Design of Illegal Wildlife Trade Prevention and Control System Based on AHP and Multiple Linear Regression Model--Based on the Practical Path of National Government

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Abstract. As a global environmental crime, illegal wildlife trade seriously threatens ecological security and biodiversity. In order to build a systematic prevention and control system, this study innovatively integrated the analytic hierarchy method (AHP) and multiple linear regression model to design a five-year data-driven intervention program based on the national government. The AHP model assesses potential implementation subjects from five dimensions: financial resources, human resources, influence, relevance of interests and legal enforcement, and determines that the national government has the highest overall score (0.4264), and its legislative authority, resource deployment and international collaboration capacity provide the core guarantee for the program to be implemented. Further combined with the multiple linear regression model, quantitatively analyzing the impact of the expansion of nature reserve area, environmental protection financial investment and education penetration rate on the export volume of illegal trade, the model was significant ($p=0.0368$), predicting a significant decrease in the export volume after implementation. Sensitivity analysis shows that disposable income and education funding are key drivers of effectiveness. The study confirms that the government-led multidimensional strategy of "regulatory enhancement-technological empowerment-international cooperation" can effectively curb illegal trade networks and provide a quantitative decision-making framework for global governance.

Keywords: Hierarchical analysis, multiple linear regression, illegal wildlife trade.

1. Introduction

1.1. Background of the study

Illegal wildlife trade, as the fourth largest illegal trade in the world, with an annual turnover of $26.5 billion, seriously threatens biodiversity and ecological security [1]. Although the international community has taken several curbing measures, it is still a challenge to effectively select implementation subjects and design data-driven long-term intervention programs. The purpose of this paper is to construct a five-year data-driven program, screen the target implementers through multi-dimensional assessment, and quantitatively analyze the feasibility and expected impact of the program.

1.2. Literature review

(1) Trade Network Structure and Driving Mechanisms

Illegal wildlife trade networks present cross-regional complexity. Wang et al. (2024) constructed a global trade network based on CITES data and found that the trade community breaks through geographic restrictions, with Germany and the Netherlands as the core nodes, and the commercial use trade accounted for 74.98% of the total, of which reptiles accounted for 21.08% [2]. Ibáñez Alonso and van Uhm (2023) take European eel as an example and reveal the regulatory loopholes of outsourced transportation, financial manipulation, and third-country transit such as Morocco in the "legal-illegal" symbiotic network through the "pipeline model" [3]. Duffy (2022) points out that the illegal trade with national security, organized crime, and some NGOs obtain funding through the

"security threat" framework, but exacerbate the negative impact of militarized law enforcement on marginalized communities [4].

(2) Policy and regulatory effectiveness

Insufficient synergy between traditional policy frameworks and emerging technologies constrains regulatory effectiveness. Hughes et al. (2023) analyzed 183 species and found that 64% of CITES assessments did not follow the precautionary principle, and 83% lacked population data, calling for optimized regulation in conjunction with the IUCN Red List [5]. Gore et al. (2022) proposed geospatial data standards for trade and risk routes to identify hotspots and risk routes through cross-sectoral data integration [6]. Moloney and Chaber (2024) pointed out that, although X-ray, AI image recognition and other technologies have improved the efficiency of detection, they are facing the problems of high cost and insufficient cross-sectoral integration [7].

(3) Regional cases and community impacts

Regional cultural needs and community engagement are key dimensions of governance. Orion et al. (2025) focused on wild cats in Côte d'Ivoire to reveal the link between traditional medicine needs and illegal trade, emphasizing the value of indigenous knowledge for monitoring, but lacking quantitative analysis [8]. The Peruvian case of Daut et al. (2015) showed that NGOs with both conservation and animal welfare goals were effective in reducing the illegal pet trade, but weak government enforcement constrains long-term effects [9]. Although captive breeding is seen as an alternative, its "legalization" is prone to abuse and requires full-chain traceability [10].

Existing analyses mostly focus on supply chain descriptions and lack quantitative assessments of the selection of implementation actors and resource suitability; Secondly, although technological empowerment enhances regulatory efficiency, insufficient policy synergy and bottlenecks in transnational collaboration constrain effectiveness, and existing governance frameworks rely on a single policy tool, with little systematic design of multidimensional intervention programs; thirdly, regional cases demonstrate the importance of community participation and cultural balance, but lack scientific screening of the comprehensive capacity of implementation actors and quantitative verification of long-term effectiveness.

Focuses on unanswered questions, this paper proposes the following innovative paths: firstly, breaking through the limitations of traditional qualitative analysis, constructing a multi-criteria assessment system through the hierarchical analysis method (AHP), and scientifically selecting the optimal implementation subject; secondly, integrating multiple linear regression models to quantify the dynamic correlation between interventions and the volume of illegal trade and exports, so as to fill the empirical gap of the prediction of the policy effect; lastly, focusing on the systemic advantages of the state government Finally, focusing on the institutional advantages of the national government, we design a five-year comprehensive governance framework of "regulations, technology and international collaboration", which provides a data-driven decision-making paradigm for solving the problem of fragmentation in the governance of transnational environmental crimes.

1.3. Research Ideas

To address the issue of implementation object selection, this study adopts the hierarchical analysis method (AHP) model to assess the potential object in five dimensions: financial resources, human resources, influence, interest and legal enforcement, and identifies the national government as the optimal implementation subject, with the highest score of comprehensive capacity and the institutional advantages of coordinated law enforcement and international cooperation. In order to validate the suitability of the program, literature analysis and relevant data are combined to clarify the necessity of government-led programs. It is further proposed that the national government needs to supplement resources such as law enforcement power, international cooperation power and professional knowledge, and the impact of the intervention is simulated through a multiple linear regression model, which shows that the project can significantly reduce the volume of illegal trade exports ($p<0.05$). Sensitivity analysis showed that disposable income percapita and education expenditure were the key factors influencing the effectiveness of the project.

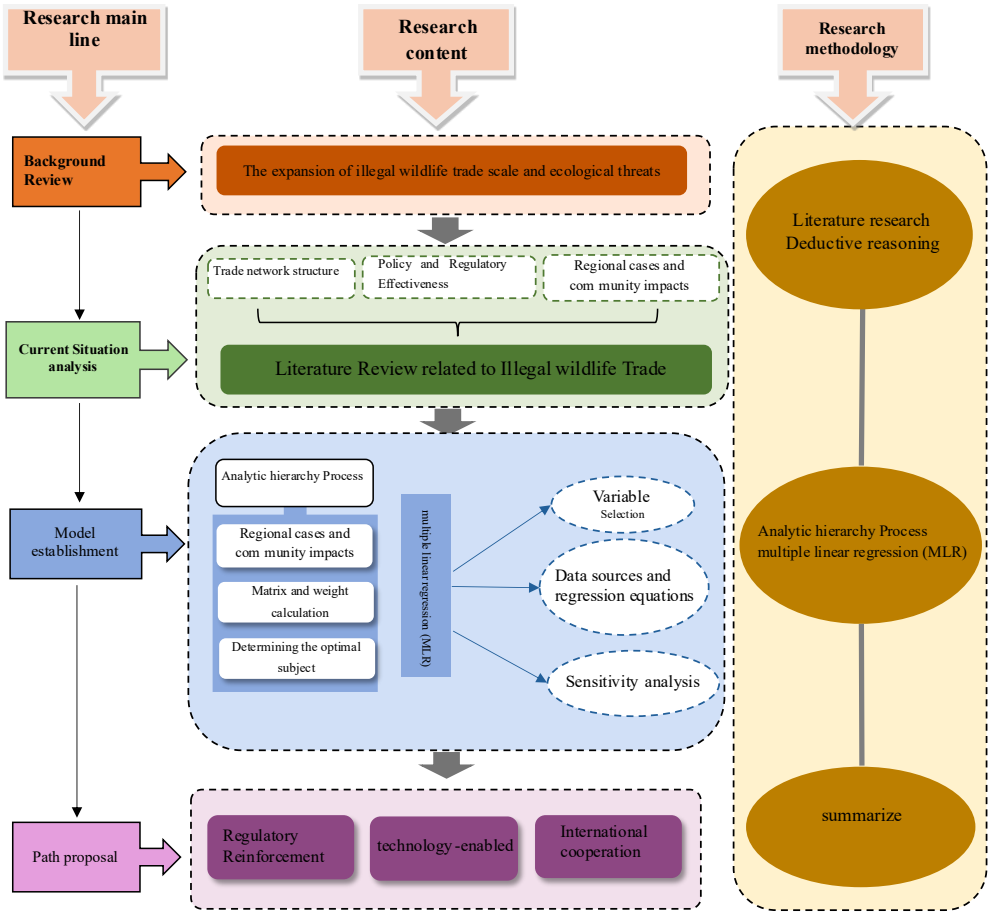

Figure 1. Diagram of the research idea

As shown in Figure 1, this paper innovatively combines hierarchical analysis with multiple linear regression modeling to provide quantitative decision support for national governments to formulate policies against illegal wildlife trade. The study confirms that the data-driven five-year project can systematically curb illegal trade networks through strengthening law enforcement synergy and international resource integration, providing a practical paradigm for global biodiversity conservation.

2. Fundamentals and applications of the Hierarchical Analysis method

2.1. Definition and formula derivation of hierarchical analysis method

Analytic Hierarchy Process (AHP) is a multi-objective decision analysis method that combines qualitative and quantitative analysis methods. The main idea of this method is to decompose the complex problem into a number of levels and a number of factors, make a comparative judgment on the importance of the two two indicators, establish a judgment matrix, by calculating the maximum eigenvalue of the judgment matrix and the corresponding eigenvectors, you can derive the weight of the degree of importance of the different programs, to provide a basis for the selection of the best program [11], the specific implementation steps are as follows:

(1) Constructing a hierarchy. Decompose the problem into goal, criterion and program layers. The goal layer is the ultimate purpose of decision-making, such as selecting the optimal object. The criterion level is the evaluation criteria specified for each program, such as financial resources, human resources, and influence. The option level is the alternatives, e.g., national government, international non-governmental organizations, etc.

(2) Constructing a judgment matrix. Compare the indicators of the criterion layer two by two to quantify their relative importance. Let there are n indicators in the criterion layer, and construct the n × n matrix $A = (a_{ij})$, where a_{ij}denotes the importance of the ith indicator relative to the jth

indicator, which satisfies $a_{ij} = \frac{1}{a_{ji}}$ and $a_{ii} = 1$. For example, the ratio of the importance of the financial resources (i) to the human resources (j) is 6:1, then $a_{ij} = 6$ and $a_{ji} = 1/6$.

(3) Calculate the weights. Solve the weight vector by eigenvector method or arithmetic mean method. Normalize each column element first:

$$b_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \tag{1}$$

Next, the row averages are calculated: $w_i = \frac{1}{n}\sum_{j=1}^{n} b_{ij}$, Get the weight vector.

(4) Consistency test to verify the logical consistency of the judgment matrix. First calculate the consistency index $CI = \frac{\lambda_{max}-n}{n-1}$, where λ_{max} is the largest eigenvalue, then check the table to obtain the average random consistency index RI, and then calculate the consistency ratio $CR = \frac{CI}{RI}$, and if CR<0.1, the test is passed.

2.2. Application of Hierarchical Analysis and Benefits

In order to maximize the impact of the project, this paper strives for excellence in the selection of implementation targets, dividing all targets into four categories: national governments (GOV); international non-governmental organizations (NGOs), such as the International Foundation for the Prevention of Cruelty to Animals (IFAW); social groups, such as the China Wildlife Conservation Association (CWCA); and enterprises with an interest in and a sense of responsibility for wildlife conservation, as the model of the target layer for the study.

Traditional studies on the governance of illegal wildlife trade are mostly based on qualitative descriptions to select implementation subjects, lacking scientific quantitative basis. This study introduces the hierarchical analysis method into the selection of governance subjects for the first time, and constructs a five-dimensional assessment model of financial resources (FR)-human resources (HR)-influence (IM)-interest relevance (IN)-legal enforcement (LM) five-dimensional assessment model, and quantitatively compare the comprehensive ability of the four types of subjects through a structured indicator system.

The above five-dimensional assessment criteria do not have the same degree of influence on the results, so in order to distinguish their importance, as shown in Table 1, this paper compares the five dimensions two by two and constructs a judgment matrix, which is used to determine the weight of each criterion.

Table 1. Judgment matrix of five-dimensional assessment criteria

factors	FR	HR	IM	IN	LM	Weights ($\mathbf{w_i}$)
	1	6	2	3	3/2	0.3750 (w_1)
	1/6	1	1/3	1/2	1/4	0.0625 (w_2)
	1/2	3	1	3/2	3/4	0.1875 (w_3)
	1/3	2	2/3	1	1/2	0.1250 (w_4)
	2/3	4	4/3	2	1	0.2500 (w_5)

Perform a consistency check on the table 1:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{2}$$

Among them, $\mathrm{CI} = \frac{\lambda_{\max}-\mathrm{n}}{\mathrm{n}-1}$, ($\lambda_{\max}$ is the largest eigenvalue of the judgment matrix, and n is the number of indicators), RI is the average random consistency index, which can be obtained by looking up the table. After calculation, CR=0 is obtained, which indicates that the judgment matrix is a consistent matrix, and there will not be any contradiction, and the weight data it obtains can naturally be used. Here, this paper uses the arithmetic mean method to calculate the weight data.

The judgment matrix was again created. This time, a judgment matrix is created for the four project implementation targets, one corresponding to each judgment criterion. Similar to the process in the second step, the evaluation criterion FR is used here as an example, the process is summarized in Table 2.

Table 2. Judgment Matrix for Project Implementation Targets

Clients	GOV	NGO	SAT	Ltd.	Score
GOV	1	3/2	6	3	0.4615
NGO	2/3	1	4	2	0.3077
SAT	1/6	1/4	1	1/2	0.0769
Ltd.	1/3	1/2	2	1	0.1538

After a consistency test, it was determined that the data from the table could be used. After that, the same arithmetic mean method was applied to calculate the score of each subject under the judgment criterion FR. By analogy, the score of each subject under different criteria was then obtained.

Based on the previous two steps the weights of the different evaluation criteria and the scores of each subject under the different evaluation criteria were obtained, using the formula:

The final score of a subject $Y = \Sigma_{i=1}^{5} x_i y_i$, with y_i denoting the score of each subject corresponding to the FR, HR, IM, IN, and LM criteria. Ultimately, the final scores of the four project implementers are shown in Table 3:

Table 3. Final scores of the four project implementers

Clients	Score
GOV	0.4264
NGO	0.3107
SAT	0.1247
Ltd.	0.1382

Therefore, the most appropriate implementation of the project with this paper is the national government.

3. Fundamentals and applications of multiple linear regression

3.1. Background of the model

This study aims to reduce the scale of the global illegal wildlife trade, for which three core objectives have been set: reducing the volume of trade, establishing international and domestic cooperation mechanisms, and enhancing public awareness of conservation. To achieve these goals, the project proposes three strategies: first, improve relevant regulations and strengthen transnational law enforcement cooperation; second, plan to increase national environmental protection financial expenditure by 5% in five years, so as to strengthen publicity and education and curb the illegal market demand; and lastly, expand the area of the national nature reserve by 8%, and crack down on illegal supply chains at borders, logistics and online trading channels. In addition, the project will use big data and artificial intelligence technology to improve monitoring capacity and deepen international exchanges in cooperation with civil society organizations. The implementation of the project is divided into three phases: from 2025 to 2027, it will focus on improving regulations and demand control; from 2028 to 2029, it will concentrate on cutting off the supply chain and technological innovation; and from 2030 onwards, it will continue to promote public participation and global cooperation.

In this study, the Chinese government was selected as the main body of the project, given its high degree of consistency with the project's objectives and its core advantages in terms of legislative power, financial resources and human resources, which can ensure the implementation of key measures such as the formulation of laws and regulations, the application of science and technology,

and cross-border cooperation. At the same time, the strong social appeal of the Chinese government will help to promote the formation of a common governance atmosphere for the whole society.

3.2. Definition and formula of multiple linear regression

Multiple Linear Regression (MLR) is used to analyze the relationship between the linear effects of multiple independent variables on the dependent variable and is mathematically modeled as:

$$Y = \beta_0+\beta_1 x_1+\beta_2 x_2+...+\beta_k x_k+\varepsilon \quad (3)$$

Where, Y is the dependent variable, such as the volume of illegal trade exports in this paper; $x_1, x_2,..., x_k$ are independent variables, such as the area of nature reserve, environmental protection financial expenditures, etc; β_0 is the intercept term, $\beta_1, \beta_2,...,\beta_k$ is the regression coefficient; ε is the random error term.

In this paper, we estimate the regression coefficients using the least squares (OLS) method with the objective of minimizing the residual sum of squares:

$$\min \sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2 \quad (4)$$

3.3. Application and Effectiveness of Multiple Linear Regression

If the project is implemented, the country's illegal wildlife trade will decrease year by year over a five-year period, and eventually there will be a significant change from the current level. In order to illustrate this, this paper builds a multiple linear regression analysis model for analysis based on the National Bureau of Statistics and CITES trade database. In conjunction with the project plan, this paper modifies some of the known five years of actual data, and substitutes the modified data into the model to predict the new illegal wildlife trade export volume, and by comparing it with the actual value, we can clearly see the change of the export volume.

Due to the limitations in accessing historical data, this study used a five-year dataset from 2011 to 2015 to construct a multiple linear regression model. Despite the small sample size, the selected data covers the critical period before policy implementation, including the fluctuations in illegal trade, the expansion of protected areas, and the growth in environmental protection investments. These data provide a comprehensive evolution trajectory of key variables, effectively reflecting their dynamic interrelationships. Subsequent rigorous model testing further confirmed the statistical significance of the model. Additionally, sensitivity analysis demonstrated that the impact of key variables on the results is relatively stable, indicating that the model remains robust even with a small sample size.

Existing studies mostly stay in the qualitative design of policies and lack quantitative correlation analysis of interventions and governance effectiveness. This study combines the multiple linear regression model with the five-year governance program for the first time, and constructs the causal prediction model of "Protected area (x_1)-Environmental protection investment (x_2)-Education penetration rate (x_3)→Illegal trade export volume (Y)", which realizes a breakthrough in the methodology from "empirical policymaking" to "data-driven". The methodological breakthrough from "empirical policy-making" to "data-driven" is realized.

Table 4. Five-year actual data

Year	x_1(million hectares)	$x_2(billion\ yuan)$	x_3(ten thousand)	Y
2011	9315.27	2640.98	2454.8	475643
2012	9414.56	2963.46	2467.2	419263.56
2013	9403.93	3435.15	2435.9	396198.72
2014	9651.63	3815.6	2400.5	454749.5
2015	9648.83	4802.89	2374.4	371302.285

Based on Table 4, The changes in the protected area (x_1) and environmental protection investment (x_2) are significantly correlated with the decline in illegal trade exports (Y). The long-term increase in education penetration rate (x_3) has a potential effect on curbing trade. This preliminary finding

highlights the potential link between enhanced protective measures and reduced trade volume, providing an empirical foundation for the subsequent construction of a multiple regression model.

A multivariate linear regression analytical model was developed by first setting up a regression plane equation:

$$Y = \beta_0+\beta_1 x_1+\beta_2 x_2+\beta_3 x_3 \quad (5)$$

After that, the empirical regression equation was finally obtained by solving for the value of$\beta_i(i=0,1,2,3)$ in the regression plane equation based on the principle of least squares and using the data in the table:

$$Y = 478.1207x_1-228.4327x_2-2800.7x_3+3503800 \quad (6)$$

In order to verify the scientific validity of the formula and the degree of correlation between the independent and dependent variables, the model was tested in this paper. It was calculated that the correlation coefficient of the model r=0.9992 and the probability of significance p=0.0368<0.05, which satisfy the conditions, the model is valid, the correlation between the independent variables and the dependent variable is strong, and the data predicted with the model are more accurate.

Next, assuming that the implementing entity has adopted the program since 2018, the new dependent variable is calculated as required.

Table 5. Actual data 2017-2020

Year	x_1 (million hectares)	$x_2(billion\ yuan)$	x_3 (ten thousand)
2017	9745.16	5617.33	2374.5
2018	9860.92	6297.61	2375.3709
2019	9811.41	7390.2	2414.305
2020	9821.27	6333.4	2494.4529

According to the project plan, this paper processes the actual data in the Table 5 to get the new value and the amount of change of each independent variable in each year of five years. After that, the new independent variables are substituted into the model to calculate the dependent variable, i.e., the export volume of illegal wildlife trade after the implementation of the project. In order to be able to illustrate the problem more objectively, this paper makes a graph to compare the two.

Figure 2. Comparison of actual illegal trade export volumes with model-simulated trade volumes, 2018-2020

From the Figure 2, each year the export volume of illegal wildlife trade has decreased from the original one, and accumulated over five years, the predicted value must be able to differ from the actual value, showing a significantly lower trend.

3.4. Model sensitivity analysis

This paper carries out a sensitivity analysis of the multiple linear regression model established above to increase the education penetration rate by increasing education funding, and then input the changed data into the model established in this paper. In this study, the adjustment range of the key parameter of education expenditure is set at 5%, referring to the actual data that the total investment in national education expenditure increased by 5.33% in 2023. This not only conforms to the realistic trend of policy regulation, but also can effectively verify the sensitivity of the model.The prediction results are shown below:

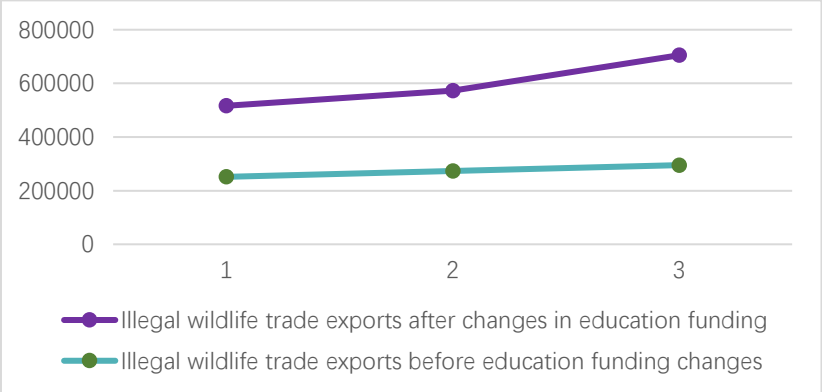

Figure 3. Multiple linear regression model sensitivity analysis plot

From the Figure 3, the export volume of illegal wildlife trade after increasing education funding is reduced but within the acceptable range, which shows that the model in this paper is stable and can solve the real problem.

4. Conclusion

The Hierarchical Analysis Model assessed four categories of potential targets (national governments, non-governmental organizations, social groups and enterprises) in terms of five dimensions: financial resources, human resources, influence, relevance of interests and law enforcement capacity. The national government stood out with the highest composite score (0.4264), which was attributed to its unparalleled legislative authority, ability to mobilize resources, and advantage in promoting international cooperation. This finding highlights the critical role of centralized governance in tackling transnational environmental crime.

To validate the feasibility of the project, the study constructed a multiple linear regression model to correlate the reduction in illegal wildlife trade exports with three core variables: expansion of nature reserve area, increase in environmental protection funding, and increase in high school education prevalence. Sensitivity analysis showed that per capita disposable income and education expenditure significantly affected program effectiveness, and rising income levels and education funding were positively correlated with the reduction of illegal trade. The probability of significance of the model ($p=0.0368$) and the high likelihood of achieving the objectives (96.32%) proved its robustness and practical applicability.

In summary, this study provides a structured framework for combating illegal wildlife trade, emphasizing the centrality of national government and data-driven policy design. The study advocates a comprehensive strategy to address current challenges through the strengthening of laws, raising public awareness, deepening international cooperation, and integrating technological innovations. By addressing existing gaps and expanding interdisciplinary research, this work lays the foundation for scalable, sustainable solutions to mitigate this pressing environmental problem.

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