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Quantitative Analysis on the Mechanism of Environmental Audit Promoting Ecological Civilization Construction in Ganzi Prefecture

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Abstract: *Ganzi Prefecture in Sichuan Province is not only an important ecological barrier in the upper reaches of the Yangtze River, but also a core ecological area on the eastern edge of the Qinghai-Tibet Plateau. Its ecological civilization construction plays a very important role in promoting the implementation of national ecological security strategies and the high-quality development of ethnic minority areas in western Sichuan.To provide theoretical reference and contribute to the optimization of the ecological audit system in ethnic regions, this article constructs a quantitative analysis framework for empowering ecological governance in Ganzi Prefecture through environmental audit by introducing three types of quantitative tools: Spatial Error Model (SEM), Data Envelopment Analysis Model (DEA), and Difference in Differences Model (DID). The framework analyzes the mechanism from three dimensions: ecological risk identification, financial benefit evaluation, and policy effectiveness verification. It not only overcomes the shortcomings of traditional environmental audit, which mainly relies on qualitative analysis and lacks quantitative support for effectiveness evaluation, but also proposes a series of targeted implementation paths based on the ecological characteristics of Ganzi Prefecture's plateau and the difficulties of audit practice.*

Keywords: *Environmental Audit; Ganzi Prefecture; Ecological Civilization Construction; Mechanism of Action; Implementation Paths*

1. Introduction

1.1. Research Background and Significance

Ganzi Prefecture in Sichuan Province covers an area of 153000 square kilometers and consists of 18 counties. It not only has world-class ecological resources such as Gongga Mountain and Daocheng Yading, but also serves as a core area for water conservation and biodiversity protection in the upper reaches of the Yangtze River. In recent years, although Ganzi Prefecture has implemented the concept of "ecological priority and green development" and carried out a series of projects such as grassland ecological rewards and subsidies, wetland restoration, and returning farmland to forests, it still faces prominent problems such as grassland desertification, glacier retreat, ecological protection, and contradictions in increasing income for farmers and herdsmen.

Traditional environmental audit relies on manual verification and sampling analysis, which makes it difficult to accurately quantify the effectiveness of ecological governance policies and the efficiency of fund utilization, and cannot meet the regulatory needs of the vast and complex plateau ecosystems in Ganzi Prefecture. Selecting appropriate mathematical models can provide precise quantitative analysis tools for environmental audit. By integrating ecological monitoring data, fiscal fund data, and socio-economic development data from Ganzi Prefecture, SEM model is used to identify the spatial diffusion patterns of ecological risks[1]. DEA model is used to measure the efficiency of ecological fund allocation[2], and DID model is used to evaluate the net effects of environmental audit policies[3]. A closed-loop system is constructed for data collection, model computation, audit application, and governance optimization. This article explores the mechanism and implementation paths of environmental audit in promoting the construction of ecological civilization in Ganzi Prefecture from the perspective of quantitative analysis based on mathematical models, and helps build a strong ecological security barrier in the upper reaches of the Yangtze River in Ganzi Prefecture[4,5].

1.2. The Dilemma of Quantitative Practice in Environmental Audit in Ganzi Prefecture

The practical difficulties in quantifying environmental audit in Ganzi Prefecture are mainly manifested in the following two aspects.

There is a shortage of composite audit talents and insufficient integration of technology and business. The personnel of grassroots audit institutions in Ganzi Prefecture are mostly skilled in traditional financial audit and lack operational abilities such as mathematical modeling, statistical software Stata, MaxDEA, etc. Insufficient technical support from universities and research institutes makes it difficult to transform model analysis results into audit decision recommendations, and the effectiveness of technology enabled audit has not been fully unleashed.

The foundation of plateau ecological data is weak and the accuracy of model fitting is limited. Some remote counties in Ganzi Prefecture, such as Shiqu and Dege, have insufficient ecological monitoring stations, and satellite remote sensing data is affected by high-altitude cloud cover, resulting in data loss and low accuracy. At the same time, the mechanism for cross departmental data sharing is not perfect, and it is difficult to effectively integrate ecological monitoring data, financial fund data, and income data of farmers and herdsmen, resulting in low sample quality for model calculations and deviations between fitting results and actual situations.

2. Selection of Mathematical Models and Adaptability to Scenarios

Based on the ecological characteristics of the plateau in Ganzi Prefecture and the core requirements of environmental audit, three types of mathematical models are selected as quantitative analysis tools to clarify model formulas, variable settings, and application scenarios, ensuring model adaptability and analysis accuracy.

2.1. Spatial Error Model (SEM)

The SEM model is a tool for identifying ecological risk space. Ecological risks in Ganzi Prefecture, such as grassland desertification and soil erosion, have significant spatial spillover effects. This model is more suitable for analyzing the impact of error shocks caused by geographical factors in Ganzi Prefecture on ecological indicators. Its core formula is

$$\begin{cases} F = \lambda X\alpha + \varepsilon, \\ \varepsilon = \beta Y\varepsilon + \gamma, \end{cases} \tag{1}$$

where F is the dependent variable for selecting grassland desertification rate and wetland shrinkage rate from 18 counties in Garze Prefecture, X is the explanatory variable for environmental audit intensity, overgrazing rate, annual average precipitation, and altitude, Y is the spatial weight matrix constructed based on the geographical adjacency relationship of counties, β is the error coefficient reflecting the spatial spillover degree of ecological risk, and γ is the random error term. This model is suitable for identifying the spatial distribution characteristics and diffusion paths of ecological risks in Ganzi Prefecture, providing quantitative basis for environmental audit to accurately target high-risk regulatory areas.

2.2. Data Envelopment Analysis Model (DEA)

The DEA model is a powerful tool for evaluating the benefits of ecological funds, and ecological special funds are the core guarantee for ecological governance in Ganzi Prefecture. This model can rank effective decision-making units, mainly based on the assumption of variable returns to scale, construct an input-output index system, and measure the efficiency of fund utilization. Its linear programming formula are

Objective Function:

$$\max_{\theta,\xi} \theta, \tag{2}$$

and *Constraint Functions:*

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$$\begin{cases} \xi_i \geq 0, & i = 1, 2, ..., m, \\ \sum_{i=1}^{m} \xi_i x_{il} \leq \theta x_{0l}, & l = 1, 2, ..., n, \\ \sum_{i=1}^{m} \xi_i w_{ij} \geq w_{0j}, & j = 1, 2, ..., k, \end{cases} \tag{3}$$

where θ is the super efficiency value, it indicates that the efficiency of the decision-making unit has reached its optimal level for $\theta > 1$. x_{il} is the input indicator for ecological special funds and management manpower investment, w_{ij} is the output indicator for vegetation coverage improvement rate, water quality compliance rate, and per capita income growth rate of farmers and herdsmen, ξ_i is the weight variable. This model is suitable for evaluating the efficiency of ecological fund allocation in 18 counties of Ganzi Prefecture and identifying key links where there is redundant investment or insufficient output of funds.

2.3. Difference in Differences Model (DID)

The DID model is a commonly used tool for evaluating the effectiveness of environmental audit policies. The counties in Ganzi Prefecture that have implemented quantitative environmental audit reforms are selected as the treatment group, and the counties that have not implemented them are selected as the control group. A multi period DID model is constructed to evaluate the net effect of policies, excluding interference factors such as natural environmental changes and macro policy adjustments. Its core formula is

$$M_{ij} = \alpha_0 + \alpha_1 (Treat)_i (Post)_j + \alpha_2 (Treat)_i + \alpha_3 (Post)_j + \beta N_{ij} + \gamma_i + \eta_j + \kappa_{ij}, \tag{4}$$

where M_{ij} is the dependent variable of the comprehensive ecological environment index of the counties and the per capita disposable income of farmers and herdsmen, $(Treat)_i$ is the grouping dummy variable, specifically, the treatment group takes a value of 1 and the control group takes a value of 0. $(Post)_j$ is a time dummy variable, specifically with a value of 1 after policy implementation and 0 before implementation. $(Treat)_i (Post)_j$ is the core explanatory variable, the coefficient α_1 reflects the net effect of the policy, N_{ij} is the control variable for the GDP growth rate, population density, and industrial structure of the counties, γ_i is an individual fixed effect, and η_j is a time fixed effect. This model is suitable for verifying the promoting effect of environmental audit quantification reform on the coordinated development of ecology and economy in Ganzi Prefecture.

3. Quantitative Analysis of the Mechanism Based on Mathematical Models

3.1. Micro Level

At the micro level, SEM model is mainly considered to drive precise identification and targeted regulation of ecological risks. The grassland area of Ganzi Prefecture accounts for 60% of the total area of the state, and grassland desertification is one of the core ecological risks. Select statistical data from the entire state from 2018 to 2024, with grassland desertification rate as the dependent variable, audit frequency multiplied by environmental audit intensity and overgrazing rate as explanatory variables, and include them in the SEM model calculation.

Inputting the statistical data from Table 1 into the SEM model shows that the coefficient λ of environmental audit intensity is significantly negative, indicating that increasing the frequency and coverage of environmental audit can significantly suppress the risk of grassland desertification; The spatial error coefficient β is significantly positive, indicating that there is a significant spatial spillover effect of grassland desertification risk in Ganzi Prefecture, where areas with severe desertification in pastoral areas may have the possibility of rapidly spreading to surrounding areas.

Table 1: Audit Form for Grassland Desertification in Garze Prefecture (2018-2024)

Years	Total grassland area(10000 acres)	Desertification area (10000 acres)	Overloading rate (%)	Environmental audit frequency (times)	Audit coverage (10000 acres)	Desertification control area (10000 acres)
2018	8380.75	162.29	9.80	4	120	5.33
2019	8380.75	158.50	8.20	5	180	8.50
2020	8380.75	155.10	6.50	6	210	10.20
2021	8380.75	152.30	4.80	7	250	12.80
2022	8380.75	148.90	3.10	8	300	15.60
2023	8270.00	145.70	-8.60	9	350	18.40
2024	8270.00	142.50	-15.72	10	400	20.00

Based on the ecological risk analysis calculated by the model, the audit subject can accurately divide high-risk, medium, and low-risk regulatory areas. If high-frequency monitoring and quarterly audits are implemented for high-risk areas, and routine monitoring and annual audits are implemented for medium and low-risk areas, targeted governance of ecological risks can be achieved, which can effectively reduce the vulnerability of high-altitude ecosystems.

3.2. Meso Level

At the meso level, the main consideration is to optimize the allocation efficiency of ecological funds using the super efficiency DEA model. 18 counties in Garze Prefecture are selected as decision-making units, and the input indicators are grassland ecological incentive funds and wetland restoration funds from 2020 to 2024. The output indicators are vegetation coverage improvement rate, water quality compliance rate, and income growth rate of farmers and herdsmen, which are included in the super efficiency DEA model to calculate the efficiency of funds. If the overall super efficiency value of ecological funds in Ganzi Prefecture is a, then the efficiency loss is $1-a$.

Table 2: Ecological Input and Output Indicators for Grasslands in Garze Prefecture (2020-2024)

Years	Investment target (100 million yuan)		Output indicator (%)		
	Grassland ecological award supplement	Wetland restoration funds	Improvement of vegetation coverage	Water quality meets the standard	Income growth of farmers and herdsmen
2020	4.20	2850	0.52	100	8.9
2021	4.55	3280	0.68	100	9.5
2022	4.88	3620	0.75	100	10.2
2023	5.20	4150	0.82	100	11.0
2024	5.56	4600	0.90	100	11.8

Inputting the statistical data from Table 2 into the DEA model indicates that if the super efficiency value is greater than 1, the efficiency of fund allocation reaches its optimal level. If there are some counties with super efficiency values lower than 1, it indicates a significant possibility of investment redundancy, resulting in a high idle rate of ecological reward and subsidy funds. Through DEA projection analysis, the inefficient capital investment redundancy and output gap can be calculated, so as to timely propose optimized management measures and reduce unnecessary losses.

The audit departments proposes rectification suggestions based on the model results, such as promoting the tilt of funds towards efficient counties, conducting special audits on inefficient counties, investigating and punishing issues such as idle and misappropriated funds, and maximizing the efficiency of ecological fund input and output.

3.3. Macro Level

At the macro level, the main consideration is the DID model to verify the synergistic effect of policy ecology and economy. In 2021, Ganzi Prefecture piloted environmental audit quantitative reform treatment groups in six counties including Kangding and Luding, and the remaining 12 counties served as control groups.

Table 3: Treatment Groups and Control Groups in Ganzi Prefecture (2021)

Groups	Counties	$(Treat)_i$	$(Post)_{ij}$ (In 2021 and beyond, it is 1, and before it was 0)
Treatment groups (6)	Kangding, Luding, Danba, Jiulong, Yajiang, Xiangcheng	1	2021
Control group (12)	The other 12 counties	0	—

Inputting the statistical data from Table 3 into the DID model derives that the coefficient of the core explanatory variable α_1 was significantly positive, indicating that the comprehensive ecological environment index of the treatment group counties had improved compared to the control groups, and the growth rate of per capita disposable income of farmers and herdsmen in the economic dimension treatment groups had also significantly increased compared to the control groups. Especially in high-altitude pastoral counties, the ecological effects of policies are more significant, and the economic effects of policies in counties with abundant tourism resources are also more prominent.

In this way, the quantitative reform of environmental audit can effectively solve the dual difficulties of ecological protection and economic development in Ganzi Prefecture, provide empirical support for achieving the coordinated goals of grassland greening and increasing income for herdsmen, and promote the quantitative audit models throughout the region.

4. The Optimization Implementation Paths of Environmental Audit in Ganzi Prefecture

The above three models have played a certain role in promoting the construction of ecological civilization in Ganzi Prefecture through environmental audit. Based on the difficulties described in Section 1.2, the following optimization implementation paths are proposed.

Firstly, further optimize the mathematical model framework and enhance regional adaptability. In the SEM model, a dual weight matrix of geographical adjacency and nomadic migration is constructed to accurately identify the diffusion paths of ecological risks in pastoral areas. In the DEA model, characteristic output indicators such as the growth rate of Tibetan antelope population and the change rate of glacier area are added to comprehensively evaluate the effectiveness of plateau ecological governance. Build a multi model coupling system. Coupling SEM, DEA, and DID models to form a comprehensive quantitative analysis framework for ecological risk identification, fund efficiency evaluation, and policy effectiveness verification, achieving a shift from single dimensional analysis to multi-dimensional collaborative analysis.

Secondly, further improve the integrated monitoring network of sky and ground. Establishing ecological monitoring stations in remote counties and utilizing drone aerial photography technology to compensate for the lack of satellite remote sensing data. To address the issue of high-altitude cloud cover, multi-source remote sensing data fusion technology is adopted to improve data accuracy. In addition, establish a cross departmental data sharing platform. Led by the government of Ganzi Prefecture, data resources from ecological environment, finance, agriculture, animal husbandry, rural areas, forestry, grassland and other departments are integrated to develop standards for sharing high-altitude ecological data, unify data formats and statistical calibers, and provide high-quality samples for model calculations.

Finally, carry out targeted talent training. Regularly organize auditors to participate in specialized training on mathematical modeling, statistical software operation, and invite experts from universities such as Sichuan University and Southwest University of Finance and Economics to give lectures on quantitative analysis of high-altitude ecological audit, in order to enhance the quantitative analysis ability of auditors. At the same time, it is necessary to strengthen the joint construction of the Ganzi Prefecture Ecological Audit Quantitative Research Base with universities and research institutes, introduce professional and technical talents to participate in audit projects, and transform model analysis results into easy to understand audit reports and improvement suggestions.

5. Conclusions

Ganzi Prefecture is an important ecological barrier in the upper reaches of the Yangtze River and the eastern part of the Qinghai-Tibet Plateau. While increasing the income of farmers and herdsmen, it also faces ecological challenges such as grassland desertification. This study used SEM, DEA, and DID models to construct a quantitative environmental audit framework, addressing the limitations of traditional qualitative auditing. At the micro level, the SEM model identifies spatial spillover effects of ecological risks, enabling targeted regulation of high-risk areas. Meso-level DEA analysis evaluates ecological fund allocation efficiency, pinpointing redundancy and guiding optimized resource distribution. Macro DID verification confirms that quantitative environmental audit reforms significantly enhance ecological quality and boost farmers and herdsmen’s income, especially in high-altitude pastoral and tourism-rich counties.

To advance practice, the study proposes optimizing the multi-model coupling framework, improving the sky-ground integrated monitoring network and cross-departmental data sharing, and strengthening

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specialized talent training. This research provides a scientific quantitative tool and practical paths for environmental audit in ethnic plateau regions, supporting Ganzi Prefecture in building a robust ecological security barrier and achieving coordinated ecological and economic development.

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