



# Social–ecological resilience of communities in facing the cumulative impacts of sand mining and climate change

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## ABSTRACT

**Background:** This study explores the socio–ecological resilience of communities, in responding to the cumulative impacts of sand mining and climate change. **Methods:** Using a qualitative case study approach grounded in a constructivist paradigm, data were collected through interviews, focus group discussions, field observations, and document analysis. **Findings:** The results show that intensive sand mining and rising sea levels have led to environmental degradation, declining agricultural productivity, and socio-economic vulnerability. Despite these challenges, local communities have developed adaptive strategies, including livelihood diversification, collective cooperation, and the strengthening of local institutions. However, resilience remains largely adaptive and short-term rather than transformative. Weak governance, fragmented policies, and economic dependency on extractive activities continue to limit sustainable transformation. **Conclusion:** This study proposes a three-pillar collaborative resilience framework—integrated governance, sustainable economy, and ecological restoration—to enhance long-term socio–ecological resilience. The findings extend socio–ecological resilience theory by demonstrating how cumulative environmental pressures interact with governance fragmentation, highlighting the importance of transformative institutional coordination. The proposed framework offers policy-relevant insights for strengthening climate adaptation and watershed governance in coastal regions of Indonesia. **Novelty/Originality of this article:** This study integrates adaptive capacity analysis with collaborative governance within a socio–ecological systems perspective, contributing both theoretical advancement and practical guidance for sustainable watershed management. The findings extend socio–ecological resilience theory by demonstrating how cumulative environmental pressures interact with governance fragmentation, highlighting the importance of transformative institutional coordination for long-term sustainability.

**KEYWORDS:** adaptive capacity; climate change; community-based management; sand mining; socio–ecological resilience; watershed governance.

## 1. Introduction

Coastal areas across Indonesia are experiencing increasing socio–ecological pressure, where human-induced degradation interacts with the accelerating impacts of climate change. In many regions, economic expansion and environmental extraction have often been prioritized over sustainability, creating complex and overlapping vulnerabilities. This

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situation is particularly evident in coastal watersheds that serve as the interface between land-based and marine ecosystems. These areas function not only as sources of livelihood but also as ecological buffers that sustain hydrological and biological balance. Yet, they are also among the most fragile socio-ecological systems in the country. Understanding how local communities cope and adapt within such fragile environments is therefore crucial for designing policies that balance economic needs and ecological stability.

Demak Regency, characterized by its low-lying coastal landscape, has long been the epicenter of various environmental crises. Sand mining activities have contributed to land subsidence, which is further exacerbated by sea level rise. The convergence of human-induced pressures and global climate change has turned the area into a kind of *living laboratory* a real-world space where the ways in which local communities build, sustain, and adjust their social-ecological resilience amid rapid and drastic environmental change can be closely observed.

The one of watershed in Demak Regency is currently facing two major stressors simultaneously. On one hand, intensive sand mining has caused severe environmental degradation around the river. On the other hand, the community must also cope with the impacts of climate change, particularly sea level rise (*rob*) and the increasing intrusion of saline water into inland areas. The combination of human pressures and natural changes has created a complex situation. It not only threatens the sustainability of river and coastal ecosystems but also directly affects the livelihoods of communities that depend on these resources. Such conditions demand continuous adaptation and adjustment to sustain life amid environmental uncertainty.

From a contemporary perspective, social-ecological resilience is no longer understood merely as a system's ability to return to its original state after disturbance. Instead, resilience is now seen as the capacity to adapt, transform, and develop new forms of stability in response to complex and layered disruptions (Biggs et al., 2021). Recent studies emphasize that resilience involves continuous social learning, innovation, and institutional flexibility rather than merely returning to a previous state (Olsson et al., 2017; Westley et al., 2011). This view highlights that resilience is both an ecological and a social capacity—rooted in networks of cooperation, collective action, and the ability to reorganize under stress (Shepon et al., 2021).

Research on coastal resilience highlights how communities facing environmental pressures require adaptive governance and social learning mechanisms to sustain socio-ecological systems (Adger, 2005). In Indonesia, these discussions increasingly intersect with local knowledge and participatory management, demonstrating that resilience-building requires the integration of community agency, ecological restoration, and inclusive policy frameworks (Lefebvre et al., 2022). Building on these insights, this study examines how social-ecological resilience emerges in a context shaped by environmental degradation and climate pressures.

In Indonesia, studies of social-ecological resilience have expanded rapidly in recent years, focusing on issues such as mangrove restoration, fisheries management, and disaster risk reduction. However, relatively few studies have examined resilience in inland-coastal transition zones, where extractive activities such as sand mining intersect with the chronic effects of climate change. Most resilience studies in Indonesia emphasize either environmental degradation or climate impacts in isolation, overlooking the interactive effects that generate cumulative stress. This research therefore fills an important gap by exploring how communities simultaneously respond to dual pressures that alter both their ecological landscape and social dynamics.

This study currently faces cumulative pressures that threaten its long-term sustainability. On one side, intensive sand mining has become a major driver of environmental degradation, reducing the landscape's natural ability to respond to hydrological and climatological stress. On the other, climate change through sea level rise and recurrent *rob* has worsened the situation, pushing the system closer to critical thresholds (*tipping points*) for local social-ecological systems (Koomson et al., 2020). In light of this complexity, this study views community resilience not as a static form of

endurance but as a dynamic capacity to adapt and transform when confronted with layered and evolving disturbances.

Accordingly, this research aims to explore the social–ecological resilience of communities, by examining how local people perceive, experience, and respond to the cumulative impacts of sand mining and climate change. The study investigates both individual and collective adaptation strategies and analyzes the role of social capital and local institutions in mediating resilience outcomes. Through a qualitative case study approach, this research contributes to a more contextual understanding of how resilience is practiced, negotiated, and sustained in environments where human and natural systems are deeply intertwined.

Despite growing scholarship on watershed degradation and climate vulnerability, limited research has integrated socio-ecological resilience theory with collaborative governance mechanisms in coastal watershed systems experiencing cumulative impacts from extractive activities and climate change. Existing studies often examine environmental degradation or climate adaptation separately, without analyzing how governance structures shape adaptive and transformative resilience at the community level. This study addresses the existing research gap by examining as a socio-ecological system simultaneously affected by sand mining activities and climate-induced hazards. The study focuses on understanding how cumulative environmental pressures resulting from sand mining and climate change influence socio-ecological resilience within the watershed area. In addition, the research explores the governance and institutional challenges that affect community adaptive capacity in responding to environmental changes and socio-economic vulnerabilities. Furthermore, the study seeks to identify how collaborative governance approaches can strengthen resilience in coastal watershed systems, particularly in areas experiencing multiple and interconnected environmental pressures.

## 2. Methods

This research on the social–ecological resilience of communities, employs a qualitative approach using an instrumental case study design. A constructivist paradigm is adopted because the study aims to understand social realities as constructed by the community itself through their lived experiences, local knowledge, and interpretations of the cumulative impacts of sand mining and climate change. The case study approach is considered the most suitable because it allows for a comprehensive and contextual exploration of resilience phenomena within the specific spatial and environmental conditions. Thus, the goal of this research is not generalization, but a deep and meaningful understanding of the unique social–ecological dynamics in the area.

Operationally, data were collected through multiple qualitative techniques, including in-depth interviews, focus group discussions (FGDs), participant observation, and document analysis. This combination enabled comprehensive exploration of community experiences, governance dynamics, and environmental conditions.

To ensure the credibility of findings, several data validation techniques were applied, including source and method triangulation, as well as *member checking* a process of verifying data interpretation with respondents to ensure meaning accuracy. The researcher's extended presence in the field also played a crucial role in building trust with the community and gaining a deeper contextual understanding of local socio–ecological dynamics. Through this systematic and reflective approach, the study aims not only to portray the factual realities of the field but also to offer policy recommendations that are contextually grounded to strengthen community resilience.

This study employs a qualitative approach because it effectively answers “how” and “why” questions about phenomena in their natural context, rather than merely explaining “how much” or “how often” such phenomena occur (Flick, 2022). This approach provides researchers with the flexibility to gain rich, in-depth, and holistic understandings of participants' perspectives. Moreover, qualitative research enables the exploration of meanings individuals attach to their lived experiences a subjective reality that cannot be

fully captured through quantitative methods (Saldana, 2021). Through this approach, the researcher seeks to understand phenomena in a comprehensive, contextual, and experience-based manner that reflects the realities of local communities.

### 2.1 Data collection techniques

Data collection was carried out through semi-structured interviews, focus group discussions (FGDs), participant observation, and document analysis. Semi-structured interviews allowed flexibility in exploring participants' experiences while maintaining consistency across key themes such as adaptation strategies, governance challenges, and livelihood changes. A total of 15 participants were selected using purposive sampling to ensure diverse representation of gender, occupation, and social role—including farmers, sand miners, traders, and local leaders. FGDs were used to deepen collective perspectives, generate discussion on shared challenges, and identify community-driven solutions related to watershed management.

Table 1. Participant characteristics (N=15)

Category	Number
Occupation	
Farmers	4
Sand miners	3
Traders / small business actors	2
Local leaders (village heads / community leaders)	3
Local government officials	2
Environmental activist / NGO representative	1
Gender	
Male	9
Female	6
Age	
25 – 40 yearse	5
41 – 60 years	8
Above 60 years	2

As presented in Table 1, participants represent a diverse cross-section of watershed stakeholders, ensuring representation of livelihood groups, governance actors, and gender perspectives relevant to socio-ecological resilience dynamics. Participant observation was conducted to document local practices of adaptation and cooperation, such as riverbank rehabilitation, water management initiatives, and livelihood diversification activities. Field notes were used to capture contextual details, behavioral patterns, and environmental conditions that could not be fully expressed through interviews. Document analysis complemented these techniques by examining local regulations, environmental reports, and policy documents related to watershed governance and climate adaptation.

Participants were selected based on several criteria, including direct exposure to the impacts of sand mining or climate-related hazards, involvement in livelihood activities that depend on watershed resources, and participation in local governance or community decision-making processes. These criteria were used to ensure that the selected participants possessed relevant experiences and insights regarding the socio-environmental dynamics and governance conditions within the watershed area. The selection aimed to capture diverse perspectives across socio-economic roles and gender. Data collection was conducted between October and November 2025 across three villages within in the Demak Regency area. Recruitment continued until data saturation was reached, indicated by repetition of themes and no emergence of new substantive insights.

## 2.2 Data analysis and validation

All qualitative data were analyzed using thematic analysis, following the steps of data familiarization, coding, theme development, and interpretation. The analysis focused on identifying key patterns related to community vulnerability, adaptation mechanisms, and institutional capacity. The coding process was conducted manually using Microsoft Word and Excel to categorize interview and FGD transcripts into emerging themes such as environmental impacts, livelihood adaptation, social cooperation, and governance challenges. This manual approach allowed for a more direct engagement with the data while maintaining analytical rigor and transparency.

The coding process followed three stages: open coding to identify initial concepts, axial coding to establish relationships between categories, and selective coding to integrate themes into broader resilience dimensions. Codes were iteratively refined through constant comparison techniques to ensure conceptual consistency. To strengthen analytical transparency, a coding matrix was developed to map empirical findings against key theoretical constructs such as adaptive capacity, governance coordination, and institutional resilience. This approach allowed both inductive emergence of themes and deductive alignment with socio-ecological resilience theory.

To ensure the credibility and dependability of findings, several validation strategies were employed. These included triangulation of sources and methods, member checking, and prolonged engagement in the field. Triangulation helped cross-verify information from interviews, FGDs, and observations, while member checking involved sharing preliminary interpretations with participants to confirm the accuracy of meaning. Prolonged engagement enhanced trust between the researcher and community members, facilitating more authentic data collection. Additionally, reflexive journaling was used to document the researcher's positionality and minimize bias during interpretation. An audit trail documenting coding decisions, theme development, and analytical memos was maintained throughout the research process to enhance dependability and confirmability.

## 2.3 Ethical considerations and methodological rationale

Ethical approval was obtained from the Institutional Review Board of the Universitas Indonesia (protocol code UI-ENV-2025-10, approved on 27 October 2025). All participants were informed about the study's purpose, procedures, and voluntary nature before giving consent. Identities were anonymized to protect confidentiality, and participation was entirely voluntary. This methodological design is consistent with current trends in resilience research, which emphasize multi-dimensional inquiry and participatory engagement (Nguyen & Tran, 2023; Westley et al., 2011). A qualitative approach provides the flexibility to trace how resilience manifests across scales—from individual coping behavior to collective institutional learning—while remaining sensitive to local context and culture. In line with Lefebvre et al. (2022), this approach also allows the integration of local knowledge with formal governance analysis, generating findings that are not only descriptive but also actionable for community-based watershed management. By combining methodological depth with contextual sensitivity, this study aims to contribute to a more grounded understanding of socio-ecological resilience in the face of cumulative environmental stressors.

## 2.4 Analytical framework

The socio-ecological resilience framework served as an analytical lens guiding data coding and interpretation. Socio-ecological resilience refers to the capacity of interconnected social and ecological systems to absorb disturbances while maintaining essential functions, structures, and feedbacks. According to resilience theory, systems may respond to disturbances through coping, adaptation, or transformation. Adaptive capacity reflects the ability of actors to adjust responses to environmental change, while

transformative resilience involves structural shifts in governance, institutions, or livelihood systems when existing conditions become untenable. The Socio-Ecological Systems (SES) framework conceptualizes resilience as emerging from interactions among resource systems, resource units, governance systems, and actors. In watershed contexts, resilience is shaped not only by environmental conditions but also by institutional arrangements, power relations, and cross-scale governance coordination. This study adopts a socio-ecological resilience perspective to analyze how environmental degradation and climate change interact with governance capacity in shaping community resilience outcomes.

### 3. Results and Discussion

#### 3.1 Overview of community conditions and key findings

A quantitative overview helps clarify the scale of socio-ecological pressures experienced by downstream communities. The BR extends approximately 35.6 km, flowing from the upper catchment in Semarang toward the low-lying coastal zone of Demak, which is increasingly affected by mining activity and tidal flooding. The watershed spans around 92.82 km<sup>2</sup>, with a high density of settlements in the downstream areas—conditions that typically elevate socio-ecological vulnerability in coastal and peri-urban watersheds (Nguyen & Tran, 2023; Lefebvre et al., 2022). According to regional population statistics (BPS, 2024), the downstream BR area supports an estimated 27,500 inhabitants across 7,300 households, with an average density of 1,350 people per km<sup>2</sup>. The livelihood structure is dominated by farming (32%), sand-mining labor (26%), small-scale trading (21%), and informal work (16%), reflecting dependence on environmentally sensitive economic sectors (Cinner et al., 2018; Béné et al., 2022). Socio-economic indicators further highlight structural vulnerability, with average household incomes ranging from IDR 1.8–2.3 million per month and poverty levels at 14–18%, consistent with broader findings from climate-stressed regions highlighted in global climate adaptation assessments (IPCC, 2022). Environmental measurements show substantial degradation of the river system, including riverbank retreat of 0.5–1.2 meters per year, sediment-driven riverbed decline of 0.3–0.8 meters, and seawater intrusion reaching 1.5–2.1 km inland—patterns typical of river basins facing cumulative anthropogenic pressures (Xiang et al., 2023; Rocha et al., 2018). Meanwhile, 72% of households depend on shallow wells with high salinity levels (TDS 1,200–2,500 mg/L), and 65% experience recurrent tidal flooding, conditions that indicate the watershed is approaching key socio-ecological thresholds (Folke et al., 2021; Folke et al., 2010).

Communities in this study face complex socio-ecological challenges driven by the dual pressures of sand mining and climate change. These pressures have disrupted the biophysical integrity of the watershed while simultaneously reshaping local social and economic structures. Respondents' narratives consistently highlight the cumulative nature of these impacts, demonstrating that ecological degradation directly translates into livelihood insecurity and social tension.

Thematic analysis of interviews and focus group discussions reveals five key dimensions of impact: environmental, economic, social, health, and education. Environmental degradation—manifested in riverbank erosion, sedimentation, and saline intrusion—has become the most visible symptom of stress, while the economic and social effects are more deeply embedded in daily life. Local farmers reported significant yield reductions due to salinized soil and irregular irrigation, forcing many to seek alternative livelihoods in sand mining or petty trade. This shift has created a paradox where communities depend economically on activities that simultaneously undermine their ecological base.

### 3.1.1 Characteristics of respondents

This study involved 15 respondents representing diverse social and economic backgrounds. Among them were five farmers, four sand-mining laborers, three small-scale traders, two housewives, and one village official. Most respondents were between 30 and 55 years old and had lived in the area for more than a decade. This long period of residence provided them with firsthand and profound experience of the social and ecological transformations resulting from sand mining and the impacts of climate change.

### 3.1.2 Key findings and pseudo quotes

Thematic analysis revealed that communities have developed various adaptive strategies to cope with cumulative pressures arising from sand mining activities and climate change. The following representative excerpts from in-depth interviews illustrate these dynamics:

*“The river water used to be clear, but now it turns muddy quickly when it rains. We still farm, but the yields have dropped.”* (Mr. S, 46, farmer)

*“We work in sand mining because there are no other job opportunities. But now the river is getting deeper, and the banks are collapsing.”* (Mr. R, 38, sand-mining worker)

*“During the rob season, we have to move our goods to higher ground. Sales often drop during that time.”* (Mrs. T, 42, small trader)

*“The well water tastes salty now, so we buy bottled water every week. My kids often cough because of the dust from the mine.”* (Mrs. L, 35, housewife)

*“We’ve held community meetings to regulate the sand mining, but most of the mining permits come from outside the village.”* (Mr. A, 50, village official)

These statements indicate that the impacts of sand mining are multidimensional encompassing economic, social, environmental, and health aspects. Nonetheless, the community demonstrates adaptive capacity through livelihood diversification, mutual cooperation (*gotong royong*), and local initiatives such as drainage improvement and riverbank reforestation. Overall, the findings confirm that sand-mining activities not only degrade the physical environment but also reshape the community’s social and economic structures. However, amid these challenges, local forms of resilience have emerged, reflecting the people’s ability to adapt, persist, and seek new balances amid growing ecological and economic pressures.

Table 2. Aspects, impacts, and resilience mechanisms

Aspect	Impact	Resilience Mechanism
Economic	Decline in income from fisheries and agriculture	Livelihood diversification, engagement in small-scale enterprises
Social	Rising community tensions and conflicts	Regular community meetings, strengthening of local cooperation networks
Environmental	Riverbank erosion and land degradation	Land rehabilitation, riparian reforestation, and community-based water conservation
Health	Increased incidence of diseases due to dust and water pollution	Public health campaigns, improved access to clean water and sanitation
Education	Disrupted school access caused by flooding and mining activities	Provision of alternative transport, local scholarship programs, and environmental awareness education

This table illustrates the multidimensional nature of impacts experienced by communities. While environmental and economic pressures are the most visible, social cohesion and local innovation serve as key adaptive responses that help sustain community resilience. The table below illustrates the distribution of sand-mining production, showing the allocation of extracted materials between local and external markets. The data indicate that the majority of coarse sand and gravel are distributed locally, while fine sand tends to be more evenly divided between local and external demands.

Table 3. Types, volume, and distribution of extracted materials

Type of Material	Volume (m <sup>3</sup> /month)	Distribution
Coarse Sand	500	Local Market 60%, External Market 40%
Fine Sand	300	Local Market 50%, External Market 50%
Gravel	200	Local Market 70%, External Market 30%
Total	1,000	—

## 3.2 Findings

### 3.2.1 Cumulative impacts on the physical environment and water resources

The research findings show that sand-mining activities and climate change have generated significant cumulative effects on the physical environment. Intensive mining has led to riverbed degradation, marked by bank erosion and sedimentation. These conditions are further aggravated by more frequent and severe *rob* flooding affecting the coastal zone. Topographical changes caused by mining pits have worsened flooding, as seawater now reaches further inland and stagnates longer. Moreover, the destruction of riparian vegetation accelerates seawater intrusion into shallow aquifers. The combined effects of these factors have lowered the quality of both surface and groundwater, with many community wells now contaminated by saline water.

### 3.2.2 Impacts on agricultural systems and livelihoods

In the agricultural sector, local farmers face serious threats to land productivity. Rice farmers have experienced recurring yield reductions due to saltwater intrusion, soil salinization, and disruptions in irrigation systems. Meanwhile, for dryland farmers, unpredictable rainfall and frequent flooding have disrupted planting schedules, making it difficult to grow secondary and horticultural crops. These ecological impacts directly affect community livelihoods. Many farmers and farm laborers have shifted to casual or non-agricultural jobs. However, this occupational shift does not necessarily improve household welfare; in fact, many families experience reduced income and heightened economic uncertainty due to the temporary and precarious nature of these new jobs.

### 3.2.3 Layered community adaptation strategies

Communities respond to environmental and economic pressures through multilayered adaptive strategies. At the individual level, actions include purchasing clean water, elevating house floors, and constructing simple drainage systems to reduce flood impacts. At the household level, livelihood diversification is key: family members combine income sources such as farming, small trading, and daily labor to maintain financial stability under uncertainty. At the community level, collective initiatives emerge through *gotong royong* (mutual cooperation), including repairing drainage channels and forming farmer groups to address irrigation and production challenges. These strategies demonstrate the adaptive capacity communities to adjust to environmental and social change, despite limited resources.

### 3.2.4 The role of social capital and local institutions

The study underscores the critical role of social capital and local institutions in strengthening resilience against environmental and economic pressures. Practices of solidarity, kinship networks, and mutual aid function as vital mechanisms for distributing support, sharing information, and reinforcing collective coping during crises. Meanwhile, community-based institutions such as water user associations (*P3A*) and farmer group federations (*Gapoktan*) serve as coordination and learning spaces to collectively address declining irrigation quality and availability. Through these forums, communities not only maintain agricultural productivity but also enhance participatory water governance.

However, findings also reveal that the capacity of local institutions remains limited in advocating for community interests against large-scale sand-mining actors with greater economic and political power. This power imbalance constrains the community's negotiation capacity in determining natural resource management outcomes.

### 3.2.5 Governance and policy gaps

The study identifies significant governance gaps in environmental management across the Babon Watershed. Sand-mining regulations are inconsistently enforced, and climate adaptation policies are poorly integrated with watershed management and farmland protection. Fragmented authority among government agencies at national, provincial, and district levels has resulted in sectoral, overlapping, and uncoordinated approaches to addressing cumulative impacts between environmental degradation, declining land productivity, and community vulnerability.

Moreover, community participation in decision-making and planning processes remains minimal. Consequently, many implemented programs fail to reflect the real needs, priorities, and local knowledge of affected residents, particularly farmers. These structural governance gaps weaken collective efforts to build long-term social-ecological resilience. Strengthening cross-sectoral coordination and ensuring meaningful community participation are therefore essential for sustainable watershed management in the future.

This aligns with recent studies emphasizing that effective resilience governance must be adaptive, polycentric, and capable of cross-scale learning to address interconnected environmental pressures (Folke et al., 2021; Béné et al., 2022). Strengthening institutional linkages between local, regional, and national levels is therefore not only administrative but also foundational for achieving transformative socio-ecological resilience in the Babon Watershed. Recent studies highlight that strengthening local governance through co-management and participatory policy frameworks significantly enhances resilience outcomes in coastal watersheds (Ostrom, 2010; IPCC, 2022). These approaches foster transparency, accountability, and collective learning—key components for achieving transformative adaptation.

## 3.3 Analysis

### 3.3.1 Systemic vulnerability and cumulative impacts

The results indicate that community vulnerability in the Babon Watershed is systemic and interconnected. The observed impacts are not merely additive but arise from feedback interactions among weak governance, economic dependence on extractive industries, and external shocks such as climate change. Sand mining functions as a *threat multiplier*, amplifying the consequences of climate change (Rocha et al., 2020). By degrading ecological structures, mining erodes the natural capital that forms the foundation of community resilience. As Xiang et al. (2023) suggest, understanding such dual pressures requires a systemic approach, as even minor disturbances can destabilize social-ecological systems.

### 3.3.2 Hierarchy and effectiveness of resilience strategies

Community adaptation strategies reveal a hierarchy of capacities from coping to adaptive to transformative. Most strategies remain within coping and adaptive levels, indicating that much community energy is devoted to short-term survival rather than building long-term resilience. This situation risks leading to maladaptive outcomes, where short-term solutions inadvertently increase future vulnerability and reduce long-term adaptive capacity (Ribot, 2011). In line with Sharifi (2020), this reflects trade-offs between immediate relief and transformative change. Without external support to enhance adaptive capacity, communities will struggle to move from endurance toward sustainable transformation.

In this sense, Babon's communities represent an early stage of transformation, where adaptive learning and incremental innovations could evolve into broader system changes if adequately supported by governance and policy frameworks (Cinner et al., 2018; Walker et al., 2004). This trajectory illustrates how localized adaptation can gradually shift toward systemic transformation consistent with emerging resilience transitions in coastal social-ecological systems.

### 3.3.3 Institutional and political disconnections

Governance gaps also reveal a deep disconnection between formal top-down policies and local socio-ecological realities. Sectoral and technocratic policy approaches often fail to capture the complexity and interdependence of issues within the Babon Watershed. Similar findings in Indonesian coastal regions also show weak coordination among agencies managing environmental risks and adaptation programs (Marfai et al., 2015). This condition creates *institutional voids* (Karpouzoglou et al., 2020), which are often exploited by actors with short-term economic interests exacerbating environmental degradation and social inequality. Meanwhile, local institutions with contextual knowledge often lack access to political and financial resources, limiting their potential contribution to environmental governance.

### 3.3.4 Potential for transformation through social learning

Community-led rehabilitation efforts along the Babon River illustrate social learning processes that are central to transformative resilience. These collective actions not only restore ecological functions such as riverbank vegetation planting and local waste management but also reinforce social cohesion and maintain socio-ecological memory (Barthel et al., 2010). Studies on adaptive co-management also show that locally driven initiatives form the foundation for sustainable transformation (Armitage et al., 2007). Hence, the key entry point for policy intervention lies in strengthening social learning through *co-production of knowledge* (Norström et al., 2020) combining local wisdom with scientific knowledge to develop contextually appropriate and sustainable solutions.

These findings reinforce that sustainability transformation relies on continuous co-production between local and scientific knowledge systems (Fazey et al., 2018; Folke et al., 2021). Strengthening participatory research, inclusive learning spaces, and multi-actor dialogues can thus accelerate the emergence of transformative resilience in the Babon Watershed.

### 3.3.5 Pathways toward transformative resilience

Overall analysis indicates that building resilience in the Babon Watershed requires a paradigm shift from reactive disaster responses to proactive, adaptive, and sustainable system-building. Transformative efforts must address the root causes of cumulative vulnerability, such as weak governance and economic dependence on unsustainable extraction. Lessons from the Citarum River (Pribadi et al., 2021) highlight that collaborative

governance involving all stakeholders from local communities to regional authorities is essential for achieving just, inclusive, and ecologically grounded solutions. Only through integrated and transformative approaches can the Babon social–ecological system be strengthened to withstand future uncertainties.

### 3.3.6 Impact and resilience analysis

Based on the field data analysis, community perception scores were obtained to assess the levels of impact and socio–ecological resilience across five main aspects. The results of this assessment are visualized in Table 4, which illustrates variations in both impact intensity and resilience capacity among different dimensions. The figure below illustrates the comparative scores of perceived impact and socio–ecological resilience across five major aspects identified in the Babon Watershed. The environmental aspect recorded the highest impact level, while social and economic aspects displayed relatively higher resilience scores due to strong community cooperation and adaptive strategies.

Table 4. Levels of impact and resilience across five key aspects

Aspect	Impact Score (1–10)	Resilience Score (1–10)	Remarks
Environmental	9	6	Severe degradation of riverbanks and water intrusion; limited restoration capacity
Economic	8	8	Livelihood diversification observed; dependence on sand mining remains high
Social	8	8	Strong community solidarity and collective adaptation efforts
Health	7	6	Limited access to clean water; increasing respiratory and waterborne diseases
Education	6	5	Disrupted access to schools during floods; low awareness of environmental issues

Overall, the environmental aspect shows the highest impact level, with a score of 9, followed by the economic and social aspects, each scoring 8. Interestingly, the community's resilience appears strongest in the social and economic dimensions, indicating that social solidarity and collective cooperation serve as the primary foundations of local resilience. Meanwhile, the health and education aspects demonstrate relatively lower resilience scores, suggesting the need for stronger institutional support to improve access to basic services in the Babon Watershed area.

These findings highlight that while communities possess strong adaptive capacity in social and economic terms, ecological resilience remains vulnerable. Addressing these disparities requires integrative interventions that strengthen both environmental management and the provision of essential public services. The analysis also reinforces the idea that resilience is multi-dimensional, where social cohesion and institutional effectiveness are key to sustaining community adaptation in the face of cumulative environmental pressures.

### 3.4 Problem-solving scheme

The findings indicate that the social–ecological resilience of communities in the Babon Watershed remains adaptive rather than transformative. While local residents have demonstrated the ability to adjust to short-term environmental and economic changes, they have not yet achieved structural transformation such as sustainable livelihood diversification or robust participatory governance. Weak institutional coordination and unequal power relations in resource management remain major barriers to achieving long-term resilience. Therefore, strengthening multi-stakeholder collaboration, promoting a

circular economy based on local resources, and restoring watershed ecosystems are critical agendas for building a resilient and equitable socio-ecological system in the future.

Overall, the community demonstrates relatively strong social adaptive capacity. This is reflected in the spirit of *gotong royong* (mutual cooperation) that has intensified in response to flooding and environmental degradation. Some local working groups even take the initiative to maintain riverbanks by planting native vegetation such as bamboo and *kaliandra* to stabilize riverbanks. However, economic dependence on sand mining remains high, particularly among the productive-age population who lack alternative livelihood options. Field observations also reveal that public awareness of environmental management is still limited. Approximately 60% of residents do not fully understand the health and environmental consequences of their daily activities, although their ecological awareness has grown in general. Weak institutional support has caused most adaptation strategies to remain individual and short-term, rather than collective and sustainable.

Social shifts within the community are also evident. Some former sand miners have started to diversify their income by opening small businesses such as food stalls, material transport services, or seasonal farming. This transition reflects a gradual movement toward more sustainable livelihoods. However, in the absence of strong local policy support, such efforts are insufficient to counteract the accelerating ecological degradation. Ecologically, residents are increasingly aware of environmental decline such as shallower rivers, damaged riparian vegetation, and higher water turbidity. Some people have attempted to use degraded land along the river for seasonal agriculture, but without adequate soil management, this practice can worsen erosion. These findings highlight the importance of applying *adaptive management* principles in Babon Watershed governance.

Overall, the results suggest that the social-ecological resilience of the Babon community is at a moderate level. Based on the resilience framework proposed by Folke (2006) and Walker et al., (2023), a resilient social-ecological system is one that can adapt to change without losing its core functions. In the context of the Babon Watershed, while social and economic adaptability is evident, ecological resilience remains fragile. The main factors hindering greater resilience are weak institutional support and limited policy integration between environmental management and local community needs. Local governments tend to prioritize short-term economic growth, such as resource extraction, while rehabilitation and conservation efforts receive less attention.

Nevertheless, field interviews reveal considerable potential for transformation if communities receive sufficient institutional and policy support. Initiatives such as environmental management training, livelihood diversification programs, and the establishment of environmental awareness groups (*Pokdarling*) could significantly strengthen community-level socio-ecological resilience.

These findings align with Adger (2000), who emphasizes the importance of social capacity, institutional capital, and adaptive learning in building community resilience to environmental change, institutional capital, and adaptive learning in building community resilience to environmental change. Therefore, to strengthen the Babon Watershed's resilience, a collaborative model that integrates government, community, and private sector participation in sustainable resource management is essential.

Table 5.. Collaborative framework for transformative resilience

Pillar	Core Components / Strategies	Expected Outputs
Pillar 1: Integrated Governance	<ul style="list-style-type: none"> <li>Upstream-downstream multi-stakeholder forum</li> <li>Participatory legal and institutional reform</li> <li>Revision of sustainable mining regulations</li> </ul>	<ul style="list-style-type: none"> <li>Integrated and coherent policy framework</li> <li>Effective monitoring and enforcement</li> <li>Representation of community voices in decision-making</li> </ul>
Pillar 2: Sustainable Economy	<ul style="list-style-type: none"> <li>Livelihood diversification based on local resources</li> </ul>	<ul style="list-style-type: none"> <li>Strengthened local economy</li> <li>Reduced dependence on extractive industries</li> </ul>

	<ul style="list-style-type: none"> <li>• Promotion of circular economy practices</li> <li>• Development of community-based ecotourism</li> </ul>	<ul style="list-style-type: none"> <li>• Enhanced social equity and economic inclusion</li> </ul>
Pillar 3: Ecological Restoration and Adaptation	<ul style="list-style-type: none"> <li>• Riparian rehabilitation and reforestation</li> <li>• Incentives for climate-smart practices</li> <li>• Ecosystem-based adaptation and watershed restoration</li> </ul>	<ul style="list-style-type: none"> <li>• Restored ecosystem services</li> <li>• Improved clean water access</li> <li>• Increased climate resilience and social cohesion</li> </ul>

Building upon these findings, the proposed collaborative framework operationalizes the principles of adaptive governance and biosphere stewardship (Folke et al., 2021) by bridging community-based adaptive practices with institutional mechanisms required for long-term transformation. This connection ensures that the framework reflects both local realities and contemporary resilience theory. Table 5 presents a holistic and systemic model consisting of three interrelated pillars designed to strengthen the transformative socio-ecological resilience of the Babon Watershed. The framework emphasizes integration between governance, economy, and ecology through collaborative and inclusive approaches.

The proposed framework is guided by the principles of collaboration, inclusiveness, equity, knowledge-based decision-making, and the integration of local wisdom. These principles serve as the foundation for developing sustainable and participatory strategies in managing the Babon Watershed. The main vision of the framework is to achieve a resilient, productive, and socially just Babon Watershed capable of responding effectively to environmental, social, and economic challenges. Through the implementation of this framework, the expected joint outcomes include the restoration of ecosystem services, the reduction of climate-related impacts, improved access to clean water, and strengthened community cohesion, ultimately contributing to the development of a socio-ecological system that is resilient to both environmental and socio-economic shocks.

To achieve this vision, the framework proposes three interlinked pillars designed to address challenges holistically and systemically. The Integrated Governance pillar seeks to establish an enabling environment through consistent, transparent, and participatory policies that strengthen institutional coordination and stakeholder involvement. The Sustainable Economy pillar aims to reduce pressure on natural resources by encouraging livelihood diversification and promoting circular economic practices based on local potential and community capacity. Meanwhile, the Ecological Restoration and Adaptation pillar focuses on environmental recovery efforts while enhancing physical and ecological resilience to climate-related and human-induced disturbances. The synergy among these three pillars is expected to support the realization of a resilient, inclusive, and ecologically just Babon Watershed.

### 3.5 Limitations and future research recommendations

While this study provides valuable insights into the social-ecological resilience of communities in the Babon Watershed, several limitations should be acknowledged. First, the research relied primarily on qualitative data collected from a relatively small number of participants. Although this approach allowed for an in-depth understanding of local experiences, it may limit the generalizability of the findings to other contexts. Future studies could integrate mixed-methods approaches—combining qualitative depth with quantitative indicators of resilience—to provide a more comprehensive and comparative picture across multiple watersheds.

Second, the research was conducted within a specific temporal frame, capturing community conditions during a particular period of environmental and economic stress. Given the dynamic nature of climate impacts and socio-economic change, longitudinal

studies are needed to trace how resilience evolves over time. Continuous observation would help identify whether current adaptive strategies can transition toward more transformative and sustainable forms of resilience.

Third, while this study focused on community-level dynamics, broader institutional and policy dimensions were only examined through secondary data and participant perceptions. Future research could employ multi-level governance analysis to explore interactions between local initiatives, regional authorities, and national policy frameworks. Such an approach would illuminate how power relations, institutional coordination, and resource allocation shape resilience outcomes in practice.

Finally, future studies should expand the scope of inquiry to include gender perspectives and intergenerational dimensions of resilience. Women and youth often play distinct yet underrecognized roles in managing natural resources and sustaining community adaptation. Exploring their contributions can enrich understanding of resilience as a socially embedded process.

Despite these limitations, this study lays an important foundation for future research on socio-ecological resilience in Indonesia's coastal and watershed regions. By combining participatory methodologies with systemic and policy-oriented analysis, future investigations can help bridge the gap between local action and structural transformation—ensuring that resilience efforts are not only adaptive but also equitable and enduring.

### *3.6 Interpreting findings through a socio-ecological resilience lens*

The findings of this study indicate that resilience in the Babon Watershed operates primarily at the adaptive level rather than the transformative level. Communities have developed coping and adaptation strategies—such as livelihood diversification, informal cooperation networks, and localized environmental management practices—yet structural governance fragmentation limits deeper institutional transformation.

From a socio-ecological systems (SES) perspective, resilience emerges from interactions among resource systems, governance arrangements, and actors. In the Babon context, environmental degradation caused by sand mining interacts with climate-induced stressors to produce cumulative pressures on both ecological stability and social livelihoods. However, governance coordination across institutional levels remains weak, constraining the system's capacity for transformative change. This finding aligns with resilience theory, which distinguishes between coping, adaptation, and transformation. While adaptive capacity is evident at the community level, transformative resilience—defined as structural shifts in governance and institutional arrangements—has not yet fully materialized.

### *3.7 Governance fragmentation and institutional constraints*

The study further highlights that collaborative governance is a critical determinant of long-term resilience. Fragmented institutional responsibilities and limited cross-sector coordination reduce the effectiveness of climate adaptation initiatives. In line with collaborative governance theory, sustained resilience requires structured interaction among state actors, community groups, and private stakeholders. Without such coordination, local adaptation efforts risk remaining reactive rather than systemic.

### *3.8 Implications for sustainability transitions*

From a sustainability transitions perspective, the Babon Watershed illustrates a system in a pre-transition phase, where pressures accumulate but institutional innovation remains incremental. Transition theory suggests that transformative change often occurs when niche innovations, community initiatives, and governance reforms align. In this case, local adaptive practices represent potential niches; however, scaling these practices requires institutional support and policy integration.

This study contributes to socio-ecological resilience scholarship by empirically demonstrating how cumulative environmental stressors interact with governance fragmentation in coastal watershed systems. By integrating adaptive capacity analysis with collaborative governance dynamics, the research extends resilience theory beyond ecological stability toward institutional and political dimensions of sustainability.

#### 4. Conclusions

This study reveals that communities in the Babon Watershed exhibit a level of social-ecological resilience shaped by adaptive responses to environmental pressures, particularly those resulting from sand mining and climate change. Socially, the community has demonstrated the capacity to adjust lifestyles, strengthen social networks, and organize collective actions to cope with economic and environmental challenges. Ecologically, local initiatives such as riverbank conservation, reduction of illegal mining, and community-based water management illustrate emerging forms of adaptive environmental stewardship.

However, the research also shows that current resilience remains largely short-term and adaptive rather than transformative. Key barriers include limited access to economic resources, weak enforcement of environmental regulations, and inadequate policy support from local government. Consequently, the sustainability of the Babon Watershed continues to depend on the balance between community initiatives and institutional reinforcement. Without stronger governance and policy frameworks, adaptive capacity may stagnate, hindering the transition toward long-term, just, and sustainable resilience. Future-oriented governance must therefore emphasize inclusive decision-making, digital monitoring, and climate-smart planning to strengthen institutional adaptability (UNDRR, 2022; Nugroho et al., 2025).

Ultimately, the study contributes to an updated and coherent understanding of socio-ecological resilience by aligning empirical evidence from the Babon Watershed with recent theoretical developments in adaptive and transformative resilience (Béné et al., 2022; Walker et al., 2004; Cinner et al., 2023). This alignment ensures that the proposed recommendations are both contextually grounded and theoretically robust, reinforcing clarity, coherence, and relevance to current sustainability discourse.

Strengthen environmental governance with a sustainability-oriented approach. This includes stricter enforcement against illegal mining, rehabilitation of degraded land, and the formulation of climate adaptation and mitigation plans based on watershed-level management. Cross-sectoral and collaborative approaches are essential to ensure effectiveness and long-term impact. Continue enhancing collective awareness and developing local innovations in natural resource management. Initiatives such as environmentally friendly farming, riparian vegetation conservation, and community-based water management can simultaneously strengthen social resilience and ecological balance at the local scale. Future studies should further explore transformative resilience mechanisms, particularly in relation to long-term adaptation to climate change and economic pressures. Multidisciplinary and participatory research can provide robust scientific foundations for context-specific and inclusive policy recommendations. NGOs can play a facilitative role in strengthening community social and institutional capacities. Through training, mentoring, and eco-based livelihood programs, NGOs can help bridge the gap between local initiatives and structural support from government and the private sector.

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### Author Contribution

Conceptualization, A.B.P.; Methodology, A.B.P.; Formal Analysis, A.B.P.; Investigation, A.B.P.; Resources, A.B.P.; Data Curation, A.B.P.; Writing – Original Draft Preparation, A.B.P.; Writing – Review & Editing, A.B.P.; Visualization, A.B.P.; Supervision, A.B.P.; Project Administration, A.B.P. The author has read and agreed to the published version of the manuscript.

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The study was conducted in accordance with Indonesian research ethics regulations and approved by the Institutional Review Board of Universitas Indonesia (protocol code UI-ENV-2025-10 and date of approval: 27 October 2025).

### Informed Consent Statement

Not available.

### Data Availability Statement

The data supporting the findings of this study are available from the author upon reasonable request. Some data may not be publicly available due to privacy and ethical restrictions.

### Conflicts of Interest

The authors declares no conflict of interest.

### Declaration of Generative AI Use

During the preparation of this work, the author used ChatGPT (OpenAI, GPT-5, 2025) to assist in refining grammar, clarity, and academic tone. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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