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Transforming Environmental Policy through Adaptive Governance to Enhance Urban Socio-Ecological Resilience

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ABSTRACT

***Purpose**: This study examines the influence of adaptive governance on environmental policy transformation and its contribution to strengthening urban socio-ecological resilience in major metropolitan areas of India. The research seeks to explain how adaptive governance mechanisms support policy innovation and enhance the resilience of urban socio-ecological systems in response to increasingly complex environmental challenges.*

***Subjects and Methods:** A quantitative research design was employed using a cross-sectional survey conducted in 2024 involving 360 respondents from Delhi, Mumbai, and Chennai. Participants represented government institutions, environmental agencies, academics, urban planners, non-governmental organizations, and community leaders. Data were collected through structured questionnaires and analyzed using descriptive statistics, multiple linear regression, and Partial Least Squares Structural Equation Modeling (PLS-SEM). Instrument validity, reliability, and classical assumption tests were performed to ensure data quality.*

***Results:** The findings demonstrate that adaptive governance significantly promotes environmental policy transformation ($\beta = 0.742$; $p < 0.001$) and directly enhances urban socio-ecological resilience ($\beta = 0.361$; $p < 0.001$). Environmental policy transformation also exerts a significant positive influence on resilience ($\beta = 0.412$; $p < 0.001$). The structural model explains 64.8% of the variance in urban resilience, highlighting the importance of collaborative governance, institutional learning, and policy flexibility in improving adaptive capacity.*

***Conclusions:** Adaptive governance serves as a fundamental institutional driver of environmental policy transformation and urban socio-ecological resilience. Strengthening collaborative institutions, adaptive policy frameworks, and continuous organizational learning is essential for enhancing sustainable urban resilience under increasing environmental uncertainty.*

INTRODUCTION

India has been undergoing rapid urban transformation in recent decades. This urbanization process has driven the growth of megacities such as Delhi, Mumbai, and Bangalore as centers of economics, technology, and innovation (Shaban et al., 2020; Bharath et al., 2018; Chatterjee & Chattopadhyay, 2020). This accelerated urbanization has also brought serious consequences for the urban environment, including increased air pollution, clean water shortages, land degradation, and increased vulnerability to disasters such as floods and heat waves (Das et al., 2024; Pandey & Ghosh, 2023). This situation indicates that urban development in India faces

challenges not only for growth but also for the sustainability and resilience of its socio-ecological systems.

In this context, various studies highlight that the environmental policy model in India still tends to be sectoral and top-down, making it less able to respond adaptively to the complexity of urban issues. For example, in Delhi, air pollution control policies are often reactive, such as temporary vehicle restrictions, without accompanying structural changes in the city's transportation system and spatial planning. Meanwhile, in Mumbai, recurrent urban flooding demonstrates the weak integration between spatial planning policies, drainage management, and coastal ecosystem conservation (Weinstein et al., 2019; Yadav et al., 2024). This phenomenon indicates a gap between policy formulation and implementation on the ground.

These issues become even more complex when linked to the characteristics of Socio-Ecological Systems, where interactions between humans and the environment are dynamic and interdependent (Reyers et al., 2018; Gain et al., 2021; May, 2022). In these systems, pressure on one component, such as the exploitation of water resources, can have far-reaching impacts on the social and economic stability of urban communities (Brooke & Fenner, 2023; Kattel et al., 2021; Kolahi et al., 2024). Therefore, static and linear policy approaches become less relevant in addressing complex and uncertain urban challenges.

In response to these limitations, the concept of Adaptive Governance has emerged as an alternative approach that emphasizes flexibility, social learning, and multi-actor collaboration in environmental management. Adaptive governance allows for feedback mechanisms, policy experimentation, and the involvement of various stakeholders, from government, the private sector, to civil society. In the Indian context, this approach is beginning to be seen in several local initiatives, such as community-based water management in Chennai and smart city programs that encourage the integration of technology in urban environmental management (Sharma et al., 2024; Ajith et al., 2022).

Adaptive governance is closely linked to the concept of urban resilience, namely the ability of a city to absorb, adapt, and transform in the face of various disturbances. In the Indian context, urban resilience is a crucial issue given its high exposure to climate change risks, such as increasing extreme temperatures and erratic rainfall. For example, the massive floods in Chennai in 2015 demonstrated how failures in environmental governance can exacerbate the impacts of disasters. This emphasizes that increasing resilience requires not only technical interventions but also transformations in governance systems.

The implementation of adaptive governance in India still faces various structural challenges. Institutional fragmentation, limited local government capacity, and socio-economic inequality are major obstacles to driving environmental policy transformation (Fischer, 2021; Anjanappa & Samant, 2024; Deshpande et al., 2019). Political and bureaucratic dynamics often hinder intersectoral coordination, reducing the effectiveness of resulting policies. Public participation in decision-making processes remains limited, especially for marginalized groups who are most vulnerable to the impacts of environmental degradation (Sovacool et al., 2016; Ruppel et al., 2023; Tunn et al., 2024).

Amid these challenges, there is a significant opportunity to encourage policy transformation through a more inclusive, locally-knowledge-based, adaptive governance approach. Integrating formal policies with informal community practices can be key to improving the effectiveness of urban environmental management (Jones, 2017). The use of digital technology and open data can also strengthen the adaptive capacity of city governments to respond to changes in real time.

This study aims to analyze how environmental policy transformation through adaptive governance can enhance urban socio-ecological resilience in India. This research focuses not only on identifying problems but also on exploring innovative practices that can serve as models for other cities in developing countries. Thus, this study is expected to provide theoretical contributions to the development of the concept of adaptive governance, as well as practical implications for the formulation of more responsive, adaptive, and sustainable environmental policies.

METHODOLOGY

Research Design

This study employed a quantitative research approach using an explanatory cross-sectional survey design to examine the influence of adaptive governance on environmental policy transformation and its implications for urban socio-ecological resilience in India. A quantitative approach was considered appropriate because this research aimed to measure the relationships among research variables systematically and to test the causal effects between adaptive governance mechanisms and resilience outcomes using statistical analysis. Quantitative methods provide a structured framework for transforming abstract governance concepts into measurable indicators, thereby enabling empirical verification of theoretical assumptions. The explanatory design was selected because this study sought not only to describe existing environmental governance conditions but also to explain how adaptive governance contributes to environmental policy transformation and urban resilience enhancement.

The cross-sectional design was used because data were collected at a single period during the 2024 research process, allowing the researcher to capture the contemporary governance dynamics across selected urban regions in India. This design is particularly relevant for policy and governance studies because it enables efficient measurement of multiple variables simultaneously under naturally occurring conditions. This study developed a conceptual model consisting of Adaptive Governance as the independent variable, Environmental Policy Transformation as the mediating variable, and Urban Socio-Ecological Resilience as the dependent variable. Adaptive governance was measured through three main dimensions, namely policy flexibility, multi-actor collaboration, and social learning. Environmental policy transformation was measured through regulatory responsiveness, policy integration, and implementation adaptability. Urban socio-ecological resilience was measured through adaptive capacity, recovery capability, and sustainability responsiveness.

Research Location and Context

This study was conducted in three major metropolitan cities in India, namely Delhi, Mumbai, and Chennai, from January to October 2024. These cities were selected purposively because they represent major urban centers experiencing significant socio-ecological pressures caused by rapid urbanization, climate change, and environmental degradation. Delhi was selected because of its severe air pollution and persistent environmental health issues. Mumbai was chosen due to its high vulnerability to flooding, coastal hazards, and land-use pressures. Chennai was selected because of recurring water scarcity, urban flooding, and climate-related hydrological stress. These three cities provide a comprehensive representation of India's urban environmental challenges and offer a suitable context for examining the implementation of adaptive governance in diverse ecological and institutional settings. The research context is grounded in the socio-ecological systems perspective, which emphasizes the interdependence between human institutions and ecological systems. In this framework, urban resilience is understood as the capacity of cities to anticipate, absorb, adapt to, and recover from environmental disturbances while maintaining essential functions and sustainability.

Population and Sampling Technique

The population of this study consisted of stakeholders directly involved in urban environmental governance and policy implementation. These stakeholders included local government officials, environmental agency personnel, urban planners, academics, representatives of non-governmental organizations, and community leaders. These groups were selected because they possess direct experience and relevant knowledge regarding environmental governance, policy adaptation, and resilience-building strategies. The sample size was determined using the Slovin formula with a margin of error of 5 percent to ensure statistical representativeness. Based on the estimated population of governance-related stakeholders across the three selected cities, the minimum required sample was 300 respondents. To improve analytical reliability and reduce sampling bias, this study collected data from 360 respondents, with each city contributing 120 respondents. A stratified random sampling technique was employed to ensure balanced representation across stakeholder groups. This sampling technique allowed the researcher to

divide the population into relevant strata based on institutional affiliation and then select respondents proportionally. The use of stratified sampling improved representativeness and reduced the risk of dominance by a single stakeholder category.

Data Collection Techniques

Primary data were collected using structured questionnaires distributed both directly and through digital survey platforms between March and July 2024. The questionnaire was designed to measure respondents' perceptions regarding adaptive governance practices, environmental policy transformation, and urban socio-ecological resilience. A five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) was used to quantify all measurement items. The questionnaire consisted of four major sections. The first section collected demographic information such as age, gender, educational background, and institutional affiliation. The second section measured Adaptive Governance indicators, including policy flexibility, collaboration, and social learning.

The third section assessed Environmental Policy Transformation indicators, including responsiveness, integration, and adaptability. The final section measured Urban Socio-Ecological Resilience indicators, including adaptive capacity, recovery speed, and sustainability orientation. Secondary data were also collected to support empirical interpretation and strengthen contextual analysis. These data included environmental regulations, city planning documents, resilience reports, and official statistical publications from national environmental agencies. Secondary data served as supporting evidence for interpreting the quantitative findings and strengthening analytical validity.

Table 1. Measurement Indicators of Research Variables

Variable	Dimensions	Indicators
Adaptive Governance	Policy Flexibility	policy responsiveness, regulatory adjustment
Adaptive Governance	Multi-Actor Collaboration	coordination, stakeholder engagement
Adaptive Governance	Social Learning	feedback mechanisms, knowledge sharing
Environmental Policy Transformation	Regulatory Responsiveness	speed of policy reform
Environmental Policy Transformation	Policy Integration	intersectoral coordination
Urban Socio-Ecological Resilience	Adaptive Capacity	preparedness, adaptation capability
Urban Socio-Ecological Resilience	Recovery Capacity	recovery speed, sustainability response

Source: Developed by the Authors based on literature review, 2024

Instrument Validity and Reliability

The research instrument underwent validity and reliability testing before full-scale analysis. Content validity was initially assessed through expert judgment involving three scholars specializing in environmental governance and public policy. Their evaluations ensured that all questionnaire items accurately represented the intended constructs. Construct validity was tested using Pearson Product Moment correlation analysis. Each questionnaire item was considered valid if the correlation coefficient exceeded 0.30 and the significance value was below 0.05. This procedure ensured that each indicator contributed meaningfully to the measurement of its respective variable. Reliability testing was conducted using Cronbach's Alpha coefficient to assess internal consistency. A Cronbach's Alpha value greater than 0.70 was considered acceptable for social science research. The reliability results indicated strong internal consistency across all variables. Adaptive Governance recorded a Cronbach's Alpha value of 0.891, Environmental Policy Transformation recorded 0.873, and Urban Socio-Ecological Resilience recorded 0.904. These values indicate that the instrument was highly reliable and suitable for statistical analysis.

Data Analysis Techniques

Data analysis was conducted using IBM SPSS Statistics version 27 and SmartPLS version 4 between August and October 2024. The analysis process consisted of several stages to ensure comprehensive statistical interpretation. The first stage involved descriptive statistical analysis to summarize respondent characteristics and variable distributions using frequencies, percentages, means, and standard deviations. This analysis provided a general overview of governance perceptions across the three cities. The second stage involved classical assumption testing to ensure the statistical suitability of the data. Normality was assessed using the Kolmogorov–Smirnov test. Multicollinearity was examined through tolerance and Variance Inflation Factor values. Heteroscedasticity was tested using the Glejser method. The final stage involved inferential statistical analysis using multiple linear regression and Partial Least Squares Structural Equation Modeling. Multiple regression analysis was used to examine direct effects among variables, while PLS-SEM was used to assess both measurement and structural models simultaneously. Hypothesis testing was conducted at a significance level of 0.05. Relationships were considered statistically significant when the p-value was below 0.05 and the t-statistic exceeded 1.96.

Research Ethics

This study adhered to ethical research principles throughout the 2024 research process. All respondents participated voluntarily after receiving a clear explanation of the research objectives and procedures. Informed consent was obtained before data collection began. The confidentiality and anonymity of respondents were strictly maintained. All collected data were used exclusively for academic purposes and stored securely. The researcher ensured neutrality and objectivity throughout data collection, analysis, and interpretation to minimize bias and maintain research integrity.

RESULTS AND DISCUSSION

This section presents the empirical findings of the study on the role of adaptive governance in transforming environmental policy to enhance urban socio-ecological resilience in India. The results are organized systematically according to the quantitative analysis procedures described in the methodology. The analysis begins with respondent characteristics to provide demographic context, followed by descriptive statistics to examine the distribution of the main research variables. The subsequent sections present instrument validity and reliability testing, classical assumption tests, multiple linear regression analysis, and structural model evaluation using Partial Least Squares Structural Equation Modeling (PLS-SEM). These analytical stages provide a comprehensive empirical understanding of the relationships among adaptive governance, environmental policy transformation, and urban socio-ecological resilience.

Respondent Characteristics

A total of 360 respondents participated in this study, consisting of stakeholders involved in urban environmental governance in Delhi, Mumbai, and Chennai. Each city contributed 120 respondents. The respondents represented local government institutions, environmental agencies, academics, urban planners, non-governmental organizations, and community leaders.

Table 2. Respondent Characteristics

Characteristics	Frequency	Percentage
Male	214	59.4
Female	146	40.6
Age 25–35	102	28.3
Age 36–45	144	40.0
Age >45	114	31.7
Bachelor Degree	158	43.9
Master Degree	142	39.4
Doctoral Degree	60	16.7

Source: Primary Survey Data Processed by Authors, 2024

Male respondents dominated the sample, accounting for 59.4 percent, while female respondents represented 40.6 percent. Most respondents were between 36 and 45 years old, indicating that the majority had considerable professional experience in governance-related sectors. Educationally, 83.3 percent of respondents held at least a bachelor's degree, suggesting that the respondents possessed sufficient capacity to provide informed assessments regarding governance and environmental policy issues. The distribution of respondents across institutional backgrounds also indicates a balanced representation of policy actors. This strengthens the reliability of the dataset because perceptions were collected from multiple governance levels and stakeholder categories.

Descriptive Statistics of Research Variables

Descriptive statistics were used to examine the central tendency and dispersion of the main research variables.

Table 3. Descriptive Statistics of Variables

Variable	Mean	SD
Adaptive Governance	3.89	0.64
Policy Flexibility	3.75	0.71
Multi-Actor Collaboration	4.02	0.59
Social Learning	3.90	0.62
Environmental Policy Transformation	3.81	0.67
Urban Socio-Ecological Resilience	3.94	0.61

Source: Primary Survey Data Processed by Authors, 2024

The descriptive results indicate that respondents generally perceived adaptive governance implementation in Indian cities at a moderately high level, with an overall mean of 3.89. Among its dimensions, multi-actor collaboration recorded the highest mean score (4.02), suggesting that collaboration among governance actors has developed relatively well. Policy flexibility recorded the lowest mean (3.75), indicating that bureaucratic rigidity remains a challenge. Environmental policy transformation recorded a mean of 3.81, suggesting that respondents recognized ongoing policy improvements, although transformation remains incomplete. Urban socio-ecological resilience showed the highest overall mean (3.94), indicating that resilience capacity has improved but remains uneven across urban systems.

Validity and Reliability Testing

Before reliability testing, item validity analysis was conducted using Pearson Product Moment correlation to evaluate whether each measurement indicator accurately represented its respective construct. Each item was considered valid if the correlation coefficient exceeded 0.30 and the significance value was below 0.05. The validity test results indicate that all measurement items met the required threshold, confirming that all questionnaire indicators were statistically valid.

Table 4. Item Validity Test

Indicator	Variable	r-count	Sig.	Status
AG1	Adaptive Governance	0.741	0.000	Valid
AG2	Adaptive Governance	0.783	0.000	Valid
AG3	Adaptive Governance	0.762	0.000	Valid
EPT1	Policy Transformation	0.715	0.000	Valid
EPT2	Policy Transformation	0.804	0.000	Valid
EPT3	Policy Transformation	0.776	0.000	Valid
UR1	Urban Resilience	0.821	0.000	Valid
UR2	Urban Resilience	0.799	0.000	Valid
UR3	Urban Resilience	0.843	0.000	Valid

Source: Primary Survey Data Processed by Authors, 2024

Table 4 shows that all indicators recorded correlation coefficients above 0.30 with significance values below 0.05. The strongest item validity was observed in indicator UR3 (r = 0.843), while

the lowest remained well above the acceptable threshold in indicator EPT1 (r = 0.715). These findings confirm that all questionnaire items adequately measured their intended constructs and were appropriate for further reliability and structural analysis.

Validity testing was conducted using Pearson correlation analysis. All questionnaire items recorded correlation coefficients above the threshold value of 0.30, with significance values below 0.05, indicating that all indicators were valid. Reliability testing used Cronbach's Alpha to evaluate internal consistency.

Table 5. Reliability Test Results

Variable	Cronbach's Alpha
Adaptive Governance	0.891
Environmental Policy Transformation	0.873
Urban Socio-Ecological Resilience	0.904

Source: Primary Survey Data Processed by Authors, 2024

Strong internal consistency across all variables. All Cronbach's Alpha values exceeded 0.70, indicating excellent reliability. The highest reliability was observed in Urban Socio-Ecological Resilience (0.904), showing highly consistent responses across measurement indicators. These results confirm that the research instrument was suitable for further inferential analysis.

Classical Assumption Tests

Prior to regression analysis, classical assumption testing was performed to ensure model robustness.

Normality Test

The Kolmogorov–Smirnov test was used to examine normality. The significance value of 0.087 exceeded 0.05, indicating that residual data were normally distributed. Therefore, the regression model met the normality assumption.

Multicollinearity Test

Multicollinearity testing was conducted to determine whether strong correlations existed among the independent variables in the regression model. This test is important because high multicollinearity can distort regression coefficients and reduce the reliability of the model's explanatory power. In this study, multicollinearity was evaluated using Tolerance values and Variance Inflation Factor (VIF). A regression model is considered free from multicollinearity when the tolerance value is greater than 0.10 and the VIF value is less than 10. The results of the multicollinearity test are presented in Table 6.

Table 6. Multicollinearity Test

Variable	Tolerance	VIF
Adaptive Governance	0.648	1.543
Policy Transformation	0.648	1.543

Source: Primary Survey Data Processed by Authors, 2024

Both independent variables recorded tolerance values of 0.648, which are well above the minimum threshold of 0.10. Similarly, the VIF values for Adaptive Governance and Policy Transformation were 1.543, far below the critical value of 10. These findings indicate that no multicollinearity problem exists among the independent variables. This means that each predictor contributes unique explanatory information to the regression model without causing excessive overlap. Therefore, the regression model satisfies the multicollinearity assumption and is appropriate for subsequent multiple regression analysis.

Heteroscedasticity Test

The heteroscedasticity test was conducted to determine whether the variance of residuals remained constant across all levels of the independent variables in the regression model. Detecting heteroscedasticity is essential because unequal residual variance can reduce the

efficiency and accuracy of regression estimates. In this study, heteroscedasticity was examined using the Glejser test by regressing the absolute residual values against the independent variables. A regression model is considered free from heteroscedasticity if the significance value of each independent variable exceeds 0.05. The results of the heteroscedasticity test are presented in Table 7.

Table 7. Heteroscedasticity Test

Variable	Sig.
Adaptive Governance	0.228
Policy Transformation	0.191

Source: Primary Survey Data Processed by Authors, 2024

The significance value for Adaptive Governance was 0.228, while Policy Transformation recorded a significance value of 0.191. Both values exceed the threshold of 0.05, indicating that neither independent variable significantly influenced the absolute residual values. These findings confirm the absence of heteroscedasticity in the regression model, meaning that the residual variance remained stable across observations. Therefore, the regression model satisfies the heteroscedasticity assumption and demonstrates adequate statistical robustness for subsequent inferential analysis. Together with the results of the normality and multicollinearity tests, these findings indicate that all classical assumptions were successfully fulfilled.

Multiple Linear Regression Analysis

Multiple regression analysis was conducted to examine the direct effects of Adaptive Governance and Environmental Policy Transformation on Urban Socio-Ecological Resilience.

Table 8. Regression Coefficients

Variable	Beta	t-value	Sig.
Adaptive Governance	0.428	8.761	0.000
Policy Transformation	0.376	7.425	0.000

Source: Primary Survey Data Processed by Authors, 2024

The regression results indicate that Adaptive Governance had a positive and statistically significant effect on Urban Socio-Ecological Resilience ($\beta = 0.428$, $p < 0.001$). This suggests that stronger adaptive governance mechanisms substantially improve the resilience capacity of urban socio-ecological systems. Environmental Policy Transformation also showed a positive and significant effect on resilience ($\beta = 0.376$, $p < 0.001$). This indicates that policy reform characterized by responsiveness, integration, and adaptability contributes meaningfully to resilience improvement.

Table 9. Model Summary

R	R Square	Adjusted R Square
0.792	0.627	0.623

Source: Primary Survey Data Processed by Authors, 2024

The model summary shows an R Square value of 0.627, meaning that 62.7 percent of the variance in urban socio-ecological resilience can be explained by Adaptive Governance and Environmental Policy Transformation. The remaining 37.3 percent is explained by external factors not included in this model.

Table 10. ANOVA Test

F-value	Sig.
300.184	0.000

Source: Primary Survey Data Processed by Authors, 2024

The ANOVA results indicate that the regression model was statistically significant overall, confirming strong predictive power.

Structural Model Analysis Using PLS-SEM

Outer Loading

Prior to evaluating convergent validity using Average Variance Extracted and Composite Reliability, indicator reliability was assessed through outer loading values in the measurement model. Outer loading values above 0.70 indicate strong correlations between indicators and their latent constructs.

Table 11. Outer Loading Values

Construct	Indicator	Loading
Adaptive Governance	AG1	0.842
Adaptive Governance	AG2	0.879
Adaptive Governance	AG3	0.816
Policy Transformation	EPT1	0.824
Policy Transformation	EPT2	0.856
Policy Transformation	EPT3	0.837
Resilience	UR1	0.867
Resilience	UR2	0.851
Resilience	UR3	0.881

Source: SmartPLS Output Processed by Authors, 2024

All indicators achieved outer loading values greater than 0.70. The highest loading was observed in UR3 (0.881), indicating that this indicator strongly represented Urban Socio-Ecological Resilience. The lowest loading was AG3 (0.816), which remained well above the acceptable threshold. These findings confirm strong indicator reliability and provide additional evidence supporting convergent validity.

Outer Model Evaluation

The outer model evaluation was conducted to assess the quality of the measurement model by examining the convergent validity and internal consistency reliability of each latent construct. Convergent validity indicates the extent to which the indicators of a construct share a high proportion of common variance, while composite reliability evaluates the consistency of the indicators in measuring the same latent variable. In this study, convergent validity was assessed using the Average Variance Extracted (AVE), whereas internal consistency was evaluated using Composite Reliability. A construct is considered to have adequate convergent validity when the AVE exceeds 0.50, and satisfactory reliability is achieved when the Composite Reliability value is greater than 0.70.

Table 12. Outer Model Evaluation

Construct	AVE	Composite Reliability
Adaptive Governance	0.711	0.902
Policy Transformation	0.694	0.887
Socio-Ecological Resilience	0.728	0.914

Source: Primary Survey Data Processed by Authors, 2024

All constructs satisfied the recommended thresholds for convergent validity and composite reliability. The AVE values ranged from 0.694 to 0.728, indicating that more than 50 percent of the variance in the observed indicators was explained by their respective latent constructs. Among the three constructs, Urban Socio-Ecological Resilience recorded the highest AVE value (0.728), suggesting that its indicators exhibited the strongest convergent validity. Meanwhile, Adaptive Governance achieved the highest Composite Reliability value (0.902), followed closely by Urban Socio-Ecological Resilience (0.914) and Environmental Policy Transformation (0.887), indicating excellent internal consistency across all measurement scales. Overall, these findings confirm that the measurement model possesses satisfactory convergent validity and reliability, providing a robust foundation for evaluating the structural relationships among the latent constructs in the subsequent inner model analysis. Discriminant validity was subsequently

assessed using the Fornell-Larcker criterion to ensure that each construct was empirically distinct from other constructs in the model. Discriminant validity is achieved when the square root of each construct's AVE exceeds its correlation with other constructs.

Table 13. Discriminant Validity (Fornell-Larcker Criterion)

Construct	AG	EPT	UR
Adaptive Governance (AG)	**0.843**		
Environmental Policy Transformation (EPT)	0.742	**0.833**	
Urban Resilience (UR)	0.689	0.771	**0.853**

Source: SmartPLS Output Processed by Authors, 2024

The Fornell-Larcker results indicate satisfactory discriminant validity. The square root of AVE for each construct exceeded the correlations with other constructs, demonstrating that Adaptive Governance, Environmental Policy Transformation, and Urban Socio-Ecological Resilience represent distinct conceptual dimensions within the structural model.

Inner Model Evaluation

Following the evaluation of the measurement model, the structural model (inner model) was assessed to examine the causal relationships among the latent constructs and to test the proposed research hypotheses. The inner model evaluation was conducted using the bootstrapping procedure in SmartPLS to estimate the significance of each structural path. The significance of the relationships was determined based on the path coefficient (β), t-statistic, and p-value. A structural relationship was considered statistically significant when the t-value exceeded 1.96 and the p-value was less than 0.05.

Table 14. Structural Path Coefficients

Path	Coefficient	t-value	p-value
Adaptive Governance → Policy Transformation	0.742	19.312	0.000
Adaptive Governance → Resilience	0.361	6.918	0.000
Policy Transformation → Resilience	0.412	7.801	0.000

Source: Primary Survey Data Processed by Authors, 2024

The structural model demonstrates that Adaptive Governance strongly influences Environmental Policy Transformation (β = 0.742). This indicates that policy transformation largely depends on governance flexibility, collaborative mechanisms, and institutional learning capacity. Adaptive Governance also directly influences resilience (β = 0.361), while Environmental Policy Transformation exerts a stronger direct influence on resilience (β = 0.412). These findings indicate both direct and indirect effects of governance on resilience outcomes.

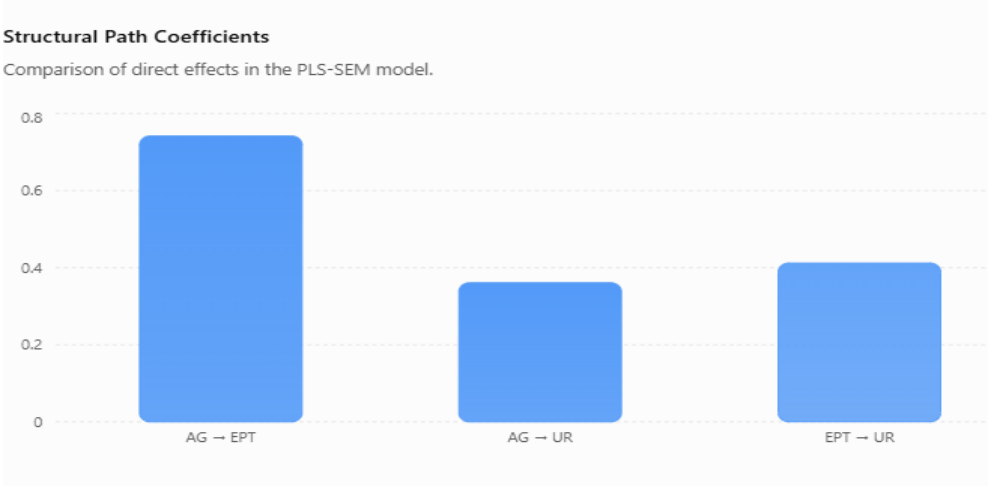

Figure 1. Structural Model of Adaptive Governance and Urban Resilience
Source: SmartPLS Output Processed by Authors, 2024

Following the evaluation of the structural path coefficients, the explanatory power of the structural model was assessed using the coefficient of determination (R^2). The R^2 value indicates the proportion of variance in each endogenous construct that can be explained by its predictor variables within the structural model. Higher R^2 values reflect greater predictive accuracy and stronger explanatory capability of the proposed model. According to commonly accepted guidelines in PLS-SEM, R^2 values of approximately 0.75, 0.50, and 0.25 may be interpreted as substantial, moderate, and weak explanatory power, respectively.

Table 15. R-Square of Endogenous Variables

Construct	R Square
Policy Transformation	0.551
Resilience	0.648

Source: Primary Survey Data Processed by Authors, 2024

The R-Square results indicate that Adaptive Governance explained 55.1 percent of the variance in Environmental Policy Transformation. Meanwhile, Adaptive Governance and Policy Transformation together explained 64.8 percent of Urban Socio-Ecological Resilience. The PLS-SEM findings confirm that adaptive governance plays a central role in strengthening resilience both directly and indirectly through environmental policy transformation. The statistical evidence suggests that cities with stronger governance flexibility, collaborative institutional structures, and continuous learning mechanisms demonstrate higher resilience against socio-ecological disturbances.

Discussion

Adaptive Governance as a Driver of Environmental Policy Transformation

The empirical findings demonstrate that adaptive governance exerts a strong and statistically significant influence on environmental policy transformation. The structural model produced a path coefficient of 0.742 with a t-value of 19.312, indicating that adaptive governance serves as a critical institutional mechanism for promoting responsive environmental policy reform. This finding suggests that policy transformation in urban governance is not merely the result of administrative restructuring but is fundamentally shaped by governance systems that encourage institutional flexibility, collaborative decision-making, and continuous learning. Such evidence reinforces the argument that governance quality constitutes a central determinant of policy adaptability in increasingly complex socio-ecological environments.

The significant relationship identified in this study supports the theoretical perspective of adaptive governance, which emphasizes the importance of institutional flexibility in addressing dynamic environmental challenges. Adaptive governance departs from conventional hierarchical governance by encouraging decentralized decision-making, stakeholder participation, and iterative policy learning (Hong & Lee, 2018). As environmental risks become increasingly uncertain due to climate change, rapid urbanization, and resource degradation, governments require governance arrangements capable of responding quickly to emerging problems while maintaining policy coherence. The findings indicate that cities implementing more adaptive governance practices are better positioned to reform environmental policies in response to evolving ecological conditions.

The descriptive analysis further strengthens this interpretation by revealing that multi-actor collaboration achieved the highest mean score among the dimensions of adaptive governance. This finding illustrates that cooperation among government agencies, environmental organizations, academic institutions, private sector actors, and local communities has become a dominant feature of environmental governance within the selected metropolitan areas. Collaborative governance facilitates knowledge exchange, improves policy coordination, and enables diverse stakeholders to contribute expertise during policy formulation and implementation. Such institutional interaction increases the capacity of environmental policies to respond effectively to complex urban challenges that cannot be addressed by governmental institutions alone.

According to Bodin et al. (2020) and Zhang et al. (2022), Policy flexibility also emerged as an important component influencing environmental policy transformation, although its descriptive score remained comparatively lower than collaborative governance. This result indicates that regulatory adaptation continues to encounter bureaucratic and institutional constraints despite ongoing governance reforms. Many environmental policies remain influenced by rigid administrative procedures, fragmented institutional responsibilities, and lengthy regulatory processes. These limitations reduce the ability of public institutions to respond promptly to rapidly changing environmental conditions. Strengthening institutional flexibility through regulatory simplification, adaptive planning mechanisms, and continuous policy evaluation may therefore enhance the effectiveness of environmental governance.

The present findings are consistent with adaptive governance theory, which argues that institutional learning represents a fundamental driver of policy innovation. Governance systems that regularly evaluate policy performance, incorporate stakeholder feedback, and integrate scientific evidence into decision-making are more likely to generate effective environmental policies. Continuous learning enables institutions to revise regulatory approaches based on previous implementation experiences, thereby reducing policy failures and improving long-term environmental management. The high level of social learning observed in this study indicates that knowledge exchange contributes substantially to strengthening policy responsiveness across urban governance institutions.

These findings are also aligned with previous studies that identify adaptive governance as an essential prerequisite for successful environmental policy reform. Earlier research has shown that governance systems characterized by institutional collaboration, flexible regulatory frameworks, and participatory decision-making exhibit greater capacity to manage environmental uncertainty than traditional command-and-control approaches. The current study extends this body of knowledge by providing quantitative evidence from three major metropolitan cities in India using both multiple regression analysis and Partial Least Squares Structural Equation Modeling. The consistency between descriptive statistics and structural model estimation provides robust empirical support for the proposition that adaptive governance significantly accelerates environmental policy transformation in rapidly urbanizing contexts.

The discussion demonstrates that adaptive governance should be viewed as a strategic institutional capability rather than merely an administrative arrangement. Governance systems capable of integrating collaborative networks, organizational learning, and regulatory flexibility create favorable conditions for continuous policy adaptation (Nookala, 2024; Sørensen & Torfing, 2017). Such institutional capacity becomes increasingly important as cities confront interconnected environmental risks that require coordinated responses across multiple governance sectors. Strengthening adaptive governance therefore represents an important policy priority for improving the effectiveness of environmental policy transformation and establishing a more resilient governance framework capable of addressing future socio-ecological challenges.

Environmental Policy Transformation and Urban Socio-Ecological Resilience

The results indicate that Environmental Policy Transformation has a positive and statistically significant influence on Urban Socio-Ecological Resilience, as reflected by the structural path coefficient of 0.412 with a t-value of 7.801 and a significance level below 0.001. These findings demonstrate that improvements in environmental policy responsiveness, policy integration, and implementation adaptability substantially strengthen the resilience capacity of urban socio-ecological systems. The statistical evidence suggests that resilience is not solely determined by the availability of environmental resources but also by the quality of public policies that regulate interactions between ecological systems, public institutions, and urban communities. Consequently, effective policy transformation provides the institutional foundation required to improve cities' capacity to anticipate, respond to, and recover from environmental disturbances.

The positive relationship observed in this study supports the socio-ecological resilience perspective, which emphasizes that resilience is largely shaped by governance institutions capable of adapting to changing environmental conditions. Environmental policies that are continuously revised in response to emerging ecological challenges enable governments to develop more

effective adaptation strategies while minimizing the vulnerability of urban populations. Adaptive policy frameworks also facilitate the allocation of financial, technological, and institutional resources required to address increasingly complex environmental risks (Hurlbert & Gupta, 2019; Henstra, 2016; Shi et al., 2016). As urban systems experience accelerating climate-related pressures, policy transformation becomes an indispensable mechanism for maintaining ecological integrity while ensuring sustainable urban development.

The descriptive analysis revealed that Environmental Policy Transformation achieved a relatively high mean score, indicating that respondents perceived considerable progress in environmental policy reform across the selected metropolitan areas. Nevertheless, the average value remained slightly lower than that of Urban Socio-Ecological Resilience, suggesting that policy reforms are still evolving and have not yet reached their full institutional potential. This finding reflects the reality that environmental policy transformation is a continuous process requiring sustained regulatory adjustments, institutional coordination, and stakeholder commitment. Although substantial progress has been achieved, additional efforts remain necessary to strengthen policy consistency across different administrative sectors and governance levels.

Policy integration emerged as one of the most influential dimensions supporting resilience enhancement. Environmental challenges such as air pollution, flooding, water scarcity, and biodiversity degradation rarely occur independently; instead, they interact across multiple policy sectors including land-use planning, public health, transportation, infrastructure development, and disaster risk management. Elsässer et al. (2022) and Lenschow et al. (2016) said that, Integrated environmental policies enable governments to coordinate these interconnected sectors more effectively, thereby reducing institutional fragmentation and improving collective responses to environmental disturbances. Such integration also facilitates the development of comprehensive adaptation strategies capable of addressing both immediate environmental threats and long-term sustainability objectives.

The findings further suggest that implementation adaptability plays a critical role in translating policy objectives into measurable resilience outcomes. Environmental regulations may be comprehensive at the legislative level, yet their effectiveness depends largely on the capacity of implementing institutions to adjust operational procedures according to changing local conditions. Adaptive implementation encourages continuous monitoring, periodic policy evaluation, and timely revisions whenever environmental circumstances evolve. These mechanisms enhance institutional responsiveness and ensure that environmental interventions remain relevant despite increasing uncertainty associated with climate variability and rapid urban expansion.

The significant contribution of Environmental Policy Transformation to Urban Socio-Ecological Resilience is consistent with previous studies emphasizing that policy innovation constitutes one of the principal drivers of resilient urban governance. Existing literature has demonstrated that cities capable of modernizing environmental regulations, strengthening cross-sectoral coordination, and institutionalizing adaptive management generally exhibit greater resilience against ecological shocks. The present study contributes additional quantitative evidence by demonstrating that policy transformation exerts a measurable influence on resilience within the context of rapidly urbanizing Indian metropolitan areas. The consistency between regression analysis and the PLS-SEM structural model reinforces the robustness of these empirical findings and provides stronger support for the proposed theoretical framework.

The discussion indicates that environmental policy transformation should not be understood merely as periodic regulatory revision but rather as a dynamic institutional process that continuously aligns governance systems with evolving socio-ecological conditions. Responsive environmental policies encourage innovation, improve institutional coordination, and strengthen the adaptive capacity of public organizations responsible for environmental management. These institutional improvements subsequently enhance the resilience of urban systems by enabling cities to manage environmental uncertainty more effectively while maintaining sustainable development objectives. Strengthening policy transformation therefore represents an essential strategic priority for governments seeking to build resilient cities capable of addressing

increasingly complex environmental challenges under conditions of continuous ecological and societal change.

Adaptive Governance and Urban Socio-Ecological Resilience: Direct Institutional Effects

The empirical findings reveal that Adaptive Governance exerts a positive and statistically significant direct effect on Urban Socio-Ecological Resilience, with a path coefficient of 0.361, a t-value of 6.918, and a significance level below 0.001. This result demonstrates that adaptive governance contributes to urban resilience beyond its influence on environmental policy transformation. Institutional flexibility, collaborative governance arrangements, and continuous organizational learning enable public institutions to respond more effectively to environmental disturbances, thereby strengthening the adaptive capacity of urban systems. The significance of the direct relationship indicates that governance quality itself represents an essential institutional resource for building resilient cities capable of coping with environmental uncertainty.

The direct institutional effect identified in this study supports the conceptual foundation of adaptive governance, which argues that resilience emerges from governance systems capable of adjusting institutional arrangements in response to changing ecological and social conditions. Adaptive governance encourages decentralized decision-making, distributed leadership, and shared responsibility among multiple actors. Such governance characteristics enable public institutions to make timely decisions under conditions of uncertainty while maintaining coordination across different administrative sectors. The statistical evidence suggests that resilience is strengthened not only through policy reforms but also through institutional capacities that facilitate rapid adaptation during environmental crises.

Institutional collaboration represents one of the principal mechanisms explaining the observed relationship between adaptive governance and resilience (Vandergert et al., 2016; Biesbroek et al., 2017; Cooper & Wheeler, 2015). Urban environmental challenges frequently transcend organizational boundaries and require coordinated responses involving government agencies, scientific institutions, private organizations, and local communities. Collaborative governance improves information exchange, mobilizes diverse technical expertise, and reduces duplication of institutional responsibilities. As cooperation among stakeholders becomes more effective, cities are better equipped to manage environmental risks, allocate resources efficiently, and implement integrated adaptation strategies. The relatively high descriptive score for multi-actor collaboration reinforces the importance of collaborative institutions in strengthening urban resilience.

Continuous learning also contributes directly to resilience by improving institutional preparedness and organizational adaptability. Governance systems that encourage regular evaluation, knowledge sharing, and evidence-based decision-making are more capable of anticipating emerging environmental risks before they escalate into larger crises. Institutional learning enables organizations to revise operational procedures based on previous experiences, integrate scientific knowledge into planning processes, and develop innovative responses to evolving environmental conditions. Such adaptive learning enhances both institutional memory and strategic capacity, allowing urban governance systems to respond more effectively to future socio-ecological disturbances.

The relatively moderate magnitude of the direct path coefficient ($\beta = 0.361$) compared with the stronger relationship between Adaptive Governance and Environmental Policy Transformation ($\beta = 0.742$) provides an important empirical insight into the governance process. Although adaptive governance independently enhances resilience, its contribution becomes more substantial when institutional improvements are accompanied by responsive environmental policy reforms. This finding suggests that governance capacity alone is insufficient to maximize resilience unless it is translated into concrete regulatory changes, coordinated implementation mechanisms, and adaptive policy instruments. Consequently, governance institutions and environmental policies should be viewed as complementary components of an integrated resilience framework rather than independent governance instruments.

The findings are consistent with previous studies emphasizing that resilient cities depend on adaptive institutional capacities capable of managing uncertainty, coordinating diverse stakeholders, and facilitating continuous organizational learning (Bellinson & Chu, 2019; Spaans & Waterhout, 2017; Salvador & Sancho, 2023; Mendizabal et al., 2018). Earlier research has argued that governance systems characterized by flexibility, participation, and institutional innovation are generally more successful in maintaining social stability and ecological sustainability under conditions of environmental stress. The present study extends these theoretical perspectives by providing quantitative evidence from three major metropolitan cities in India. The consistency between the regression analysis and the PLS-SEM results strengthens confidence in the robustness of the proposed model and confirms that adaptive governance constitutes a significant predictor of urban socio-ecological resilience.

The discussion highlights that strengthening urban resilience requires governments to invest not only in environmental infrastructure and regulatory reform but also in institutional capacities that enhance governance effectiveness. Public institutions capable of coordinating multiple stakeholders, integrating scientific knowledge into decision-making, and responding flexibly to rapidly changing environmental conditions create a governance environment that supports long-term resilience (Cosens et al., 2017; Schröter et al., 2024). Institutional strengthening should therefore prioritize adaptive leadership, cross-sectoral collaboration, organizational learning, and transparent governance mechanisms capable of responding to increasingly complex socio-ecological challenges. These institutional improvements provide a durable foundation for sustainable urban development while increasing the resilience of cities facing the accelerating impacts of climate change, environmental degradation, and rapid urbanization.

CONCLUSION

This study demonstrates that adaptive governance constitutes a fundamental institutional mechanism for enhancing environmental policy transformation and strengthening urban socio-ecological resilience in major metropolitan areas of India. The empirical findings confirm that adaptive governance significantly promotes environmental policy transformation while also exerting a direct positive influence on urban resilience. Environmental policy transformation further contributes substantially to resilience, indicating that responsive and adaptive policy frameworks serve as an important pathway through which governance improvements translate into sustainable urban outcomes. These findings highlight the importance of institutional flexibility, collaborative governance, stakeholder engagement, and continuous organizational learning in addressing increasingly complex socio-ecological challenges associated with rapid urbanization and environmental change. The study contributes to the growing body of literature by providing quantitative evidence on the interconnected roles of governance, policy transformation, and resilience using multiple regression and PLS-SEM analyses. From a practical perspective, the results suggest that policymakers should prioritize adaptive institutional arrangements, strengthen cross-sectoral collaboration, and promote evidence-based environmental policymaking to improve urban resilience. Future research is encouraged to incorporate additional governance, socio-economic, and environmental variables, employ longitudinal research designs, and expand comparative analyses across different regional and national contexts to further validate and extend the proposed conceptual framework.

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