Hebei Province, with a decrease of –3.19 % over the past 10 years instead of an increase; Zhejiang Province has increased from 0.1927 in 2013 to 0.2173 in 2022, an increase of 12.77 % over the past 10 years; Guangdong Province has increased from 0.2035 in 2013 to 0.2156 in 2022, an increase of 5.95 % over the past 10 years. This indicates that Zhejiang Province has made greater efforts in responding to environmental governance policies, especially in terms of funding investment, compared to Hebei Province and Guangdong Province, and Hebei Province has invested more in the early stage than in the later stage.

Table 9

Score values of environmental pollution prevention and control response factor index in three provinces

Indicator code	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Hebei Province	0.2226	0.2139	0.2409	0.3292	0.2415	0.2105	0.2181	0.2210	0.2255	0.2155
Zhejiang Province	0.1927	0.2051	0.2255	0.2330	0.2212	0.2215	0.2099	0.2085	0.2086	0.2173
Guangdong Province	0.2035	0.2053	0.2075	0.2076	0.2062	0.2099	0.2182	0.2227	0.2154	0.2156

Note: The data in the table has no unit of measurement [-]

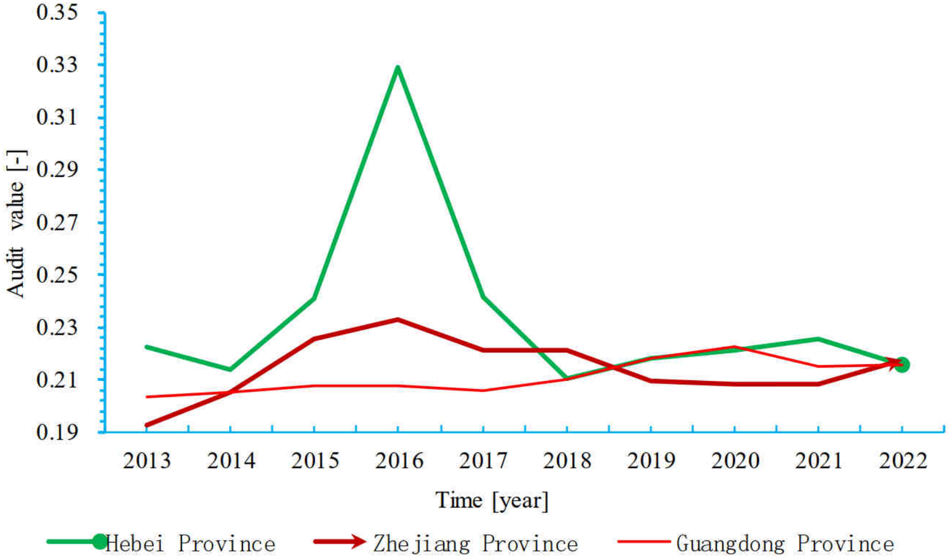

Fig. 4. Score values of environmental pollution prevention and control response indicators

Conclusion

This study conducted a systematic audit-based evaluation of environmental pollution prevention and control performance in Hebei, Guangdong, and Zhejiang Provinces from 2013 to 2022. By constructing an integrated PSR–AHP–GRA evaluation framework, the research provides robust empirical evidence on how government environmental audits shape regional pollution control outcomes under China's ecological civilisation strategy and the "dual-carbon" goals. The findings highlight several important insights:

- First, the overall performance of pollution prevention and control in all three provinces has improved steadily over the past decade, especially after the implementation of the 13th and 14th Five-Year Plans. This upward trend reflects the growing strength of national environmental policy, increasing social awareness, and the expanding role of environmental audits in reinforcing institutional responsibility and regulatory enforcement.
- Second, significant regional disparities remain. Zhejiang demonstrates consistently strong performance, characterised by stable emission reduction, high environmental governance efficiency, and effective alignment between audit requirements and policy execution. Guangdong also shows improvement but experiences fluctuations due to uneven industrial transitions and differentiated municipal governance capacities. Hebei, despite substantial investments in pollution control, continues to face prominent environmental pressures, particularly in managing industrial "three wastes". This confirms that financial alone does not guarantee effective pollution control; rather, governance capability, technology adoption, and the structure of local industries play decisive roles.
- Third, the results confirm that government environmental audits can meaningfully support pollution governance by strengthening policy implementation, improving

resource allocation, and enhancing compliance incentives. However, their effectiveness varies depending on regional industrial bases, administrative efficiency, and audit follow-up mechanisms. Zhejiang’s success illustrates the positive synergy between audit oversight, green development pathways, and public environmental participation, whereas Hebei’s challenges reveal the limits of audit influence in regions burdened with heavy industry and slower structural transformation.

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