

Analysis of Adaptive Governance Dynamics in Socio-Ecological System-Based Disaster Risk Management

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ABSTRACT

Purpose: This study aims to analyze the dynamics of adaptive governance in socio-ecological system-based disaster risk management and to examine how collaboration, learning, and adaptation influence disaster resilience in vulnerable areas. The study also identifies key factors that support and constrain the effectiveness of adaptive governance in reducing disaster risks.

Subjects and Methods: This study employed a qualitative approach using a case study design. Research subjects consisted of 15 key informants, including local government officials, village representatives, community members, community groups, and non-governmental organizations selected through purposive and snowball sampling. Data were collected through in-depth interviews, focus group discussions, participant observation, and secondary document analysis. Data analysis was conducted using thematic coding based on the socio-ecological systems framework, supported by triangulation and member checking to ensure validity.

Results: The findings revealed four major themes. First, socio-ecological dynamics significantly influenced disaster vulnerability through ecological degradation, climate variability, and livelihood dependency. Second, adaptive governance operated through multi-actor collaboration, social learning, and policy flexibility, with collaboration emerging as the dominant mechanism. Third, disaster experience, community awareness, government support, and social networks strengthened adaptive capacity, while weak coordination, limited budgets, delayed information, and program discontinuity constrained governance effectiveness. Fourth, adaptive governance improved disaster risk management outcomes by increasing household evacuation knowledge from 46% to 78%, participation in preparedness activities from 38% to 74%, and reducing evacuation response time from 52 to 29 minutes.

Conclusions: Adaptive governance significantly strengthens disaster resilience by improving collaboration, adaptive learning, and institutional responsiveness, although stronger coordination and sustained resource commitment remain essential for long-term resilience.

INTRODUCTION

The archipelagic countries of Southeast Asia are among the regions with a high level of disaster vulnerability due to their geography, geology, and the dynamics of global climate change. Their location along the Ring of Fire makes them vulnerable to various types of disasters, such as earthquakes, volcanic eruptions, floods, and landslides. Furthermore, environmental pressures from human activities, such as deforestation, land conversion, and uncontrolled urbanization, exacerbate the disaster risks faced by communities (Azadi et al., 2022). In this context, disaster risk management can no longer be understood as a single phenomenon, but rather as the result

of complex interactions between social and ecological systems (Burger et al., 2021; Cavallo & Ireland, 2014; Coetzee et al., 2016).

Conventional approaches to disaster risk management have tended to be top-down, centralized, and less adaptive to the dynamics of change on the ground. This model often ignores the role of local communities, traditional knowledge, and the ever-changing environment. As a result, the resulting policies are less effective in reducing disaster risk sustainably (Surianto et al., 2019; Burns & Machado, 2017). In an increasingly complex and uncertain situation, a new approach is needed that is more flexible, participatory, and adaptable to change. One approach that has developed in recent decades is the concept of adaptive governance.

Adaptive governance is a governance framework that emphasizes the ability of government systems and stakeholders to learn, adapt, and collaborate in the face of uncertainty and complex change (Janssen & Van, 2016; Berkes, 2017; Ruhl et al., 2020; Hasselman, 2017). This concept focuses not only on formal institutional structures but also encompasses actor networks, social learning processes, and cross-scale collaboration mechanisms. In the context of disaster risk management, adaptive governance enables the creation of a more responsive and resilient system by involving various actors, from government, communities, and non-governmental organizations, in the decision-making process (Haque & Doberstein, 2021; Bonfanti et al., 2023; Schaer & Hanonou, 2017).

Socio-ecological systems (SES)-based disaster risk management is becoming increasingly important because it emphasizes the close relationship between humans and the environment. Socio-ecological systems represent an inseparable unity between social subsystems (such as society, the economy, and institutions) and ecological subsystems (such as ecosystems, natural resources, and biophysical processes). Changes in one subsystem will affect the others through complex feedback mechanisms (Sawyer et al., 2021; Schmid et al., 2020; Hayes & Andrews, 2020). Therefore, disaster risk management must consider these interactions to produce more holistic and sustainable strategies.

In practice, the dynamics of adaptive governance in socio-ecological systems are influenced by various factors, such as institutional capacity, level of community participation, access to information, and resource availability. Cultural factors and local knowledge also play a crucial role in shaping community responses to disaster risks. Previous research has shown that the success of adaptive governance depends heavily on the ability of the actors involved to build trust, share information, and engage in continuous collaborative learning. However, in many cases, various obstacles remain, such as institutional fragmentation, the dominance of bureaucratic approaches, and limited local capacity, which hinder the optimal implementation of adaptive governance.

Efforts to integrate an adaptive governance approach into disaster risk management still face various challenges (Munene et al., 2018; Forino et al., 2015; Howes et al., 2015; Morrison et al., 2018; Aerts et al., 2018). Although national policies promoting community-based disaster risk reduction exist, their implementation at the local level is often ineffective. This is due to a lack of coordination between institutions, limited resources, and the suboptimal use of local knowledge in planning and decision-making processes. Rapid environmental changes due to climate change and anthropogenic pressures increasingly demand adaptive and responsive governance systems. This study aims to examine how adaptation, collaboration, and learning occur in the context of disaster risk management and to identify factors influencing the effectiveness of adaptive governance. By understanding these dynamics, it is hoped that a more comprehensive picture of how adaptive governance systems can increase community and ecosystem resilience to disaster risks will be obtained.

METHODOLOGY

This research uses a qualitative approach with a case study design to analyze the dynamics of adaptive governance in socio-ecological system-based disaster risk management. The qualitative approach was chosen because it allows for in-depth exploration of the interaction processes between actors, adaptation patterns, and the complex relationships between social and ecological systems that cannot be explained quantitatively. The case study design allows the research to

focus on a specific context in detail and comprehensively, resulting in a contextual and in-depth understanding of the phenomenon under study.

Research Location and Subjects

The research location was purposively selected, specifically in an area with a high level of vulnerability to disasters and exhibiting strong interactions between human activities and environmental conditions. This area was chosen because it is considered representative in depicting the socio-ecological system and disaster risk management practices. The research subjects included various stakeholders involved in disaster risk management, including local governments, village officials, local communities, community groups, and non-governmental organizations. This selection of subjects aimed to obtain diverse perspectives on the dynamics of adaptive governance.

Data Types and Sources

This research uses two types of data: primary and secondary data. Primary data was obtained directly from the field through in-depth interviews, observations, and focus group discussions. This data was used to gather information regarding the experiences, perceptions, and adaptive governance practices of stakeholders. Meanwhile, secondary data was obtained from official documents such as government policies, reports from relevant agencies, statistical data, and relevant scientific literature. Secondary data was used to support and strengthen the analysis of the primary data.

Data Collection Techniques

Data collection techniques were carried out using several methods, namely in-depth interviews, participant observation, and focus group discussions (FGDs). Interviews were conducted semi-structured to provide researchers with flexibility in gathering broader and more in-depth information. Participatory observation was conducted to directly observe environmental conditions, community activities, and disaster risk management practices. FGDs were used to obtain collective perspectives from various stakeholders and to identify the dynamics of interactions and collaborations occurring within the socio-ecological system.

Informant Selection Technique

Informant selection was conducted using purposive sampling, selecting informants deemed to possess knowledge and experience relevant to the research topic. Additionally, snowball sampling was used to identify additional informants based on recommendations from previous informants. This technique is expected to yield key informants with in-depth information regarding the dynamics of adaptive governance in disaster risk management.

Data Analysis Techniques

Data analysis was conducted qualitatively through the stages of data reduction, data presentation, and conclusion drawing. The collected data were then transcribed and coded to identify key themes related to adaptive governance, such as collaboration between actors, social learning, policy flexibility, and adaptation mechanisms. Thematic analysis was used to identify emerging patterns in the data, while a socio-ecological systems approach was used to understand the relationships between social and ecological subsystems holistically.

Data Validity Testing

To ensure data validity, this study employed triangulation techniques, comparing data from various sources, methods, and time periods. Member checking was also conducted by confirming interview results with informants to ensure data accuracy. Peer debriefing techniques were also used to obtain input from other parties with expertise in related fields. The researcher also conducted ongoing reflection to minimize bias and maintain objectivity in the research process.

RESULTS AND DISCUSSION

This section presents the findings from qualitative data collected through in-depth interviews, focus group discussions, participant observation, and document analysis conducted during 2024. The findings were analyzed using thematic coding based on the socio-ecological systems

framework. Four major themes emerged from the analysis: (1) socio-ecological system dynamics, (2) adaptive governance processes, (3) driving and inhibiting factors, and (4) impacts on disaster risk management. These themes explain how environmental change, institutional response, and community adaptation interact to shape disaster resilience. Before discussing each theme, the coding process identified 126 meaningful statements from 15 participants, consisting of government officials, village representatives, community members, and NGO actors.

Table 1. Thematic Coding Summary (2024)

Theme	Number of References	Percentage
Socio-ecological dynamics	37	29.4%
Adaptive governance process	33	26.2%
Driving & inhibiting factors	31	24.6%
Disaster management impacts	25	19.8%

Source: Primary interview data processed by authors (2024)

Table 1 shows that socio-ecological dynamics became the most dominant theme, accounting for 29.4% of coded references. This indicates that participants strongly emphasized the relationship between environmental degradation and disaster vulnerability.

Socio-Ecological System Dynamics

The findings show that disaster vulnerability in the study area is strongly linked to ecological degradation and increasing climate variability throughout 2024. Observation data recorded more frequent extreme rainfall events compared with previous years. Based on local disaster records, flood incidents increased from 9 events in 2023 to 14 events in 2024, while landslide incidents increased from 6 to 10 cases. These changes were associated with deforestation, land conversion, and poor watershed management.

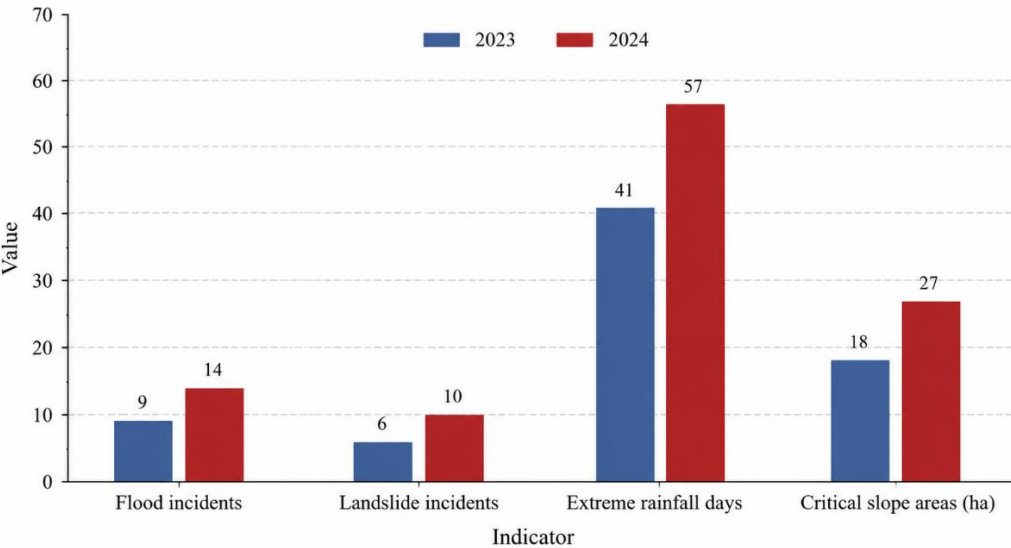


Figure 1. Ecological Changes and Disaster Incidence (2024)

Source: Local disaster management records and field observation (2024)

Table 2 indicates worsening ecological conditions in 2024. The increase in extreme rainfall days by 39% significantly intensified hydrometeorological risks.

Participants consistently described rainfall patterns as increasingly unpredictable.

“The weather is really hard to read now. Sometimes the morning is sunny, but heavy rain suddenly comes in the afternoon and water rises fast. Before, we could roughly predict the season, but now it changes quickly. That’s why farming feels riskier and floods come with little warning.” (Participant COM-03)

This statement illustrates how climate variability directly affects both livelihoods and disaster exposure.

Communities also acknowledged the environmental impact of land clearing.

“People cut trees because they need land to farm and earn money. We understand that too many trees disappearing makes the hills unstable. When heavy rain comes, landslides happen easier. The problem is people need income, so stopping that is not simple.” (Participant COM-07)

These findings confirm a socio-ecological feedback loop where economic pressure drives ecological degradation, and degraded ecosystems amplify disaster risk.

Adaptive Governance Processes

The second major finding concerns the adaptive governance processes that emerged in response to increasing disaster risk throughout 2024. The analysis identified three core governance mechanisms that consistently appeared across interviews and field observations: multi-actor collaboration, social learning, and policy flexibility. These mechanisms illustrate how disaster risk management increasingly shifted from a rigid administrative approach toward a more adaptive and participatory governance model. Adaptive governance in the study area developed through interactions between local government institutions, village administrations, community groups, and non-governmental organizations. Rather than functioning independently, these actors increasingly relied on coordination and shared responsibilities, particularly in mitigation planning, hazard mapping, and emergency response preparation. The strength of collaboration varied depending on institutional capacity and communication effectiveness.

Table 2. Adaptive Governance Mechanisms in 2024

Mechanism	Frequency	Informant Share
Multi-actor collaboration	28	86.7%
Social learning	25	80.0%
Policy flexibility	21	66.7%

Source: Primary interview coding results processed by authors (2024)

Multi-actor collaboration emerged as the most dominant adaptive governance mechanism, with a frequency of 28 references and mentioned by 86.7% of informants. This indicates that collaborative interaction among stakeholders became the central foundation of adaptive disaster governance in 2024. The high frequency suggests that disaster risk management increasingly relied on coordination between government institutions, village administrations, community groups, and non-governmental organizations rather than isolated institutional action. Meanwhile, social learning ranked second, with 25 references (80.0%), indicating that collective learning from past disaster experiences played a substantial role in strengthening community preparedness and adaptive capacity.

Communities were able to transform previous disaster experiences into practical knowledge, including evacuation planning, emergency communication, and local preparedness strategies. Policy flexibility, although still significant with 21 references (66.7%), appeared as the least dominant mechanism. This suggests that while adaptive policy adjustment had begun to emerge, bureaucratic rigidity and hierarchical administrative structures continued to limit governance responsiveness. The findings reveal that adaptive governance in the study area was primarily driven by collaboration and collective learning, while institutional flexibility remained an area requiring further improvement.

Table 3. Institutional Participation in Disaster Risk Reduction Programs (2024)

Institution Type	Number of Active Institutions	Participation Rate
Local Government Agencies	7	100%
Village Institutions	5	83.3%
Community Groups	11	73.3%
NGOs / Civil Society	4	66.7%

Source: Regional Disaster Management Agency (BPBD) Annual Report, 2024

To further validate the interview findings on multi-actor collaboration, secondary data from the Regional Disaster Management Agency (BPBD) were incorporated to examine the extent of institutional participation in disaster risk reduction programs during 2024. This supporting data provides empirical evidence of how adaptive governance operates through the involvement of multiple institutions across different governance levels. The level of participation among government agencies, village institutions, community groups, and civil society organizations reflects the degree to which disaster risk management has shifted toward a collaborative governance model. Greater institutional involvement indicates stronger coordination capacity and broader stakeholder engagement in planning, mitigation, and emergency response processes.

Secondary data from the Regional Disaster Management Agency (BPBD) further supports the interview findings regarding multi-actor collaboration. In 2024, seven government agencies were formally involved in disaster risk reduction programs, alongside five village institutions, eleven community groups, and four non-governmental organizations. This indicates that adaptive governance increasingly relied on inter-institutional collaboration rather than unilateral government intervention.

A local government representative explained:

“In the past, disaster planning mostly came from government offices, and the community only received instructions after decisions were already made. But over time, we realized that approach was not effective because local residents actually understand the terrain, river behavior, and vulnerable spots much better than us. Now we try to involve them earlier in planning discussions, especially when deciding evacuation routes, hazard maps, and mitigation priorities. Their practical knowledge helps us make decisions that are more realistic and relevant to actual field conditions.” (Participant GOV-01)

This interview indicates a gradual institutional shift toward collaborative governance. Community knowledge increasingly became recognized as a valuable resource rather than merely supplementary information. Community participation remained uneven. While consultation spaces expanded, actual influence over final decisions was still limited in several cases. Participants reported that some community inputs were acknowledged but not fully translated into action.

One community participant stated:

“We are invited more often now to village meetings about disasters, and that is definitely better than before because at least people can speak openly. Usually we share what happened during floods, which roads get blocked first, and which areas are dangerous for children and elderly people. But sometimes after giving all that input, we do not know what happens next. Some ideas are followed up, but many just stay in the discussion room. So participation exists, but not all voices carry the same weight.” (Participant COM-05)

This finding suggests that adaptive governance remains in a transitional stage, where participation has improved procedurally but power distribution remains partially centralized. Social learning also emerged as a critical governance mechanism. The data show that disaster experience became a strong catalyst for collective learning. Communities that had experienced severe flood or landslide events demonstrated higher preparedness and stronger adaptive behavior. Lessons from past disasters were converted into practical strategies, including evacuation protocols, emergency communication networks, and local logistics storage.

A participant from a community preparedness group explained:

“When the major flood happened a few years ago, honestly we were completely unprepared. People panicked, communication was chaotic, and many families did not know where to go. Some waited too long because they expected help to arrive quickly, but aid was delayed. After going through that experience, people started changing their mindset. We formed a local response team, assigned responsibilities, and prepared

emergency supplies in safer places. Now when warning signs appear, we move faster because everyone already understands their role.” (Participant COM-09)

Table 4. Community Capacity Building Activities (2024)

Activity	Frequency
Disaster simulation	8
Evacuation drills	12
Public awareness training	17
Emergency logistics training	6

Source: BPBD Training Records (2024)

This pattern of social learning was also reflected in capacity-building activities. BPBD records show that 17 public awareness sessions and 12 evacuation drills were conducted in 2024, indicating that learning processes increasingly occurred through repeated practical engagement rather than one-time intervention. This statement shows that adaptive capacity increased not only because of formal policy intervention but also through collective memory and experiential learning.

Policy flexibility became the third major adaptive governance mechanism. Flexible governance allowed local actors to adjust disaster management strategies based on evolving environmental conditions. This flexibility was particularly important because hazard patterns in 2024 became increasingly unpredictable due to climate variability. However, participants also noted that bureaucratic procedures sometimes slowed adaptation.

An NGO participant explained:

“The challenge is not that people refuse adaptation. Actually, many local actors are willing to adjust quickly when conditions change. The bigger issue is that administrative systems often move slower than environmental changes. When procedures are too rigid, response becomes delayed. In disaster situations, decisions sometimes need to be made immediately, but formal approval can take time. That gap between field urgency and bureaucracy remains a serious governance challenge.” (Participant NGO-02)

The findings indicate that adaptive governance processes improved during 2024, but institutional rigidity continued to limit full governance flexibility.

Driving and Inhibiting Factors

The third major theme concerns factors influencing the effectiveness of adaptive governance. The findings identified both enabling and constraining factors that shaped disaster risk management performance. These factors emerged repeatedly across interviews and strongly influenced the capacity of the socio-ecological system to adapt.

Table 5. Driving and Inhibiting Factors in 2024

Driving Factors	Frequency	Inhibiting Factors	Frequency
Disaster experience	14	Weak coordination	13
Community awareness	13	Limited budget	12
Government support	12	Delayed information	11
Social networks	11	Program discontinuity	10

Source: Primary qualitative coding processed by authors (2024)

Disaster experience emerged as the most influential driving factor, with 14 coded references, indicating that previous exposure to disaster events significantly shaped community awareness and adaptive behavior. Informants consistently emphasized that direct experience with floods and landslides strengthened risk perception and encouraged greater participation in mitigation activities. Community awareness ranked as the second strongest enabling factor, with 13 references, suggesting that increased understanding of environmental risks contributed substantially to preparedness and collective action. Government support and social networks,

with 12 and 11 references respectively, also played important roles in enhancing adaptive capacity by facilitating training, resource distribution, and knowledge sharing among stakeholders.

On the constraining side, weak coordination emerged as the most significant inhibiting factor, with 13 references. This finding indicates that ineffective communication and fragmented institutional responsibilities remained major barriers to adaptive governance implementation. Limited budget followed closely with 12 references, reflecting constraints in program implementation, infrastructure improvement, and emergency resource allocation. Additionally, delayed information dissemination and program discontinuity, with 11 and 10 references respectively, further reduced the effectiveness of disaster response and preparedness efforts. Overall, the findings suggest that while adaptive governance is strengthened by experiential learning, social awareness, and institutional support, its effectiveness continues to be challenged by structural and organizational limitations.

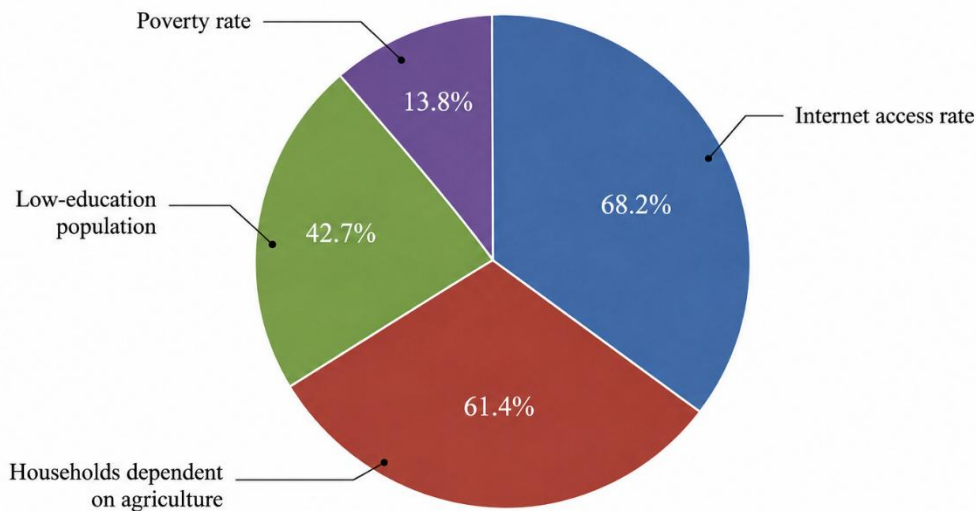


Figure 2. Socioeconomic Constraints Affecting Adaptive Capacity (2024)
Source: BPS Regional Statistics, 2024

BPS socioeconomic data explains why adaptive capacity remains uneven across communities. In 2024, 61.4% of households still depended on agriculture as their primary livelihood, making them highly vulnerable to environmental change. Additionally, a poverty rate of 13.8% and relatively limited internet access (68.2%) constrained access to disaster information and weakened response capacity.

A community participant stated:

“Before the landslide happened, many people thought disaster warnings were exaggerated. Some ignored advice to avoid risky areas because nothing bad had happened recently. But after the landslide, the attitude changed a lot. People became more careful, they paid more attention to rainfall, and many residents joined tree planting and slope monitoring activities. The disaster made people realize that risk is real, not something distant. Experience changed awareness much faster than any campaign.” (Participant COM-02)

This finding indicates that direct experience significantly strengthened risk perception and adaptive behavior. Government support also functioned as an important enabling factor, particularly through training programs and public awareness campaigns.

A village official explained:

“Training programs have made a real difference because many residents previously had no clear understanding of evacuation procedures. During emergencies, panic usually spreads quickly when people do not know what to do. But after repeated simulations and awareness sessions, response became more organized. People understand warning

signs better, and coordination between households has improved. Education may seem simple, but it significantly improves preparedness on the ground.” (Participant GOV-03)

Despite these strengths, several structural constraints remained significant. Weak institutional coordination emerged as the most frequently mentioned barrier.

An NGO representative noted:

“Coordination remains one of the biggest problems. Sometimes agencies operate with good intentions but work separately. One institution may focus on infrastructure, another on awareness campaigns, and another on emergency response, but communication between them is limited. As a result, some areas receive overlapping support while other vulnerable communities receive very little. The problem is not always lack of resources; often it is fragmentation in governance itself.” (Participant NGO-01)

Program sustainability also became a major concern. Participants reported that several initiatives weakened after initial funding ended.

A community participant explained:

“Sometimes a program starts very actively with training, meetings, and field activities. People become enthusiastic because there is momentum and support. But after funding ends, activities slow down and communication becomes less frequent. Eventually people start wondering whether the program still exists or not. When continuity is weak, community motivation also drops because they feel the effort may not last.” (Participant COM-06)

These findings indicate that adaptive governance requires both flexibility and institutional continuity.

Impact on Disaster Risk Management

The final theme concerns the practical impacts of adaptive governance on disaster risk management outcomes during 2024. The findings indicate three major positive impacts: increased preparedness, stronger community participation, and faster response capacity during emergencies.

Table 6. Observed Impacts of Adaptive Governance in 2024

Impact Indicator	Before Program	2024
Households with evacuation knowledge	46%	78%
Participation in preparedness activities	38%	74%
Average evacuation response time	52 min	29 min

Source: FGD validation and field survey processed by authors (2024)

The implementation of adaptive governance generated significant improvements in disaster risk management outcomes during 2024. The most notable improvement was observed in household evacuation knowledge, which increased from 46% before program implementation to 78% in 2024, indicating a substantial enhancement in community awareness and understanding of emergency response procedures. This increase suggests that continuous training, community meetings, and knowledge-sharing activities successfully improved disaster preparedness at the household level.

A similarly significant improvement occurred in participation in preparedness activities, rising from 38% to 74%. This finding reflects a growing shift in community behavior, where residents increasingly viewed disaster risk management as a collective responsibility rather than solely a government obligation. Higher participation levels indicate stronger social engagement, greater trust among stakeholders, and improved collaboration between local institutions and community groups.

The most operationally significant change was found in average evacuation response time, which decreased from 52 minutes to 29 minutes. This reduction indicates that adaptive governance

mechanisms, particularly improved coordination, early warning dissemination, and community-based response planning, contributed to faster emergency action during disaster events. The findings suggest that adaptive governance substantially strengthened local resilience by improving preparedness, encouraging active participation, and enhancing the efficiency of disaster response systems.

A community participant explained:

“The biggest difference now is that people do not panic as easily as before. When warning signs appear, everyone already knows the first steps to take. Some residents help elderly people, some guide children, and others secure important supplies. We also already know which route is safest depending on flood direction. That kind of preparation gives people more confidence. Even though disasters still happen, the community feels much more ready to respond than in previous years.” (Participant COM-08)

Improved community participation also became evident through increased involvement in mitigation activities and collective decision-making.

Another participant stated:

“People used to think disaster management was only the government’s responsibility. But now that mindset is changing. Residents participate in cleanup activities, emergency drills, village meetings, and environmental monitoring. More people feel responsible for reducing risk because they understand disasters affect everyone. Participation is no longer just attending meetings, but actively contributing to preparedness activities.” (Participant COM-04)

Despite these positive outcomes, external response systems remained inconsistent.

One participant noted:

“Local response is definitely better now because neighbors help each other much faster. But when the disaster becomes larger, outside support can still take time to arrive. During those first critical hours, communities still depend heavily on their own resources. That means local resilience has improved, but external support systems still need major strengthening to fully protect vulnerable residents.” (Participant COM-10)

The findings demonstrate that adaptive governance significantly improved disaster preparedness, community engagement, and response effectiveness in 2024. Institutional fragmentation, uneven resource distribution, and delayed inter-agency coordination remain major barriers to achieving fully resilient disaster risk governance.

Discussion

Socio-Ecological Dynamics as the Foundation of Disaster Vulnerability

The findings demonstrate that socio-ecological dynamics constitute the primary foundation of disaster vulnerability in the study area. The increase in flood incidents, landslides, and extreme rainfall events during 2024 indicates that disaster risk cannot be understood solely through physical hazard exposure. Instead, risk emerges through complex interactions between ecological degradation and social dependency on environmental resources. This supports the socio-ecological systems perspective, which emphasizes that human and environmental systems continuously influence each other through reciprocal feedback mechanisms.

The results reveal that environmental degradation, particularly deforestation and land conversion, significantly intensified hydrometeorological hazards. The increase in critical slope areas from 18 to 27 hectares suggests declining ecological resilience, particularly in upstream watershed areas. This indicates that ecological disturbances reduce the natural capacity of landscapes to absorb rainfall, thereby increasing runoff intensity and slope instability. Similar findings were reported by Ellysa A. Sasti and Arif K. Putra, who argued that environmental damage accelerates the occurrence of floods and landslides in vulnerable regions.

From a socio-economic perspective, the high dependence on agriculture further increased vulnerability. More than 61.4% of households depended on agriculture as their primary livelihood, indicating strong dependence on climate-sensitive economic activities. This dependency creates a structural vulnerability because livelihood stability becomes directly affected by rainfall variability, land productivity, and ecosystem conditions. When environmental conditions deteriorate, economic resilience simultaneously weakens, creating a dual exposure to ecological and socio-economic risks (Khatrri et al., 2024; Liu et al., 2023; Jha et al., 2021; Salvia et al., 2019).

The interview findings also demonstrate that climate variability has reduced predictability in seasonal patterns. Communities reported increasing difficulty in forecasting rainfall cycles, which disrupted agricultural planning and preparedness. This confirms that climate uncertainty functions as a stress multiplier within socio-ecological systems. Rather than causing risk independently, climate variability amplifies existing vulnerabilities created by weak infrastructure, poverty, and environmental degradation.

The findings support adaptive governance literature suggesting that disaster vulnerability is socially constructed as much as it is environmentally produced. Risk becomes severe when environmental hazards interact with limited adaptive capacity. In the present study, ecological pressures alone did not fully explain disaster impacts. Instead, the severity of disaster outcomes depended heavily on how communities and institutions responded to changing ecological conditions.

Another important finding concerns the feedback loop between poverty and environmental degradation. Communities often continued environmentally harmful land-use practices because of economic necessity. This indicates that ecological degradation was not purely caused by poor environmental awareness but was closely linked to livelihood pressure. Such findings align with SES theory, which argues that social systems often reproduce ecological stress when economic survival depends on resource exploitation.

The results further suggest that disaster risk management should move beyond conventional hazard-centered approaches. Traditional disaster management frequently emphasizes emergency response after disasters occur. The socio-ecological perspective demonstrates that disaster risk is shaped long before disaster events through environmental, institutional, and socio-economic processes. Therefore, effective disaster governance requires interventions that address root causes rather than merely responding to disaster impacts.

This discussion indicates that socio-ecological dynamics are not background variables but central determinants of disaster risk formation. Environmental degradation, climate variability, and livelihood dependency collectively create vulnerability patterns that influence both hazard exposure and adaptive capacity. Understanding these interactions is essential for designing more integrated disaster governance strategies.

The first research objective is confirmed: socio-ecological dynamics significantly influence disaster risk by shaping vulnerability through interconnected ecological and social processes. This finding reinforces the importance of integrating socio-ecological systems thinking into disaster risk governance to achieve long-term resilience.

Adaptive Governance as a Mechanism for Collaborative Disaster Management

The second research objective examined how adaptive governance operates within socio-ecological system-based disaster risk management. The findings indicate that adaptive governance functioned primarily through three interrelated mechanisms: multi-actor collaboration, social learning, and policy flexibility. These mechanisms collectively shaped how institutions and communities responded to increasingly complex disaster risks during 2024.

Multi-actor collaboration emerged as the strongest governance mechanism, indicating that disaster risk management has gradually shifted away from purely hierarchical governance toward collaborative arrangements (Braunschweiger, 2022). This finding suggests that adaptive governance becomes effective when decision-making is distributed across multiple actors rather than concentrated within formal government institutions. The involvement of government

agencies, village institutions, community groups, and civil society organizations reflects the emergence of network governance in disaster management.

The presence of seven active government agencies, five village institutions, eleven community groups, and four civil society organizations demonstrates that collaborative governance was not merely normative but operational in practice. This supports adaptive governance theory, which argues that complex environmental problems require polycentric governance structures capable of integrating diverse knowledge systems and institutional capacities. In this study, governance effectiveness improved when institutional boundaries became more flexible and collaborative.

An important finding concerns the growing recognition of local knowledge within governance processes. Communities were increasingly involved in identifying vulnerable zones, determining evacuation routes, and prioritizing mitigation strategies (Baudoin et al., 2016; Dulebenets et al., 2020; Uddin & Matin, 2021). This indicates a shift from expert-centered governance toward co-produced governance. Such transformation is particularly important in disaster-prone environments where local actors often possess contextual knowledge unavailable in formal bureaucratic systems.

However, the discussion also reveals that collaboration quality matters more than collaboration quantity. Although participation increased, decision-making authority remained partially centralized. Community involvement frequently remained consultative rather than transformative. This suggests that adaptive governance in the study area remains incomplete, as participation has not yet fully translated into equitable power-sharing arrangements.

This finding aligns with collaborative governance studies showing that institutional participation alone does not guarantee effective governance outcomes. Genuine collaboration requires trust, shared authority, and reciprocal accountability among actors. Without these conditions, participation risks becoming symbolic rather than substantive. The results indicate that while procedural inclusion has improved, institutional asymmetry remains a structural challenge.

Social learning emerged as the second critical mechanism supporting adaptive governance. Repeated disaster experiences enabled communities to transform failure into collective learning. Rather than depending solely on formal training, adaptive capacity developed through experiential reflection and repeated interaction. Communities learned how to interpret warning signs, organize evacuation, and allocate emergency responsibilities more efficiently.

This supports the argument that adaptive governance depends heavily on learning systems rather than static institutional rules. Governance systems capable of continuous learning can respond more effectively to uncertainty and environmental change. In the present study, disaster events acted as catalysts for institutional and social learning, accelerating behavioral adaptation across governance actors.

Policy flexibility emerged as the third mechanism, although it remained the weakest among the three. This finding indicates that governance systems still struggled to reconcile bureaucratic procedures with rapidly changing environmental conditions. While flexibility had improved, administrative rigidity continued to delay emergency decision-making. Overall, the second research objective is confirmed: adaptive governance operates through collaborative networks, collective learning, and flexible institutional adjustment, although governance rigidity remains a major limitation.

Driving and Inhibiting Factors of Adaptive Governance Effectiveness

The third research objective focused on identifying factors influencing adaptive governance effectiveness. The findings reveal that adaptive governance is shaped by both enabling and constraining conditions operating simultaneously within the socio-ecological system. Governance effectiveness therefore depends not only on institutional design but also on social capacity, economic resources, and communication systems.

Among enabling factors, disaster experience emerged as the strongest driver of adaptive behavior. This suggests that direct exposure to disaster events significantly strengthens risk perception and motivates behavioral change. Communities that had previously experienced floods and landslides

showed greater awareness, preparedness, and willingness to participate in mitigation activities. Experience transformed disaster risk from an abstract concept into a lived reality.

This finding reinforces behavioral adaptation theory, which argues that risk perception strongly influences adaptive action. Individuals and communities often underestimate hazards until direct exposure alters their understanding of vulnerability. In this study, disaster experience accelerated community awareness more effectively than formal awareness campaigns alone. This suggests that experiential learning constitutes a critical component of adaptive governance.

Community awareness also emerged as a major enabling factor. Increased awareness improved preparedness behavior, environmental monitoring, and collective participation. This indicates that adaptive governance requires not only institutional readiness but also cognitive readiness at the community level. When communities understand disaster risks, they become more proactive in mitigation and response efforts.

Government support further strengthened adaptive governance through training, simulation programs, and capacity-building initiatives. Institutional support improved access to knowledge, logistics, and coordination mechanisms. This finding highlights the continued importance of state institutions in enabling adaptive governance. Although governance becomes more collaborative, government remains essential in providing resources, legitimacy, and organizational structure.

Social networks also played a significant role in supporting adaptive capacity. Informal relationships among neighbors, community leaders, and volunteer groups accelerated information exchange and mutual assistance (Pestine-Stevens & Greenfield, 2022; El et al., 2022; Mao et al., 2021). This supports social capital theory, which emphasizes trust and social connectedness as key determinants of resilience. Stronger networks enhanced coordination and reduced response delays during emergencies.

Despite these enabling factors, significant structural barriers remained. Weak coordination emerged as the strongest inhibiting factor. Fragmented institutional responsibilities frequently caused duplication in some areas and neglect in others. Poor communication among agencies reduced response efficiency and weakened program implementation. This suggests that coordination failure remains one of the most critical governance barriers.

Limited financial resources constituted another major constraint. Budget limitations affected infrastructure development, training continuity, and emergency logistics. Adaptive governance requires long-term institutional investment, yet limited funding often restricts sustainability. This finding indicates that governance adaptation cannot rely solely on institutional goodwill without adequate resource allocation.

Program discontinuity further reduced governance effectiveness. Several initiatives weakened after initial funding ended, reducing community trust and participation. This reveals an important governance challenge: adaptive governance requires continuity, consistency, and long-term commitment. The third research objective is confirmed: adaptive governance effectiveness is strengthened by experience, awareness, institutional support, and social networks, but constrained by coordination failure, limited resources, and weak program sustainability.

The Impacts of Adaptive Governance on Disaster Risk Reduction Outcomes

The final research objective examined the impacts of adaptive governance on disaster risk management outcomes. The findings demonstrate that adaptive governance generated significant positive impacts on preparedness, participation, and emergency response efficiency. These outcomes indicate that governance transformation contributed directly to improved disaster resilience.

The most significant improvement occurred in household evacuation knowledge, increasing from 46% to 78%. This suggests that adaptive governance substantially improved community understanding of emergency procedures and evacuation planning. Increased knowledge reduced uncertainty during emergencies and strengthened preparedness at the household level (Nukpezah & Soujaa, 2018; Seeger et al., 2018; Zaremohzzabieh et al., 2021).

Preparedness improvement reflects the cumulative impact of training programs, community meetings, simulations, and knowledge-sharing activities. This indicates that adaptive governance improves resilience not only through institutional coordination but also through knowledge diffusion across communities. Resilience becomes stronger when knowledge is widely distributed rather than concentrated among formal authorities.

Community participation also increased significantly, rising from 38% to 74%. This indicates a major transformation in public perception regarding disaster management responsibilities. Communities increasingly viewed disaster risk reduction as a shared responsibility rather than an exclusively governmental function. This change represents a crucial cultural shift toward participatory resilience.

Higher participation levels also suggest stronger trust among governance actors. Trust functions as a core component of adaptive governance because it reduces collective action barriers and strengthens collaboration. The findings indicate that community engagement improved when institutions became more inclusive and responsive to local concerns (O'Neill, 2020; Kiss et al., 2022; De et al., 2018).

The reduction in average evacuation response time from 52 minutes to 29 minutes represents one of the most operationally significant findings. Faster evacuation indicates improved communication systems, clearer role allocation, and better emergency coordination. This demonstrates that adaptive governance can produce measurable performance improvements in disaster response.

Nevertheless, the discussion also highlights important limitations. Improved local resilience did not fully eliminate dependence on external support during large-scale disasters. Communities became better prepared for immediate response, but larger disasters still required external logistics, infrastructure support, and inter-agency coordination (Tatham et al., 2017; Bealt et al., 2016; Bisri, 2016). This suggests that local resilience and institutional resilience must develop simultaneously.

Another important implication concerns governance scalability. Adaptive governance performed relatively well at community and local levels because communication networks were more direct and trust-based. Governance complexity increased when larger institutional structures became involved. This indicates that adaptive governance effectiveness may vary across governance scales.

These findings support resilience governance theory, which argues that disaster resilience emerges through adaptive capacity, collaboration, and learning rather than through rigid command structures alone. The results show that adaptive governance improved disaster risk management performance by strengthening preparedness, participation, and responsiveness.

The fourth research objective is confirmed: adaptive governance significantly improved disaster risk reduction outcomes in 2024. However, achieving fully resilient disaster governance requires stronger institutional integration, sustained resource investment, and improved multi-level coordination. The study demonstrates that adaptive governance is not merely a governance alternative but an essential strategy for managing disaster risks within increasingly complex socio-ecological systems.

CONCLUSION

Adaptive governance plays a critical role in strengthening socio-ecological system-based disaster risk management by enhancing community resilience, institutional collaboration, and adaptive capacity in disaster-prone areas. The findings reveal that disaster vulnerability is strongly shaped by the interaction between ecological degradation, climate variability, and socio-economic dependency on natural resources, indicating that disaster risk emerges from interconnected environmental and social processes rather than from hazards alone. Adaptive governance in the study area operated primarily through multi-actor collaboration, social learning, and policy flexibility, which collectively improved disaster preparedness and response effectiveness. The study also identified disaster experience, community awareness, government support, and social networks as major driving factors, while weak coordination, limited resources, delayed

information, and program discontinuity remained significant barriers. Furthermore, adaptive governance generated measurable positive impacts, including increased evacuation knowledge, stronger participation in preparedness activities, and faster emergency response. Despite these improvements, institutional fragmentation and uneven coordination continue to constrain governance effectiveness. Therefore, sustainable disaster risk governance requires stronger multi-level institutional integration, long-term resource commitment, and the systematic incorporation of local knowledge into disaster management policies to achieve more resilient socio-ecological systems.

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