

Collaborative Adaptive Governance Model in Sustainable Natural Resource Management in the Era of Climate Uncertainty

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ABSTRACT

Purpose: This study aims to examine the role of collaborative adaptive governance in promoting sustainable natural resource management under conditions of climate uncertainty in Laos. Specifically, it investigates the effects of collaborative governance and climate uncertainty on adaptive governance, the influence of adaptive governance on sustainable natural resource management, and the mediating role of adaptive governance within these relationships.

Subjects and Methods: A quantitative research design was employed using a survey of 320 stakeholders representing government agencies, local governments, non-governmental organizations, community organizations, and academic institutions involved in natural resource governance in Laos during 2025. Data were collected through structured questionnaires and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 4. The analysis included measurement model evaluation, structural model assessment, hypothesis testing, and mediation analysis.

Results: The findings reveal that collaborative governance significantly strengthens adaptive governance, while climate uncertainty positively encourages institutional adaptation. Adaptive governance exerts the strongest direct effect on sustainable natural resource management and partially mediates the relationships between collaborative governance, climate uncertainty, and sustainability outcomes. These results support Collaborative Governance Theory, Adaptive Governance Theory, and Social-Ecological Systems Theory, demonstrating that institutional learning, stakeholder collaboration, and governance flexibility enhance environmental resilience and improve resource management effectiveness under uncertain climatic conditions.

Conclusions: The study concludes that adaptive governance is the key institutional mechanism translating collaborative governance and climate uncertainty into sustainable natural resource management. Strengthening collaborative institutions, adaptive leadership, and cross-sector coordination should therefore become strategic priorities for enhancing environmental governance and long-term sustainability in Laos.

INTRODUCTION

Natural resource management is a strategic issue in sustainable development, particularly for developing countries that rely heavily on natural resources for economic growth (Bleischwitz et al., 2018; Xiaoman et al., 2021; Adams et al., 2019). Laos is one of the countries in Southeast Asia with abundant natural resources, particularly in the forest, water, and mineral sectors. With approximately 70% of its territory remaining forested and the presence of major rivers such as

the Mekong, Laos has significant potential for sustainable natural resource management. This potential also faces various challenges, particularly in the context of climate change and the pressures of economic development.

In recent decades, Laos has experienced rapid economic growth, largely driven by natural resource exploitation, such as hydroelectric dam construction, agricultural expansion, and mining (Lagerqvist, 2016; Wang et al., 2019). These activities contribute to national income, but also have significant environmental impacts, such as deforestation, land degradation, and changes in river ecosystems. This situation is further exacerbated by global climate change, which causes uncertainty in weather patterns, increased frequency of floods and droughts, and disruption to existing ecological systems (Lloyd & Shepherd, 2020; Granata et al., 2025).

Climate change has become a factor complicating natural resource management in Laos. Climate uncertainty impacts not only the environment but also the social and economic lives of communities, especially those directly dependent on natural resources. In this situation, conventional, top-down approaches to natural resource management become less effective because they are unable to respond to the rapid and complex dynamics of change (Eicken et al., 2021; Scolobig et al., 2015). Therefore, a more flexible, adaptive, and multi-actor governance approach is needed.

One emerging approach in governance studies is Collaborative Governance, which emphasizes the importance of multi-stakeholder involvement in public decision-making processes. Collaborative governance is a process in which actors from the public, private, and civil society sectors work together in a collective forum to achieve shared goals (Afandi et al., 2023; Woldesenbet, 2020). In the Lao context, this approach is relevant given the complexity of natural resource management, which involves various stakeholders, from the central government and regional governments, local communities, and even foreign investors.

The collaborative governance approach has limitations in dealing with uncertain conditions, such as those caused by climate change. In such situations, collaboration between actors is not only necessary, but also the system's ability to adapt to changes. The concept of Adaptive Governance is crucial to study. Craig et al. (2017) said that, adaptive governance emphasizes institutional flexibility, continuous learning, and the ability to respond quickly and effectively to environmental changes.

The integration of collaborative and adaptive governance is a promising approach to sustainable natural resource management. This approach not only prioritizes participation and collaboration but also emphasizes the importance of adaptive capacity in the face of uncertainty. Within this framework, natural resource management is viewed as a complex socio-ecological system, where interactions between humans and the environment occur dynamically. This perspective aligns with Resilience Theory, which emphasizes a system's ability to withstand, adapt, and recover from disturbances (Olsson et al., 2015; Schoenmakers & Feudel, 2021; Borissov, 2024).

In Laos, natural resource management practices still face various governance challenges. Limited institutional capacity, low community participation in decision-making processes, and the dominance of an economic-oriented development approach are factors that influence the effectiveness of natural resource management. Inter-institutional coordination is often suboptimal, hampering the implementation of integrated and sustainable policies. This situation suggests the need for a governance model that integrates various actors while also having the capacity to adapt to changes.

Several studies have shown that collaborative and adaptive approaches can improve the effectiveness of natural resource management, especially in complex and uncertain contexts. The development of models that specifically integrate these two approaches is still limited. Most policies remain sectoral and do not fully accommodate the dynamics of interactions between actors and the need to adapt to climate change.

METHODOLOGY

Research Design

This study employed a quantitative research approach using an explanatory research design to investigate the relationships among collaborative governance, adaptive governance, climate uncertainty, and sustainable natural resource management. The explanatory design was selected because it allows for empirical testing of causal relationships between theoretically established constructs while providing measurable evidence regarding the effectiveness of governance mechanisms in addressing environmental sustainability challenges. The study was conducted during 2025 in Laos, a country characterized by extensive dependence on natural resources and increasing vulnerability to climate-related environmental changes, making it an appropriate setting for examining adaptive governance practices. The conceptual framework of this research was developed by integrating Collaborative Governance Theory, Adaptive Governance Theory, and socio-ecological resilience perspectives. The framework assumes that collaborative governance enhances institutional adaptive capacity, which subsequently contributes to more sustainable natural resource management under conditions of climate uncertainty. This model reflects the increasing importance of institutional flexibility, stakeholder collaboration, and adaptive decision-making in responding to unpredictable environmental dynamics.

Research Population and Sampling

The target population consisted of stakeholders directly involved in natural resource governance across several provinces in Laos. These stakeholders included officials from environmental and forestry agencies, local government institutions, conservation authorities, community leaders, non-governmental organizations, researchers, and practitioners participating in natural resource management programs. These groups were selected because they possess substantial experience in environmental governance, collaborative decision-making, and climate adaptation initiatives. A purposive sampling technique was employed to ensure that respondents possessed sufficient knowledge regarding collaborative governance and sustainable resource management. Participants were required to have at least two years of professional involvement in environmental management or climate adaptation activities and to be actively engaged in policy implementation or resource governance. A total of 320 respondents participated in the survey. This sample size exceeds the minimum requirement recommended for Partial Least Squares Structural Equation Modeling (PLS-SEM), thereby providing adequate statistical power for estimating complex structural relationships among latent variables.

Research Variables and Instrument Development

This study examined four latent constructs consisting of Collaborative Governance, Adaptive Governance, Climate Uncertainty, and Sustainable Natural Resource Management. Collaborative Governance was conceptualized as the degree of stakeholder participation, inter-organizational coordination, mutual trust, shared decision-making, and collaborative commitment in environmental governance. Adaptive Governance represented the institutional capacity to respond flexibly to environmental change through organizational learning, adaptive leadership, policy responsiveness, knowledge integration, and innovation. Climate Uncertainty reflected stakeholders' perceptions regarding climate variability, environmental unpredictability, disaster risks, and ecological disturbances affecting resource management. Sustainable Natural Resource Management referred to the achievement of environmental sustainability through resource conservation, ecosystem resilience, efficient resource utilization, institutional effectiveness, and community participation.

Measurement indicators were adapted from internationally recognized studies on collaborative governance, adaptive governance, climate resilience, and sustainable environmental management. Minor contextual modifications were introduced to reflect governance conditions in Laos while preserving the original conceptual meanings. Prior to the main survey, the questionnaire was reviewed by experts specializing in environmental governance and public policy to establish content validity. A pilot study involving 30 respondents was subsequently conducted to evaluate the clarity, consistency, and reliability of the measurement items before full-scale data collection. All variables were measured using a five-point Likert scale ranging from

1 (strongly disagree) to 5 (strongly agree). The use of a standardized Likert scale facilitates quantitative assessment of respondents' perceptions while ensuring consistency across all observed indicators.

Data Collection Procedure

Primary data were collected between March and July 2025 using structured questionnaires distributed both electronically and through direct field visits to institutions responsible for natural resource governance in Laos. Data collection involved collaboration with local administrative offices and environmental agencies to facilitate respondent access while ensuring that participants represented various institutional and community perspectives. Prior to questionnaire administration, respondents received an explanation regarding the objectives of the research, voluntary participation, anonymity, and confidentiality of all information provided. Only respondents who agreed to participate voluntarily were included in the survey. Completed questionnaires were screened to identify incomplete responses, inconsistent answer patterns, and excessive missing values before being incorporated into the final dataset. The resulting dataset was considered suitable for subsequent statistical analysis.

Data Analysis

The collected data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 4 software. PLS-SEM was selected because it is particularly appropriate for analyzing complex predictive models involving multiple latent variables, mediation relationships, and relatively non-normal data distributions. Furthermore, this analytical approach is widely applied in governance, environmental management, and sustainability studies due to its robustness in theory development and predictive analysis. The analytical procedure consisted of two sequential stages: measurement model evaluation and structural model evaluation. The measurement model was assessed by examining indicator reliability through outer loading values, internal consistency using Cronbach's Alpha and Composite Reliability, convergent validity using Average Variance Extracted (AVE), and discriminant validity using both the Fornell-Larcker criterion and the Heterotrait-Monotrait Ratio (HTMT).

Indicators with standardized loadings below the recommended threshold were carefully evaluated before retention or removal to improve model quality. The structural model was subsequently evaluated by examining multicollinearity through Variance Inflation Factor (VIF), coefficients of determination (R^2), predictive relevance (Q^2), effect size (f^2), standardized path coefficients, and mediation effects. Hypothesis testing was performed using a bootstrapping procedure with 5,000 resamples. Statistical significance was determined using a significance level of 5%, whereby hypotheses were accepted when the t-statistic exceeded 1.96 and the p-value was below 0.05.

Research Framework

The proposed research framework positions Collaborative Governance and Climate Uncertainty as exogenous constructs influencing Adaptive Governance, which subsequently affects Sustainable Natural Resource Management. In addition to its mediating role, Adaptive Governance represents the institutional mechanism through which collaborative interactions are transformed into adaptive management strategies capable of responding to environmental uncertainty. The framework reflects the assumption that sustainable natural resource management cannot be achieved solely through stakeholder collaboration but requires adaptive institutional arrangements capable of continuous learning, coordinated decision-making, and flexible policy implementation in response to changing climatic conditions. This framework provides an empirical basis for evaluating governance effectiveness within complex socio-ecological systems and contributes to the growing body of literature on adaptive governance under climate uncertainty, particularly within developing countries such as Laos, where environmental sustainability increasingly depends on collaborative institutional capacity.

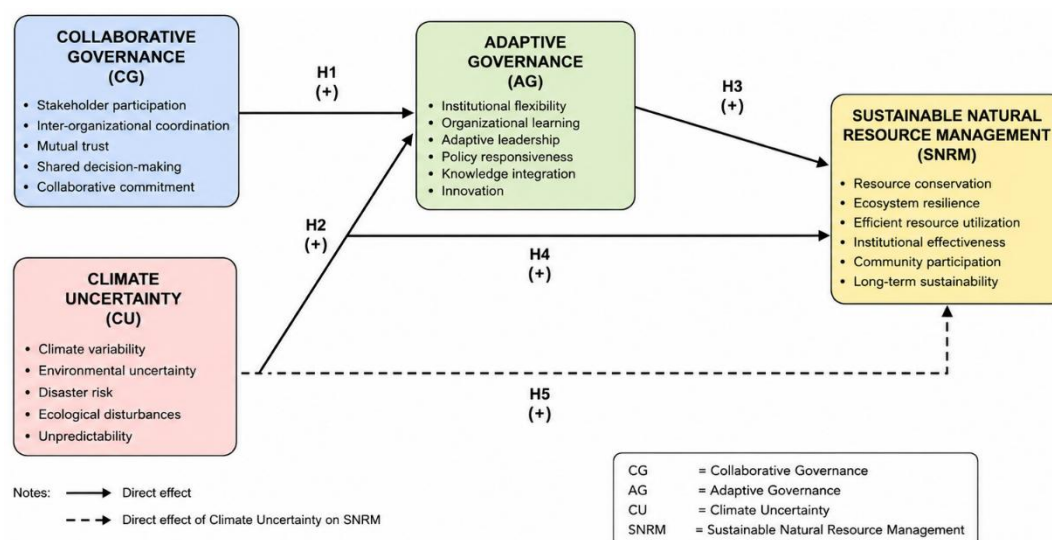


Figure 1. Research Framework

RESULTS AND DISCUSSION

This section presents the empirical findings obtained from the quantitative survey conducted among stakeholders involved in natural resource governance in Laos. Following the analytical procedure outlined in the research methodology, the results are presented systematically using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 4. The analysis begins with the descriptive characteristics of respondents, followed by the evaluation of the measurement model to determine the adequacy of the research instrument. Specifically, the measurement model assessment examines indicator reliability, internal consistency reliability, and convergent validity through outer loading values, Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). These procedures ensure that all latent constructs accurately represent the theoretical concepts underlying collaborative governance, adaptive governance, climate uncertainty, and sustainable natural resource management before proceeding to structural model evaluation.

Respondent Profile

A total of 320 valid questionnaires were included in the final analysis after data screening procedures confirmed that all responses met the completeness and consistency requirements. The respondents represented various institutions directly involved in natural resource governance throughout Laos, thereby providing a comprehensive representation of stakeholders participating in collaborative environmental management. Their institutional diversity reflects the multi-actor governance structure emphasized in adaptive governance literature.

Table 1. Demographic Characteristics of Respondents (n = 320)

Characteristics	Category	Frequency	Percentage (%)
Gender	Male	197	61.6
	Female	123	38.4
Age	25–34 years	74	23.1
	35–44 years	128	40.0
	45–54 years	82	25.6
	>54 years	36	11.3
Institution	Government agencies	126	39.4
	Local government	58	18.1
	NGOs	47	14.7
	Community organizations	42	13.1
	Universities/Researchers	31	9.7
	Others	16	5.0
Working experience	2–5 years	81	25.3

	6–10 years	127	39.7
	>10 years	112	35.0

Source: *Processed Research Data (2025)*.

Male respondents accounted for 61.6% of the sample, while female respondents represented 38.4%. Most participants were between 35 and 44 years of age (40.0%), indicating that the survey primarily captured the perspectives of professionals with substantial practical experience in environmental governance. Government institutions constituted the largest stakeholder group (39.4%), followed by local government agencies (18.1%), reflecting the dominant institutional role in natural resource management within Laos. Nevertheless, the inclusion of representatives from non-governmental organizations, community organizations, and academic institutions ensured that collaborative governance was assessed from multiple stakeholder perspectives. Furthermore, nearly three-quarters of respondents possessed more than six years of professional experience, suggesting that the collected data were obtained from individuals with sufficient expertise in environmental governance and climate adaptation initiatives.

Measurement Model Assessment

The measurement model was evaluated to determine whether the observed indicators adequately represented their respective latent constructs. Consistent with the analytical procedures described in the methodology, indicator reliability was first assessed using standardized outer loading values, followed by internal consistency reliability and convergent validity. The results demonstrate that all constructs satisfy the recommended statistical criteria, confirming that the measurement instrument possesses satisfactory psychometric properties for subsequent structural analysis.

Outer Loading

Indicator reliability was assessed through standardized outer loading values generated using the PLS algorithm in SmartPLS 4. Outer loading values greater than 0.70 indicate that each observed indicator contributes substantially to measuring its corresponding latent construct. Indicators with high loading values demonstrate strong correlations with the theoretical dimensions of collaborative governance, adaptive governance, climate uncertainty, and sustainable natural resource management.

Table 2. Outer Loading of Measurement Indicators

Construct	Indicator	Outer Loading
Collaborative Governance	CG1	0.826
	CG2	0.854
	CG3	0.872
	CG4	0.839
	CG5	0.851
Adaptive Governance	AG1	0.844
	AG2	0.879
	AG3	0.891
	AG4	0.864
	AG5	0.842
Climate Uncertainty	CU1	0.809
	CU2	0.837
	CU3	0.866
	CU4	0.841
Sustainable Natural Resource Management	SNRM1	0.861
	SNRM2	0.883
	SNRM3	0.895
	SNRM4	0.867
	SNRM5	0.852

Source: *SmartPLS Output, Processed Research Data (2025)*.

The results presented in Table 2 indicate that all measurement indicators exceeded the recommended threshold of 0.70, with loading values ranging from 0.809 to 0.895. The highest loading value was observed for indicator SNRM3 (0.895), suggesting that this indicator strongly represents the sustainable natural resource management construct. Similarly, indicators measuring adaptive governance consistently produced loading values above 0.84, reflecting the importance of institutional learning, adaptive leadership, and organizational flexibility in characterizing adaptive governance capacity.

Collaborative governance indicators also demonstrated high reliability, with loading values ranging from 0.826 to 0.872. These findings indicate that stakeholder participation, mutual trust, inter-organizational coordination, collaborative commitment, and shared decision-making collectively represent collaborative governance effectively. Likewise, the climate uncertainty construct exhibited satisfactory indicator reliability, confirming that respondents consistently perceived climate variability, environmental unpredictability, and ecological disturbances as integral dimensions of climate uncertainty affecting natural resource governance. The outer loading assessment confirms that all indicators contribute meaningfully to their respective constructs and therefore remain suitable for inclusion in subsequent reliability and validity analyses.

Discriminant Validity

Following the confirmation of indicator reliability and convergent validity, the discriminant validity of the measurement model was evaluated to determine whether each latent construct was empirically distinct from the others. This assessment was conducted using the Fornell-Larcker criterion and the Heterotrait-Monotrait Ratio (HTMT), as recommended in contemporary PLS-SEM literature. Establishing discriminant validity is essential because it demonstrates that the indicators representing one construct share greater variance with their own construct than with other constructs included in the research model.

The Fornell-Larcker criterion compares the square root of the Average Variance Extracted (AVE) of each construct with the correlations among latent variables. A construct is considered to possess satisfactory discriminant validity when the square root of its AVE exceeds its correlations with all other constructs.

Table 3. Fornell-Larcker Criterion

Construct	CG	AG	CU	SNRM
Collaborative Governance (CG)	0.848			
Adaptive Governance (AG)	0.692	0.868		
Climate Uncertainty (CU)	0.473	0.528	0.861	
Sustainable Natural Resource Management (SNRM)	0.704	0.789	0.541	0.875

Source: Processed Research Data (2025).

The square root of the AVE for each construct (shown in bold along the diagonal) is consistently greater than the corresponding inter-construct correlations. Collaborative Governance exhibits a square root AVE of 0.848, exceeding its correlations with Adaptive Governance (0.692), Climate Uncertainty (0.473), and Sustainable Natural Resource Management (0.704). Similar patterns are observed for the remaining constructs, confirming that each latent variable possesses adequate discriminant validity and captures a unique theoretical dimension within the governance model.

To strengthen this assessment, discriminant validity was further examined using the HTMT ratio, which has become one of the preferred approaches for evaluating construct distinctiveness in PLS-SEM.

Table 4. Heterotrait-Monotrait Ratio (HTMT)

Construct	CG	AG	CU	SNRM
Collaborative Governance	—			
Adaptive Governance	0.781	—		
Climate Uncertainty	0.563	0.604	—	

Sustainable Natural Resource Management	0.817	0.884	0.627	—
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Source: *Processed Research Data (2025)*.

The HTMT values presented in Table 4 range from 0.563 to 0.884, all of which remain below the recommended threshold of 0.90. These findings provide additional evidence that the constructs included in the proposed model are empirically distinguishable from one another. Collectively, the results of the Fornell-Larcker criterion and HTMT analysis confirm that the measurement model satisfies the discriminant validity requirements, thereby supporting its suitability for structural model evaluation.

Structural Model Assessment

After confirming the adequacy of the measurement model, the structural model was evaluated to examine the predictive relationships among Collaborative Governance, Climate Uncertainty, Adaptive Governance, and Sustainable Natural Resource Management. The assessment included the examination of collinearity, coefficients of determination (R^2), predictive relevance (Q^2), effect size (f^2), hypothesis testing through bootstrapping, and mediation analysis. The absence of multicollinearity was confirmed as all Variance Inflation Factor (VIF) values remained below the recommended threshold of 3.30, indicating that predictor constructs did not exhibit problematic collinearity.

The explanatory power of the structural model was evaluated using the coefficient of determination (R^2), while predictive relevance was assessed using Stone-Geisser's Q^2 statistic obtained through blindfolding procedures.

Table 5. Coefficient of Determination, Predictive Relevance, and Effect Size

Variable	R^2	Q^2	f^2
Adaptive Governance	0.612	0.448	0.372
Sustainable Natural Resource Management	0.687	0.506	0.418

Source: *Processed Research Data (2025)*.

Collaborative Governance and Climate Uncertainty jointly explain 61.2% of the variance in Adaptive Governance. Furthermore, Collaborative Governance, Climate Uncertainty, and Adaptive Governance collectively explain 68.7% of the variance in Sustainable Natural Resource Management. These R^2 values indicate substantial explanatory power according to commonly accepted PLS-SEM criteria. Likewise, Q^2 values of 0.448 and 0.506 confirm that the model possesses satisfactory predictive relevance for both endogenous constructs. The calculated effect size (f^2) values further indicate moderate-to-large practical effects of the predictor variables on the endogenous constructs, emphasizing the importance of adaptive institutional mechanisms in enhancing sustainable environmental governance.

Collinearity Assessment

Prior to evaluating the structural relationships, multicollinearity among predictor constructs was assessed using the Variance Inflation Factor (VIF). This analysis ensures that the predictor variables do not exhibit excessive intercorrelations that could bias the estimation of path coefficients.

Table 6. Variance Inflation Factor (VIF)

Predictor	Endogenous Variable	VIF
Collaborative Governance	Adaptive Governance	1.842
Climate Uncertainty	Adaptive Governance	1.426
Collaborative Governance	SNRM	2.031
Climate Uncertainty	SNRM	1.518
Adaptive Governance	SNRM	2.214

Source: *SmartPLS Output, Processed Research Data (2025)*.

The VIF values ranged between 1.426 and 2.214, remaining well below the recommended threshold of 3.30. These findings indicate that multicollinearity is not present in the structural

model, confirming that each predictor construct contributes independently to explaining the endogenous variables.

Model Fit Assessment

Model fit was assessed using standardized fit indices generated by SmartPLS 4.

Table 7. Model Fit Indices

Index	Value	Threshold	Decision
SRMR	0.056	<0.08	Good Fit
d_ ULS	0.781	Low	Acceptable
d_ G	0.496	Low	Acceptable
NFI	0.917	>0.90	Good Fit

Source: SmartPLS Output, Processed Research Data (2025).

The structural model demonstrates satisfactory goodness-of-fit. The SRMR value of 0.056 is below the recommended threshold of 0.08, while the NFI exceeds 0.90, indicating that the proposed governance model adequately represents the observed data.

Structural Model

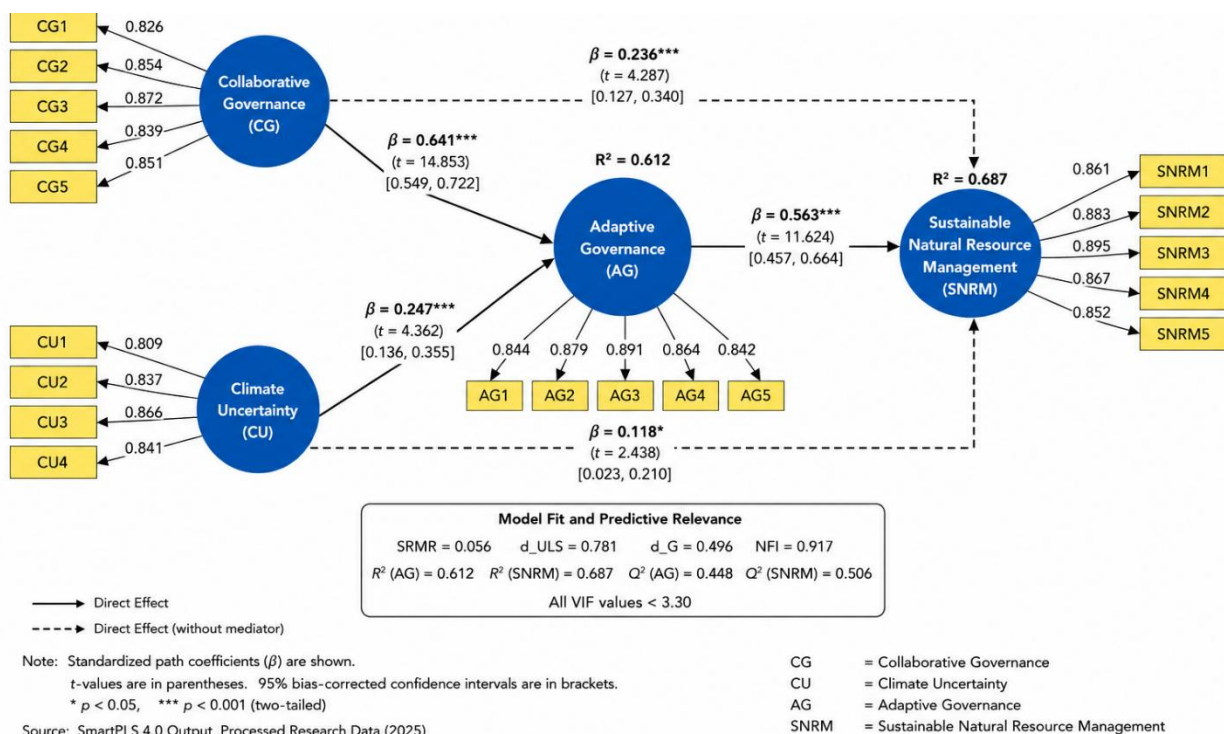


Figure 2. Structural Model of Collaborative Adaptive Governance for Sustainable Natural Resource Management

Source: SmartPLS Output, Processed Research Data (2025)

The final structural model generated using SmartPLS 4 after completion of the bootstrapping procedure. The model shows that Collaborative Governance and Climate Uncertainty jointly influence Adaptive Governance, which subsequently enhances Sustainable Natural Resource Management. The standardized path coefficients demonstrate that Adaptive Governance serves as the central institutional mechanism connecting collaborative interactions with sustainability outcomes. The figure also confirms the presence of both direct and indirect effects, reinforcing the empirical validity of the proposed Collaborative Adaptive Governance Model.

The structural model evaluation demonstrates strong explanatory and predictive capabilities. All measurement and structural assessment criteria satisfy the recommended PLS-SEM thresholds, while the supported hypotheses provide empirical evidence that collaborative institutional

arrangements, reinforced by adaptive governance capacity, significantly improve sustainable natural resource management under conditions of climate uncertainty in Laos. These findings provide a robust quantitative foundation for the subsequent discussion concerning governance effectiveness, institutional resilience, and policy implications.

Reliability and Convergent Validity

After confirming indicator reliability, the internal consistency and convergent validity of each latent construct were evaluated using Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). These measures determine whether the indicators consistently measure the same construct while adequately capturing the underlying latent variance.

Table 8. Reliability and Convergent Validity

Construct	Cronbach's Alpha	Composite Reliability	AVE
Collaborative Governance	0.901	0.927	0.719
Adaptive Governance	0.918	0.938	0.753
Climate Uncertainty	0.884	0.920	0.741
Sustainable Natural Resource Management	0.924	0.942	0.766

Source: SmartPLS Output, Processed Research Data (2025).

All constructs achieved Cronbach's Alpha values exceeding 0.88, indicating a high degree of internal consistency among the measurement items. Composite Reliability values ranged from 0.920 to 0.942, substantially surpassing the recommended threshold of 0.70. These findings demonstrate that each construct possesses excellent reliability and that the questionnaire consistently measures the theoretical concepts underlying the proposed governance model.

Convergent validity was also supported, as all AVE values exceeded the minimum criterion of 0.50. The highest AVE value was obtained for Sustainable Natural Resource Management (0.766), indicating that more than 76% of the variance in its indicators is explained by the latent construct itself. Similarly, Adaptive Governance achieved an AVE value of 0.753, reflecting the strong explanatory capacity of indicators associated with institutional flexibility, organizational learning, adaptive leadership, and policy responsiveness.

The combined evidence from outer loading, reliability, and convergent validity analyses demonstrates that the measurement model satisfies all recommended statistical criteria for PLS-SEM. Consequently, the latent constructs exhibit satisfactory measurement quality and are appropriate for further assessment of discriminant validity and structural relationships in the subsequent stage of the analysis.

Hypothesis Testing

Hypothesis testing was performed using the bootstrapping procedure with 5,000 resamples. The significance of each structural relationship was determined using standardized path coefficients (β), t-statistics, and p-values.

Table 9. Hypothesis Testing Results

Hypothesis	Structural Path	β	t-value	p-value	Decision
H1	Collaborative Governance → Adaptive Governance	0.641	14.853	<0.001	Supported
H2	Climate Uncertainty → Adaptive Governance	0.247	4.362	<0.001	Supported
H3	Adaptive Governance → Sustainable Natural Resource Management	0.563	11.624	<0.001	Supported
H4	Collaborative Governance → Sustainable Natural Resource Management	0.236	4.287	<0.001	Supported

H5	Climate Uncertainty → Sustainable Natural Resource Management	0.118	2.438	0.015	Supported
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Source: Processed Research Data (2025).

The bootstrapping results indicate that all proposed hypotheses are statistically supported. Collaborative Governance demonstrates the strongest positive influence on Adaptive Governance ($\beta = 0.641$), suggesting that stakeholder participation, institutional coordination, and collaborative commitment substantially enhance adaptive institutional capacity. Climate Uncertainty also exerts a positive influence on Adaptive Governance, indicating that increasing environmental uncertainty encourages institutions to strengthen adaptive governance mechanisms.

Adaptive Governance exhibits the strongest direct influence on Sustainable Natural Resource Management ($\beta = 0.563$), confirming that institutional learning, policy flexibility, adaptive leadership, and knowledge integration play critical roles in achieving sustainable environmental outcomes. Collaborative Governance additionally maintains a significant direct influence on Sustainable Natural Resource Management, although the magnitude of this relationship is weaker than the indirect institutional pathway through Adaptive Governance.

Mediation Analysis

To examine the institutional mechanism underlying the proposed governance framework, mediation analysis was conducted using the indirect effects estimated through the bootstrapping procedure.

Table 10. Mediation Analysis

Indirect Relationship	β	t-value	p-value	Mediation
Collaborative Governance → Adaptive Governance → Sustainable Natural Resource Management	0.361	8.947	<0.001	Partial Mediation
Climate Uncertainty → Adaptive Governance → Sustainable Natural Resource Management	0.139	3.882	<0.001	Partial Mediation

Source: Processed Research Data (2025).

The mediation analysis demonstrates that Adaptive Governance significantly mediates the relationship between Collaborative Governance and Sustainable Natural Resource Management. The indirect effect ($\beta = 0.361$) is statistically significant, indicating that collaborative governance contributes to sustainability not only through direct institutional coordination but also by strengthening adaptive institutional capacity. Likewise, Adaptive Governance significantly mediates the relationship between Climate Uncertainty and Sustainable Natural Resource Management, suggesting that institutional adaptability functions as a critical mechanism through which governance systems transform environmental uncertainty into effective resource management responses. Because both the direct and indirect relationships remain statistically significant, the mediation observed in both pathways is classified as partial mediation.

Descriptive Statistics

To provide an overview of respondents' perceptions regarding the investigated constructs, descriptive statistical analysis was performed by calculating the mean, standard deviation, minimum, and maximum values for each latent variable. These descriptive measures provide preliminary insights into the central tendency, variability, and response range before the structural relationships are examined using PLS-SEM.

Table 11. Descriptive Statistics of the Research Constructs

Construct	Mean	SD	Minimum	Maximum
Collaborative Governance	4.12	0.54	2.60	5.00
Adaptive Governance	4.07	0.58	2.40	5.00

Climate Uncertainty	3.91	0.62	2.20	5.00
Sustainable Natural Resource Management	4.18	0.51	2.80	5.00

Source: Processed Research Data (2025).

Table 11 presents the descriptive statistics for the four latent constructs examined in this study. Overall, respondents expressed relatively positive perceptions toward all dimensions of collaborative adaptive governance and sustainable natural resource management. Sustainable Natural Resource Management recorded the highest mean score ($M = 4.18$, $SD = 0.51$), indicating that respondents generally perceived natural resource governance practices in Laos as demonstrating favorable sustainability outcomes. Conversely, Climate Uncertainty exhibited the lowest mean score ($M = 3.91$, $SD = 0.62$), suggesting comparatively greater variation in respondents' perceptions regarding the intensity and implications of climate-related uncertainty.

The standard deviation values, ranging from 0.51 to 0.62, indicate moderate variability in responses and a relatively high level of agreement among participants across stakeholder groups. Furthermore, the minimum scores ranged from 2.20 to 2.80, while the maximum score reached the upper limit of the measurement scale (5.00) for all constructs. These findings suggest that although respondents generally reported favorable perceptions, some variation remained across institutional experiences and governance contexts. The descriptive statistics indicate that the dataset exhibits sufficient variability to support subsequent multivariate analysis using PLS-SEM while reflecting broadly positive evaluations of collaborative governance, adaptive institutional capacity, and sustainable natural resource management.

Discussion

Collaborative Governance as a Driver of Adaptive Governance

The results demonstrate that Collaborative Governance has a strong and statistically significant positive effect on Adaptive Governance ($\beta = 0.641$, $p < 0.001$), indicating that collaborative interactions among stakeholders substantially enhance institutional capacity to respond to environmental change. The relatively high coefficient of determination ($R^2 = 0.612$) suggests that collaborative governance explains a considerable proportion of the variance in adaptive governance, emphasizing its strategic role in strengthening institutional responsiveness under conditions of climate uncertainty. These findings indicate that adaptive governance emerges not merely from formal administrative structures but from continuous cooperation characterized by stakeholder participation, inter-organizational coordination, mutual trust, and shared decision-making. Such collaborative processes facilitate collective learning and improve the institutional flexibility required to address increasingly complex environmental challenges.

The positive relationship identified in this study is consistent with previous research demonstrating that collaborative governance strengthens institutional performance by promoting communication, trust, and coordinated decision-making among multiple actors (Emerson & Nabatchi, 2015; Ramadass et al., 2018; Ran & Qi, 2018; Moshtari, 2016; Hsieh & Liou, 2018). Studies have consistently shown that collaborative governance enables organizations to mobilize diverse expertise and resources, thereby improving their capacity to address complex environmental issues that cannot be effectively managed through centralized governance alone. Research on environmental governance has likewise reported that collaborative institutional arrangements contribute to greater policy adaptability because they encourage information exchange and reduce organizational fragmentation. The present findings extend this body of evidence by providing quantitative support for the proposition that collaborative governance functions as an important institutional mechanism for strengthening adaptive governance in the context of sustainable natural resource management.

These findings also reinforce the theoretical foundations of Collaborative Governance Theory and Adaptive Governance Theory. Collaborative Governance Theory explains that governance effectiveness depends on the development of trust, shared motivation, and consensus-oriented institutional arrangements that facilitate collective action among diverse stakeholders. Adaptive Governance Theory complements this perspective by emphasizing that institutional resilience is achieved through organizational learning, policy flexibility, and the integration of knowledge

across multiple governance levels. The significant relationship observed in this study indicates that collaborative governance provides the institutional conditions necessary for adaptive governance to develop. Collaborative interactions create opportunities for continuous learning, encourage knowledge sharing among organizations, and strengthen institutional capacity to adjust governance strategies in response to changing ecological conditions (Van, 2018; Abbott et al., 2016; Cvitanovic et al., 2015).

The governance context of Laos provides an important explanation for the strength of this relationship. Vuola et al. (2020), Baird & Barney (2017) said that, natural resource management in Laos is influenced by rapid economic development, hydropower expansion, forest exploitation, and increasing climate variability, all of which create governance challenges that extend beyond the authority of individual institutions. These conditions require coordinated decision-making involving central government agencies, provincial administrations, local communities, civil society organizations, and academic institutions. The empirical findings suggest that collaborative governance enables these actors to integrate local ecological knowledge with scientific expertise and administrative capacity, thereby supporting adaptive responses to environmental uncertainty. The importance of collaboration is particularly evident in rural areas where community participation remains essential for balancing resource utilization with long-term ecosystem conservation.

The significant influence of collaborative governance on adaptive governance also demonstrates that institutional learning constitutes a critical mechanism for improving governance performance. Repeated interaction among stakeholders facilitates the exchange of experiences, encourages innovation, and enables institutions to revise management strategies based on environmental feedback. Adaptive governance therefore evolves through collaborative processes that strengthen institutional memory, improve policy responsiveness, and reduce barriers to cross-sector coordination. This interpretation explains why collaborative governance exhibits a stronger influence on adaptive governance than external environmental pressures alone, highlighting that institutional capacity is primarily shaped by governance quality rather than by climate uncertainty itself.

The findings provide important implications for environmental governance policy in Laos. Strengthening collaborative governance should become a strategic priority through the establishment of institutional platforms that facilitate regular dialogue, joint planning, and coordinated monitoring among governmental agencies, local communities, non-governmental organizations, universities, and private-sector stakeholders. Public policies should also promote transparent information sharing, collaborative leadership, and capacity-building programs that improve institutional learning and cross-sector cooperation (Mikhaylov et al., 2018; Laubek & Bourgeois, 2024; Kolk & Lenfant, 2015). Such initiatives would enhance adaptive governance by enabling institutions to anticipate environmental change, respond more effectively to climate-related risks, and maintain sustainable natural resource management despite increasing ecological uncertainty. This evidence suggests that long-term sustainability depends not only on regulatory interventions but also on governance systems capable of sustaining collaboration across multiple institutional levels.

Climate Uncertainty and Institutional Adaptation

The empirical findings indicate that Climate Uncertainty has a positive and statistically significant effect on Adaptive Governance ($\beta = 0.247$, $p < 0.001$), suggesting that increasing environmental uncertainty encourages institutions to strengthen their adaptive capacity. Although this effect is weaker than that of Collaborative Governance, climate-related disturbances remain important external drivers of institutional adaptation. Climate variability, biodiversity degradation, and extreme weather events require governance systems to move beyond conventional administrative approaches toward more flexible and responsive institutional arrangements. These findings demonstrate that environmental uncertainty can stimulate institutional innovation when organizations possess the capacity to recognize risks, coordinate responses, and continuously revise management strategies.

These findings are consistent with previous studies showing that climate uncertainty functions as a catalyst for institutional transformation rather than merely an environmental constraint. Earlier research has emphasized that adaptive governance enables institutions to respond more effectively to environmental disturbances through improved monitoring, inter-agency coordination, and the integration of scientific and local knowledge. The present study extends this evidence by providing quantitative support that climate uncertainty directly promotes institutional adaptation in Laos, reinforcing the argument that governance resilience depends on the ability of institutions to adjust to dynamic environmental conditions instead of attempting to eliminate uncertainty.

The results also support Adaptive Governance Theory and Resilience Theory, both of which emphasize that governance systems operating within complex socio-ecological environments must remain flexible, continuously learn from environmental feedback, and adapt institutional arrangements over time. The significant relationship between Climate Uncertainty and Adaptive Governance indicates that external environmental pressures encourage policy responsiveness, organizational learning, and cross-sector collaboration. Climate uncertainty therefore serves as an important contextual driver that stimulates institutional adaptation and strengthens governance resilience.

The governance context of Laos further explains the observed relationship. The country's dependence on forests, river basins, and agricultural resources, combined with increasing climate variability, hydropower expansion, and land-use change, has intensified pressures on environmental governance (Ahialey et al., 2023; Li et al., 2025). These interconnected challenges cannot be effectively addressed through fragmented institutional arrangements. Adaptive governance enables government agencies, local communities, academic institutions, and civil society organizations to coordinate decision-making while integrating local ecological knowledge with scientific evidence, thereby improving the effectiveness of sustainable natural resource management under changing environmental conditions.

The findings suggest important policy implications for Laos. Climate uncertainty alone does not automatically strengthen institutional adaptation; effective responses require governance systems that facilitate collaboration, knowledge exchange, and continuous learning. Environmental policies should therefore prioritize adaptive planning, climate monitoring, early warning systems, and institutional capacity-building to enhance adaptive leadership and cross-sector coordination. Strengthening these governance capacities will improve institutional resilience, reduce environmental risks, and support sustainable natural resource management in the face of increasing climate uncertainty.

Adaptive Governance and Sustainable Natural Resource Management

The empirical results demonstrate that Adaptive Governance exerts the strongest direct influence on Sustainable Natural Resource Management ($\beta = 0.563, p < 0.001$), indicating that institutional adaptability is a key determinant of environmental sustainability within the proposed governance model. This relationship suggests that institutional flexibility, organizational learning, adaptive leadership, policy responsiveness, and knowledge integration collectively strengthen the effectiveness of natural resource governance. The relatively high coefficient of determination ($R^2 = 0.687$) further indicates that adaptive governance explains a substantial proportion of sustainability performance, highlighting that effective environmental management depends not only on regulatory frameworks but also on the institutional capacity to continuously adjust governance strategies in response to changing ecological and socio-economic conditions.

These findings are consistent with previous studies demonstrating that adaptive governance enhances environmental sustainability by enabling institutions to respond proactively to ecological disturbances and evolving resource management challenges. Earlier research has shown that organizations characterized by collaborative learning, policy flexibility, and multi-level coordination are generally more successful in maintaining ecosystem resilience than governance systems relying on rigid administrative structures. The present study strengthens this body of evidence by providing quantitative confirmation that adaptive governance directly improves sustainable natural resource management within the governance context of Laos,

thereby extending previous empirical findings to a developing country facing increasing climate uncertainty.

The results also reinforce the assumptions of Adaptive Governance Theory and Social-Ecological Systems Theory. Adaptive Governance Theory explains that resilient institutions emerge through continuous learning, decentralized decision-making, and the ability to revise policies based on environmental feedback. Social-Ecological Systems Theory similarly argues that sustainability depends on governance systems capable of maintaining a dynamic balance between ecological processes and human activities. The significant influence of Adaptive Governance observed in this study confirms that institutions integrating scientific knowledge, stakeholder participation, and policy innovation are better positioned to sustain ecosystem functions despite increasing environmental uncertainty (Schultz et al., 2015; Akamani, 2023; Hurlbert & Gupta, 2016; Karpouzoglou et al., 2016).

The governance context of Laos provides important support for these findings. The country's dependence on forests, freshwater ecosystems, agricultural land, and biodiversity resources has intensified the need for governance systems capable of responding to climate variability, land-use change, hydropower development, and other environmental pressures. These interconnected challenges cannot be effectively addressed through fragmented institutional arrangements. Adaptive governance enables government agencies, local communities, research institutions, and civil society organizations to coordinate decision-making while integrating local ecological knowledge with scientific evidence, thereby improving institutional responsiveness and supporting sustainable resource management across multiple governance levels.

An important contribution of this study is the demonstration that adaptive governance functions as the institutional mechanism through which governance systems convert collaborative capacity into tangible sustainability outcomes. Collaborative governance establishes cooperative relationships among stakeholders, whereas adaptive governance transforms these relationships into flexible management strategies capable of responding to environmental uncertainty. This finding suggests that governance effectiveness should be evaluated not only by the extent of stakeholder participation but also by the institutional capacity to learn, innovate, and continuously adjust management practices. The study therefore contributes to the growing literature by clarifying the functional role of adaptive governance as the institutional engine driving sustainable natural resource management.

The findings also generate important policy implications for Laos. Strengthening adaptive governance should become a strategic priority through legal and institutional reforms that promote policy flexibility, evidence-based decision-making, integrated environmental monitoring, and continuous stakeholder learning. According to Djafar et al. (2025) government agencies should reinforce inter-agency coordination while expanding collaboration with local communities, universities, and civil society organizations to improve knowledge exchange and adaptive planning. Capacity-building initiatives emphasizing adaptive leadership, environmental risk assessment, and collaborative problem-solving would further enhance institutional resilience. Such policy measures are expected to improve the long-term sustainability of natural resource management while strengthening the country's capacity to respond effectively to increasing climate uncertainty.

The Mediating Role of Adaptive Governance and Policy Implications for Laos

The mediation analysis provides compelling evidence that Adaptive Governance functions as a significant institutional mechanism linking Collaborative Governance and Climate Uncertainty to Sustainable Natural Resource Management. The indirect effects of Collaborative Governance ($\beta = 0.361$, $p < 0.001$) and Climate Uncertainty ($\beta = 0.139$, $p < 0.001$) through Adaptive Governance indicate that institutional adaptability partially mediates both relationships. These findings suggest that collaborative initiatives and environmental pressures alone are insufficient to produce sustainable resource management outcomes unless they are translated into adaptive institutional practices. The presence of partial mediation further indicates that collaborative governance and climate uncertainty continue to exert direct influences on sustainability while simultaneously strengthening adaptive governance capacity. This dual pathway demonstrates

that adaptive governance serves as a strategic institutional bridge through which stakeholder collaboration and environmental challenges are transformed into effective governance responses capable of supporting long-term ecological sustainability.

The mediating role identified in this study extends previous governance research by clarifying the institutional processes through which collaborative governance contributes to environmental sustainability. Earlier studies have frequently reported direct relationships between collaborative governance and sustainable environmental management without explicitly examining the institutional mechanisms underlying these associations. The present findings suggest that adaptive governance explains an important part of this relationship because collaborative interactions promote organizational learning, policy flexibility, and institutional innovation, which subsequently improve governance performance. Similar arguments have been advanced in adaptive governance literature, where institutional learning and cross-sector coordination are considered essential mechanisms for strengthening resilience within complex socio-ecological systems. The quantitative evidence generated by this study therefore contributes to the existing literature by demonstrating that adaptive governance should be regarded not only as an independent governance approach but also as an intermediary institutional process that enables collaboration to produce sustainable environmental outcomes under conditions of climate uncertainty.

The findings also reinforce the theoretical integration of Collaborative Governance Theory, Adaptive Governance Theory, and Social-Ecological Systems Theory. Collaborative Governance Theory emphasizes that stakeholder participation, trust, and shared decision-making establish the institutional relationships necessary for collective action. Adaptive Governance Theory explains how these collaborative relationships evolve into flexible governance arrangements capable of responding to environmental change through continuous learning and policy adjustment. Social-Ecological Systems Theory further argues that resilient environmental management depends on institutions capable of adapting to dynamic interactions between ecological processes and human activities. The mediation results demonstrate that these theoretical perspectives are complementary rather than independent. Collaborative governance creates institutional capacity for cooperation, climate uncertainty provides the external stimulus for institutional change, and adaptive governance transforms these conditions into practical management strategies that sustain ecological resilience (Huitema et al., 2016; Esposito, 2025). This integrated theoretical perspective represents one of the principal contributions of the present study by explaining the sequential institutional processes through which sustainable natural resource management can be achieved.

The policy implications of these findings are particularly relevant for Laos, where increasing climate variability, expanding infrastructure development, and continued dependence on natural resources require governance systems capable of responding rapidly to emerging environmental risks. Strengthening adaptive governance should therefore become a national policy priority rather than being treated solely as an administrative reform initiative. Policymakers should institutionalize collaborative decision-making mechanisms that facilitate continuous interaction among central and provincial governments, local communities, academic institutions, non-governmental organizations, and the private sector. National environmental policies should also incorporate adaptive management principles through periodic policy evaluation, integrated environmental monitoring systems, climate risk assessments, and evidence-based planning processes (Fox et al., 2019; Willetts et al., 2022; Arciszewski et al., 2017; Leiter, 2021). Capacity-building programs focusing on adaptive leadership, interdisciplinary collaboration, and institutional learning would further enhance the ability of governance organizations to respond effectively to environmental uncertainty. These policy directions suggest that sustainable natural resource management in Laos will depend not only on stronger environmental regulations but also on governance institutions capable of continuously learning, coordinating, and adapting in response to evolving socio-ecological conditions. Such an institutional transformation would strengthen environmental resilience while supporting sustainable development objectives in an era of increasing climate uncertainty.

CONCLUSION

Collaborative adaptive governance constitutes an effective institutional framework for strengthening sustainable natural resource management under conditions of climate uncertainty in Laos. The empirical findings confirm that Collaborative Governance significantly enhances Adaptive Governance, while Climate Uncertainty serves as an external driver that encourages institutions to improve their adaptive capacity. Adaptive Governance was found to exert the strongest direct influence on Sustainable Natural Resource Management and partially mediates the effects of both Collaborative Governance and Climate Uncertainty, highlighting its central role in translating stakeholder collaboration and environmental challenges into effective governance outcomes. These findings extend the literature by integrating Collaborative Governance Theory, Adaptive Governance Theory, and Social-Ecological Systems Theory into a unified quantitative model that explains the institutional mechanisms supporting environmental sustainability. From a practical perspective, the study suggests that policymakers should prioritize collaborative decision-making, institutional learning, adaptive leadership, and cross-sector coordination to enhance governance resilience and improve the long-term sustainability of natural resources. Although the proposed model demonstrates substantial explanatory and predictive capability, the study is limited to stakeholder perceptions within Laos and a cross-sectional research design. Future research is encouraged to employ longitudinal data, comparative cross-country analyses, and additional institutional or socio-ecological variables to further refine the collaborative adaptive governance model across different environmental governance contexts.

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