Review Article

Integrating Ecosystem Restoration, Climate Adaptation, and Governance Reform for Flash Flood Mitigation: Lessons from the 2025 Sumatra Disaster and Evidence-Based Policy Framework

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Abstract

The catastrophic flash floods and landslides that struck Aceh, North Sumatra, and West Sumatra in late November 2025 represent one of the most devastating hydrometeorological disasters in recent Indonesian history, claiming over 836 lives and displacing more than 151,000 families. This qualitative literature review synthesizes lessons learned from this disaster through analysis of peer-reviewed literature, government reports, and disaster documentation. The study identifies four critical contributing factors:

a) Decades of upstream watershed deforestation resulting in loss of natural flood regulation capacity.
b) Climate change-intensified extreme rainfall associated with Tropical Cyclone Senyar.
c) Governance failures, including weak policy enforcement and coordination gaps.
d) Inadequate early warning system dissemination and community preparedness.

Findings reveal that the disaster magnitude resulted from the convergence of environmental degradation, meteorological extremes, and institutional deficits rather than any single factor. The study proposes comprehensive policy recommendations organized across immediate (0-2 years), medium-term (2-5 years), and long-term (5-10 years) horizons, emphasizing ecosystem-based disaster risk reduction, nature-based solutions, strengthening multi-stakeholder governance, mainstreaming climate change adaptation, and building community resilience. This research contributes to disaster risk reduction scholarship by demonstrating the critical importance of integrating environmental conservation with disaster management. It provides evidence-based guidance for policymakers addressing Indonesia's escalating flood vulnerability under climate change.

JEL Classification Codes : Q54, Q57, H84, O13, Q58

Introduction

Background of November 2025 Flash Flood Events

Between November 24-30, 2025, catastrophic flash floods and landslides struck three provinces in Sumatra-Aceh, North Sumatra, and West Sumatra-leaving an unprecedented trail of destruction across Indonesia's western region. The disaster claimed over 836 fatalities, with 509 persons still missing and approximately 2,700 injured across the affected provinces. An estimated 151,000 families were displaced from their homes, with more than 62,000 families seeking emergency shelter in 514 evacuation centers established across the region. The scale of human suffering was compounded by extensive infrastructure damage, including the complete paralysis of the critical Tarutung-Sibolga Road, which was buried by landslides, the destruction of power transmission towers, thecollapse of bridges, and the disruption of water supply and communication networks [1-3].

The immediate meteorological trigger was Tropical Cyclone Senyar, which formed in the Strait of Malacca in late November 2025—a rare event in the equatorial region. The cyclone brought extraordinary rainfall, with daily precipitation exceeding 300 millimeters in parts of North Sumatra and cumulative rainfall exceeding 770 millimeters in West Sumatra within one week. However, extreme rainfall alone cannot explain the catastrophic scale of destruction. As emphasized by hydrological experts at Universitas Gadjah Mada, the disaster's magnitude was profoundly exacerbated by decades of extensive deforestation and watershed degradation in the upper catchment areas. This convergence of climate extremes and environmental degradation transformed what might have been a manageable rainfall event into a catastrophic humanitarian and ecological crisis [4].

Historical Context and Pattern Recognition

The November 2025 disaster did not occur in isolation but represents an intensifying pattern of hydrometeorological disasters across Sumatra. Previous major flood events include the May 2024 West Sumatra floods, which claimed 67 lives; the March 2024 Sumatra flash floods, which resulted in 26 fatalities; and recurring seasonal flooding that has become increasingly severe over the past two decades. This escalating trend correlates with dramatic forest cover loss across all three affected provinces. Aceh lost more than 700,000 hectares of forest between 1990 and 2020, reducing forest coverage to approximately 59% of the province. North Sumatra's condition is even more precarious: by 2020, forest cover accounted for only 29% of the land area, and the remaining forests were highly fragmented across the Bukit Barisan mountains. West Sumatra experienced deforestation of approximately 320,000 hectares of primary forest and 740,000 hectares of total tree cover between 2001 and 2024, representing one of Indonesia's highest deforestation rates [5-9].

The systematic destruction of forest ecosystems in upstream watersheds has fundamentally altered the hydrological cycle, diminished natural water retention capacity and accelerated surface runoff. When intact, tropical forest canopies can intercept 15-35% of rainfall, while forest soils facilitate deep infiltration and gradual water release. The conversion of these protective forests to oil palm plantations, mining operations, and agricultural land has created a "ticking time bomb" in which heavy rainfall triggers immediate, destructive flooding rather than being absorbed and released gradually [10,11].

Urgency of the Study

The urgency of synthesizing lessons from this disaster stems from multiple converging factors. First, climate change is demonstrably intensifying tropical cyclones and extreme rainfall events in Southeast Asia. Research published in Nature Climate and Atmospheric Science analyzing over 64,000 modeled tropical storms from the 19th through 21st centuries reveals that climate change is causing tropical cyclones in Southeast Asia to form closer to coastlines, intensify more rapidly, and linger longer over land. The World Weather Attribution study confirmed that warmer Indian Ocean waters (+0.2°C above seasonal averages) provided enhanced energy for Cyclone Senyar, and that without human-driven climate change, ocean temperatures would have been approximately 1°C cooler. Climate modeling projects that annual flood losses, currently at USD 388 billion globally, will reach USD 407-439 billion by 2050, with flood risk in Indonesian urban areas potentially increasing by 322-402% by mid-century [12].

Second, governance and institutional deficits severely undermine disaster risk reduction efforts despite Indonesia's relatively comprehensive legal framework established through Law No. 24/2007 on Disaster Management. Weak law enforcement, poor coordination between national and regional governments, and inadequate budget allocation to prevention rather than emergency response create persistent vulnerabilities. Third, the socio-economic impacts extend far beyond immediate casualties and infrastructure damage. Economic losses from the November 2025 floods exceeded $20 billion across the three provinces, with long-term development setbacks including food security crises in isolated areas, disruption of education affecting over 15,500 children, and destruction of 113 hectares of agricultural land [13].

Research Objectives

This qualitative literature review pursues three interrelated objectives. First, to synthesize lessons learned from the November 2025 flash floods through systematic analysis of academic literature, government reports, and disaster documentation, identifying critical factors contributing to disaster magnitude from environmental, governance, and socio-economic perspectives. Second, to evaluate the effectiveness of existing disaster risk mitigation frameworks in Indonesia, including implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030, Indonesia's national disaster management legal architecture, and emerging approaches such as nature-based solutions and community-based disaster preparedness. Third, to develop evidence-based policy recommendations for comprehensive flash flood risk mitigation, organized across immediate, medium-term, and long-term time horizons, that address the systemic nature of flood vulnerability through integrated interventions spanning ecosystem restoration, infrastructure development, governance reform, early warning system enhancement, and community resilience building.

Literature Review

Disaster Risk Reduction (DRR) has evolved from reactive emergency response paradigms to proactive risk management approaches that address underlying vulnerability factors. The Sendai Framework for Disaster Risk Reduction 2015-2030, adopted by United Nations member states, provides the contemporary global blueprint for DRR with four priority areas:

a) Understanding disaster risk through comprehensive assessment,

b) Strengthening disaster risk governance at all levels,

c) Investing in disaster risk reduction for resilience.

Enhancing disaster preparedness for effective response and "Build Back Better" in recovery. The framework explicitly recognizes that disaster risk results from complex interactions between hazard exposure, vulnerability conditions, and inadequate capacity to manage risk [14].

Flash floods represent particularly challenging hazards due to their rapid onset, typically developing within six hours of causative rainfall, and their localized but intense impacts. Formation mechanisms involve the convergence of extreme precipitation, steep topography, land use patterns, and watershed hydrological conditions. The vulnerability and resilience framework conceptualizes disaster risk as a function of exposure (the presence of people and assets in hazard-prone areas), sensitivity (the degree to which systems are affected by hazards), and adaptive capacity (the ability to adjust to potential damage or cope with its consequences). Community resilience-defined as the sustained ability of communities to withstand and recover from adversity-represents the desired outcome of DRR investments, encompassing physical, social, economic, and institutional dimensions [15].

Environmental and Ecological Dimensions of Flood Risk

Forest ecosystems provide irreplaceable flood regulation services through multiple mechanisms: rainfall interception by canopy vegetation, enhanced soil infiltration capacity, evapotranspiration that returns moisture to the atmosphere, and erosion control that prevents sedimentation. Research on ecosystem services for flood regulation demonstrates that intact forest cover in upper watersheds substantially reduces peak flow rates and flood frequency downstream. A comprehensive study evaluating flood-regulation ecosystem services under the influence of climate and vegetation found that vegetation restoration through programs such as China's Grain for Green Program increased flood-regulation capacity by 8.6%. Conversely, deforestation systematically degrades these protective functions, with documented impacts including reduced water retention capacity, accelerated surface runoff, soil erosion, and disruption of groundwater recharge patterns [16].

The Sumatra case exemplifies these dynamics on a catastrophic scale. The Batang Toru ecosystem in North Sumatra, which should serve as a vital water catchment area, has lost 1,550 hectares of forest cover since 2010, leaving bare soil highly vulnerable to erosion. Forest conversion to oil palm plantations and mining operations has been particularly destructive, with mangrove and forest conversion to plantations most notable in Sumatra compared to other Indonesian regions. A study of spatial and temporal deforestation patterns in Indonesian watersheds found significant correlations between deforestation and increased flood event frequency. Land-use change impacts extend beyond forests to include urbanization effects on impervious surfaces, reduced drainage capacity, and fragmentation of natural floodplains and wetlands that historically provided water storage capacity [17].

Climate Change and Tropical Cyclone Intensification

Climate change is fundamentally altering tropical cyclone behavior in Southeast Asia with profound implications for flood risk. Comprehensive modeling published in npj Climate and Atmospheric Science analyzing tropical cyclone trajectories from the 19th through 21st centuries identified critical changes including:

a) Poleward shifts in cyclone genesis and peak intensification.

b) Formation and fastest intensification occurring closer to coastlines.

c) Increased likelihood of cyclones moving slowly over mainland Southeast Asia.

d) Longer persistence of cyclone tracks over land. In cities such as Hai Phong, Yangon, and Bangkok, these variations are expected to lead to future increases in both peak cyclone intensity and duration relative to historical patterns [12].

The physical mechanism driving these changes involves warmer ocean temperatures providing enhanced heat and moisture energy for storm development. Studies show that, as climate change warms the oceans, tropical cyclones that cross them pull in more water vapor and heat, resulting in stronger winds, heavier rainfall, and more severe flooding when storms make landfall. Attribution analysis of climate change impacts on recent Asian floods confirmed that climate change amplified storm intensity, with projected future impacts including 8% more intense landfalling tropical cyclones, 2.8% faster translation speeds, and altered size distributions by the end of the 21st century. Critically, research emphasizes that climate extremes alone are insufficient to explain the magnitude of disasters; rather, the interaction between extreme rainfall and degraded watersheds creates compounding effects that exponentially increase flood impacts [18].

Governance and Institutional Framework

Indonesia's disaster management legal framework centers on Law No. 24/2007 on Disaster Management, which established the National Agency for Disaster Management (BNPB) and mandated the creation of Regional Disaster Management Agencies (BPBD) at provincial and district levels. The law represents a paradigm shift from reactive responses to comprehensive risk management, encompassing prevention, mitigation, preparedness, emergency response, and recovery. However, implementation reveals substantial gaps between legal provisions and operational reality. Research on disaster risk reduction and management institutional frameworks in Indonesia identifies critical weaknesses, including: insufficient budget allocation for DRR relative to emergency response, limited technical capacity at regional levels, weak coordination mechanisms between national and sub-national authorities, and emphasis on post-disaster activities over prevention and mitigation [19].

Multi-stakeholder collaboration has emerged as essential for effective disaster risk reduction, requiring coordinated engagement among government agencies, non-governmental organizations, private sector entities, and affected communities. A systematic review of collaborative governance mechanisms in disaster risk reduction found that multi-stakeholder participation enhances disaster response by integrating resources, fostering the synthesis of diverse knowledge, and improving the legitimacy of interventions. Key characteristics of effective collaborative governance include shared decision-making processes, transparent communication, formal coordination mechanisms, and clearly delineated roles and responsibilities. However, persistent barriers include organizational silos, communication gaps, overlapping mandates among government agencies, and limited logistical resources [20].

Spatial planning integration is another critical governance dimension that is often inadequately addressed. Research on land-use planning for flood risk management demonstrates that disaster vulnerability assessments must be incorporated into regional spatial plans (RTRWs), with mandatory risk-based zoning that restricts development in high-hazard floodways and requires flood-proofing measures in moderate-risk areas. Studies evaluating spatial planning deficiencies in Indonesian cities reveal that planning documents frequently fail to incorporate landscape dynamics, climate change projections, and flood vulnerability assessments, resulting in continued development in hazardous areas [21].

Early Warning Systems and Community Preparedness

a) Flood Early Warning Systems (FEWS) function through four interconnected components:
b) Risk knowledge based on hazard assessment and vulnerability mapping.
c) Monitoring and warning service using real-time observation networks and forecasting models.
d) Dissemination and communication ensuring warnings reach all at-risk populations.
e) Response capability through preparedness planning and institutional coordination.

Flash floods pose particular challenges for early warning due to their rapid onset, localized spatial extent, and the difficulty of predicting small-scale convective precipitation. A systematic literature review of 19 flash flood early warning case studies from 2016 to 2021 identified diverse methodological approaches, including empirical rainfall thresholds, Flash Flood Guidance systems using inverse hydrological modeling, and probabilistic forecasting methods [22].

Technology integration has advanced substantially through the incorporation of weather radar, satellite remote sensing, stream and rain-gauge networks, and hydrological models, enabling improved detection and prediction capabilities. However, technological capacity proves insufficient without effective dissemination mechanisms and community response capability. Research on early warning effectiveness emphasizes the critical importance of multi-channel communication strategies, including SMS alerts, radio broadcasts, social media, and community-based warning networks, to ensure redundancy when infrastructure fails during disasters. The integration of local and indigenous knowledge with scientific monitoring enhances the relevance of warning systems and community ownership, improving protective action responses [23].

Community-Based Disaster Preparedness (CBDP) has gained global recognition as essential for reducing disaster risk and enhancing community resilience. A structured narrative review synthesizing current knowledge on CBDP effectiveness found that programs strengthen disaster response through participatory planning, community-driven early warning systems, and institutional partnerships with NGOs and local governments. Community participation enhances intervention responsiveness and legitimacy, particularly when grounded in local knowledge and cultural context. However, systemic barriers, including poverty, low levels of education, inadequate infrastructure, and policy misalignments, significantly constrain community capacity, highlighting the need for responsive, inclusive, and decentralized governance that supports grassroots action [24].

Nature-Based Solutions and Hybrid Infrastructure Approaches

Nature-Based Solutions (NBS) for flood management have emerged as innovative, sustainable alternatives or complements to conventional grey infrastructure, offering multiple co-benefits beyond flood risk reduction. NBS encompasses natural approaches such as protected areas and wetland conservation, soft engineering, including ecological restoration and beach nourishment, and hybrid solutions that integrate natural and grey infrastructure. Countries in Asia and the Pacific face heightened flood risk yet often lack adequate infrastructure, with existing measures relying primarily on hard-engineered solutions that are increasingly challenged by climate change [25].

Economic assessments demonstrate the viability of NBS when co-benefits are comprehensively valued. Research employing life-cycle cost-benefit analysis in Serbia found that while grey infrastructure measures had higher costs than flood-damage-reduction benefits alone, several NBS achieved net positive economic impact when incorporating co-benefits, with afforestation/reforestation generating benefit-cost ratios of 3.5 and retention ponds achieving 5.6. A systematic review of NBS for fluvial flood mitigation, synthesizing evidence from 131 peer-reviewed papers, documented substantial reductions in flood peaks and flow attenuation, with additional ecosystem service co-benefits including carbon sequestration, biodiversity enhancement, water quality improvement, and recreational opportunities [26].

Implementation in Indonesian contexts shows promise but faces barriers. Jakarta Governor's Instruction 52/2020 piloted vertical drainage systems and expanded green open spaces, demonstrating potential for urban flood management. However, challenges include limited awareness among policymakers and practitioners, higher perceived upfront costs compared to grey infrastructure, lack of technical capacity for design and maintenance, and institutional inertia favoring conventional engineering approaches. The OECD emphasizes that the growing imperatives of climate adaptation call for complementary, forward-looking solutions that combine NBS with grey infrastructure in hybrid approaches that maximize resilience while optimizing costs [27].

Post-Disaster Recovery and Build Back Better

The "Build Back Better" (BBB) concept originated following the 2004 Indian Ocean tsunami. It was subsequently institutionalized in the Sendai Framework as Priority 4, which advocates using post-disaster recovery to reduce vulnerability and enhance resilience. BBB represents a holistic approach that addresses physical, social, environmental, and economic dimensions of recovery, moving beyond mere restoration to pre-disaster conditions toward transformation that reduces future risk. Key principles include: incorporating disaster risk reduction measures into reconstruction, relocating critical facilities to safer areas, strengthening governance structures, including institutional mandates for risk management, using reconstruction to address urban development deficiencies, and promoting community participation in recovery planning [28].

Evidence from post-disaster recovery implementations reveals critical success factors. A comprehensive study of recovery from Cyclone Idai in Zimbabwe found that BBB considerations must address pre-existing vulnerabilities, strengthen building codes and land-use planning, and create opportunities for infrastructure that did not previously exist, such as improved schools and health facilities. Lessons from Central Sulawesi post-earthquake recovery in Indonesia identified four key practices:

a) Flexibility and resilience balance allowing adaptive management.
b) Integrated coordination with unified leadership across stakeholders.
c) Community prioritization through participatory relocation and recovery planning.
d) Debris recycling, converting disaster waste into reconstruction materials, generating both cost savings and employment.

However, recovery programs frequently prioritize speed over comprehensive risk reduction, potentially recreating pre-existing vulnerabilities if not carefully managed [29].

Methodology

Research Design

This study employs a qualitative literature review approach to synthesize lessons learned from the November 2025 Sumatra flash floods and develop evidence-based policy recommendations for disaster risk mitigation. A qualitative literature review methodology was selected over a systematic literature review based on research objectives that emphasize an exploratory synthesis of diverse sources to identify patterns, themes, and lessons from recent disaster events. Unlike systematic reviews requiring exhaustive, protocol-driven literature searching with predetermined inclusion criteria, qualitative reviews employ flexible search strategies that adapt iteratively as themes emerge, incorporate interpretive analysis recognizing multiple perspectives, and deliberately include grey literature such as government reports, policy documents, and disaster situation reports that provide essential contextual information unavailable in peer-reviewed journals [30,31].

The research philosophy adopts a constructivist-interpretive approach, recognizing that disaster causation and mitigation involve multiple valid perspectives shaped by disciplinary orientations, stakeholder positions, and contextual factors. Simultaneously, critical realism acknowledges both objective environmental and physical factors (e.g., deforestation impacts, hydrological processes, meteorological extremes) and socially constructed dimensions (e.g., governance arrangements, policy implementation, risk perception) that interact to produce disaster outcomes. This philosophical stance enables the integration of natural science literature on ecosystem services and climate change with social science research on governance, community resilience, and institutional capacity [32].

Literature Search Strategy and Selection

Literature searches were conducted across multiple databases, including Scopus, Web of Science, and Google Scholar, with a temporal focus on publications from 2020 to 2025 to capture recent scholarship while allowing the inclusion of seminal works that established foundational concepts. Search terms combined location identifiers ("Indonesia," "Sumatra," "Aceh," "North Sumatra," "West Sumatra"), hazard types ("flash flood," "flood," "flooding," "hydrometeorological disaster," "landslide"), and thematic areas ("disaster risk reduction," "mitigation," "early warning," "watershed management," "deforestation," "climate change," "governance," "community resilience," "nature-based solutions"). Boolean operators were used to connect these term categories and capture relevant literature across multiple dimensions.

Supplementary sources essential for contextualizing the November 2025 events included: BNPB and provincial BPBD situation reports documenting disaster impacts and response activities, UN agencies reports including UNDRR Sendai Framework implementation assessments and OCHA humanitarian situation reports, World Bank and Asian Development Bank policy analyses on disaster risk financing and resilience investment, academic institution research outputs including UGM expert analyses of watershed degradation factors, and reputable news media providing event chronology and impact documentation. The deliberate inclusion of grey literature reflects the reality that peer-reviewed literature specifically addressing November 2025 events remains limited due to publication timeframes, necessitating triangulation with authoritative non-academic sources.

Inclusion criteria encompassed: peer-reviewed articles from Scopus or Web of Science indexed journals published 2020-2025, studies addressing flash floods, riverine floods, or hydrometeorological disasters in Indonesia or comparable Southeast Asian contexts, literature examining environmental, governance, social, technological, or policy dimensions of flood risk, and authoritative grey literature from government agencies, multilateral organizations, and research institutions. Exclusion criteria: studies focused exclusively on non-flood hazards without multi-hazard relevance; literature predating 2020, except foundational works; non-English or non-Indonesian language sources due to accessibility constraints; and opinion pieces lacking empirical grounding or policy relevance.

Data Analysis and Synthesis

Analysis followed a thematic synthesis approach combining deductive and inductive coding. Deductively, the Sendai Framework's four priority areas provided an organizing structure for examining governance, risk assessment, investment, and preparedness dimensions. Inductively, careful reading of disaster-specific literature identified emergent themes, including ecosystem degradation as the primary causal factor, climate change amplification, coordination failures, and gaps in early warning dissemination. The constant comparative method facilitated pattern identification across sources, comparing findings on similar topics to distinguish convergences, divergences, and knowledge gaps [30].

Data extraction employed structured forms capturing bibliographic information, research methodology, and geographic focus; key findings related to research objectives; policy implications or recommendations; and quality indicators, including journal ranking and evidence strength. Thematic coding organized content into six major categories:

a) Environmental degradation and watershed dynamics.
b) Climate change and meteorological extremes.
c) Governance and institutional arrangements.
d) Early warning systems and communication.
e) Community vulnerability and resilience.
f) Recovery and reconstruction approaches. Within each category, sub-themes were iteratively refined through repeated engagement with literature.

Narrative synthesis integrated findings across thematic areas, weaving together environmental, governance, and socio-economic dimensions to construct a holistic understanding of disaster causation and mitigation options. Critical analysis identified areas of scholarly consensus (e.g., the deforestation-flood linkage and the importance of multi-stakeholder collaboration) and ongoing debates (e.g., the optimal balance between grey and green infrastructure and the most effective early-warning dissemination strategies for rapid-onset hazards). Knowledge gaps highlighted where current evidence base proves insufficient for confident policy recommendations, signaling priorities for future research.

Validity and Limitations

Credibility measures included triangulation across diverse source types (peer-reviewed journals, government reports, international agency assessments, news media), researcher reflexivity acknowledging the interpretive nature of qualitative synthesis, and transparency in search strategies and selection criteria. However, several limitations warrant acknowledgment. First, temporal constraints mean peer-reviewed literature specifically analyzing the November 2025 events remains limited, necessitating reliance on news media and preliminary reports for event details, while drawing on broader disaster literature for analytical context. Second, language limitations that restrict the review to English and Indonesian sources may overlook relevant literature in other languages. Third, publication bias potentially over-represents positive findings or high-profile disasters relative to failed interventions or smaller-scale events. Fourth, geographic scope focusing on Indonesian and Southeast Asian contexts may limit the transferability of findings to other regions with different institutional, environmental, or socio-economic conditions.

Results: Thematic Issues from Literature

Environmental Degradation as Primary Risk Driver

The literature unequivocally establishes decades of deforestation and watershed degradation as the primary factor amplifying flood impacts in Sumatra. Extensive forest loss across upper watersheds has systematically dismantled natural flood regulation capacity through multiple mechanisms. In Aceh, more than 700,000 hectares of forest disappeared between 1990 and 2020, reducing forest cover to approximately 59% of the provincial area despite the province's relatively extensive remaining forests. North Sumatra's situation is even more precarious, with forest cover accounting for merely 29% of the land area by 2020, and remaining forests highly fragmented across the Bukit Barisan mountains. West Sumatra experienced catastrophic deforestation of 320,000 hectares of primary forest and 740,000 hectares of total tree cover (primary and secondary combined) between 2001 and 2024, with 32,000 hectares lost in 2024 alone-among the highest rates nationally [1].

The ecological consequences of this deforestation prove devastating for hydrological functioning. Intact tropical forest canopies intercept 15-35% of rainfall before it reaches the ground, while forest soils facilitate deep infiltration and gradual water release through enhanced permeability and organic matter content. Studies in natural tropical forests demonstrate that these ecosystem services reduce peak flow rates and extend flood recession periods, providing critical buffering against extreme rainfall. Conversely, deforestation eliminates canopy interception, degrades soil structure through compaction and loss of organic matter, and accelerates surface runoff that rushes directly into rivers and downstream settlements [33].

The Batang Toru ecosystem exemplifies this trajectory of degradation. Protected forests that should serve as vital water catchment areas have been systematically converted to plantations and cleared by illegal logging operations. Since 2010, the ecosystem has lost 1,550 hectares of forest cover, leaving bare soil highly vulnerable to erosion during intense rainfall. Four of the ten studied watersheds in the affected regions exhibited high disaster potential based on a morphometric analysis incorporating drainage density, relief ratio, and land-use patterns. River narrowing and sedimentation resulting from upstream erosion further reduce channel capacity, increasing the probability of overflow during high-flow events [34].

Expert analysis emphasizes that extreme weather served merely as a trigger; the severity of the disaster fundamentally reflected extensive environmental degradation accumulated over decades. As framed by Dr. Suryatmojo from UGM, "The flash flood tragedy that struck Sumatra in November 2025 was essentially the accumulation of long-standing 'ecological sins' in the upper watershed. This characterization underscores that addressing flood risk requires confronting the structural causes of watershed degradation rather than treating symptoms through downstream engineering alone [4].

Climate Change and Meteorological Extremes

Tropical Cyclone Senyar's formation in the Strait of Malacca was a meteorologically exceptional event, with such development along the equator historically rare due to insufficient Coriolis force for rotation. The cyclone brought unprecedented rainfall intensity, with daily precipitation exceeding 300 millimeters in North Sumatra and cumulative totals surpassing 770 millimeters in West Sumatra within one week. Climate attribution analysis confirms that anthropogenic climate change substantially contributed to this extreme event. World Weather Attribution studies found that warmer Indian Ocean waters—0.2°C above long-term seasonal averages—provided enhanced heat and moisture energy fueling cyclone intensification. Without human-driven climate change, ocean temperatures would have been approximately 1°C cooler, significantly reducing storm intensity [35].

Comprehensive modeling of tropical cyclone trajectories in Southeast Asia projects accelerating risks under continued warming. Analysis of over 64,000 simulated tropical cyclones from the 19th century through end of 21st century under moderate and high emissions scenarios reveals critical trajectory changes including: poleward shifts in genesis locations bringing cyclone formation closer to populated coastlines, faster intensification rates occurring nearer to landfall reducing preparation time, increased likelihood of slow-moving storms over mainland areas extending rainfall duration, and longer persistence of cyclone tracks over land. In cities such as Hai Phong, Yangon, and Bangkok, these variations indicate future increases in both peak cyclone intensity and storm duration relative to historical patterns [12].

The interaction between climate extremes and land-use degradation creates compounding effects that exceed the impacts of either factor alone. Research emphasizes that while Cyclone Senyar's extreme rainfall would have caused flooding under any circumstances, the absence of protective forest cover in the upper watersheds transformed manageable rainfall into a catastrophe. This synergy between meteorological and environmental factors explains why regions with comparable rainfall but intact watersheds experienced substantially lower impacts. Climate projections indicating 322-402% increases in flood risk for Indonesian urban areas by 2050 assume continued land use patterns; actual risk trajectories depend on whether watershed restoration and nature-based solutions are implemented at scale [6].

Governance and Institutional Failures

Despite Indonesia's comprehensive legal framework established by Law 24/2007 on Disaster Management, implementation reveals persistent governance failures that undermine the effectiveness of risk reduction. Critical weaknesses identified through institutional analysis include: disconnect between conservation laws such as the Soil and Water Conservation Law and regional budget allocation patterns that prioritize development over protection, poor coordination between national BNPB and regional BPBDs creating confusion during emergency response, inadequate enforcement of forest protection regulations and spatial planning mandates allowing continued encroachment on protected areas, and emphasis on post-disaster emergency response over prevention and mitigation despite legal mandates for comprehensive risk management [36].

Spatial planning deficiencies represent a particularly critical governance gap. Regional spatial plans (RTRW) across the three provinces inadequately incorporate landscape dynamics, flood vulnerability assessments, and climate change projections into development zoning decisions. Research on spatial planning integration demonstrates that effective disaster risk reduction requires mandatory hazard mapping at appropriate scales, risk-based zoning that restricts development in high-hazard areas, and enforcement mechanisms including building code requirements for flood-proofing in moderate-risk zones. The absence of these elements results in continued development in floodplains and watersheds, perpetuating vulnerability [37].

Institutional capacity constraints at the regional levels further impede effective disaster management. BPBDs across Aceh, North Sumatra, and West Sumatra lack substantial technical capacity, financial resources, and trained personnel to fulfill their mandates, despite their legal establishment. Studies on disaster risk reduction institutional frameworks identify systemic problems, including: limited technical expertise for conducting disaster risk assessments and operating early warning systems, insufficient budget allocation for DRR activities relative to emergency response needs, weak coordination mechanisms both horizontally across sectors and vertically between government levels, and absence of systematic monitoring and evaluation frameworks to track DRR investment effectiveness [38].

The political economy dimension proves equally consequential. Short-term economic incentives favor plantation development and mining operations in upland areas, generating immediate revenue but creating long-term disaster vulnerability. Institutional path dependencies make it difficult to transform centralized, reactive disaster management approaches despite recognition of their limitations. Regulatory capture, in which economic interests influence policy implementation, undermines the enforcement of forest-protection and spatial-planning regulations. Breaking these patterns requires not merely technical solutions but also fundamental governance reforms that address power relations, incentive structures, and accountability mechanisms [39].

Early Warning System and Communication Failures

While early detection systems identified developing hazards, communication failures between central and regional governments prevented effective protective action. BMKG (Meteorology, Climatology, and Geophysics Agency) issued forecasts warning of extreme rainfall associated with Tropical Cyclone Senyar. Still, regional governments lacked the capacity to interpret warnings and trigger appropriate response protocols. This detection-action gap reflects broader challenges in early warning systems for flash floods, including rapid-onset timeframes that limit preparation windows, localized spatial scales that require fine-resolution monitoring, and prediction difficulties associated with small-scale convective precipitation [40].

Infrastructure failures during the disaster severely compromised the dissemination of warnings. Power outages and telecommunications disruptions eliminated communication channels precisely when warnings proved most critical. Research on early warning effectiveness emphasizes that technological detection capacity is insufficient without multi-channel dissemination strategies that ensure redundancy when primary systems fail. Practical approaches integrate SMS alerts, radio broadcasts, mosque loudspeakers, community-based warning networks, and environmental cues to reach diverse populations through multiple pathways. The November 2025 experience revealed the absence of such redundancy, with communities receiving delayed or no warnings, leaving insufficient time for evacuation [41].

Community preparedness deficits compounded warning system failures. Limited disaster education programs meant that many residents lacked an understanding of appropriate protective actions when warnings were issued. Low risk perception among populations accustomed to seasonal flooding contributed to delayed evacuation decisions. The absence of regular evacuation drills and unclear evacuation routes created confusion during the emergency response. Research on community-based disaster preparedness demonstrates that effective early warning requires end-to-end functionality spanning detection, dissemination, public understanding, and response capability—with weakness in any component undermining the entire system [42].

Socio-Economic Vulnerability and Infrastructure Impacts

High population concentrations in flood-prone areas reflect economic necessity rather than choice for many residents. Dependence on agriculture and natural resource-based livelihoods necessitates proximity to rivers and fertile floodplains, despite exposure to hazards. Limited financial resources constrain household-level adaptation measures such as elevated housing, flood-proofing, or insurance coverage. These patterns create poverty-disaster traps where economic marginalization drives settlement in high-risk areas, disaster impacts deepen poverty, and recovery proves difficult without external assistance [43-46].

Infrastructure damage extended across multiple critical systems. The Tarutung-Sibolga Road, a vital transportation artery, was completely paralyzed by floods reaching a depth of 3 meters and landslides that buried sections under debris. Power transmission towers collapsed, leaving extensive areas without electricity for days. Bridge collapses isolate communities and disrupt supply chains. Schools and health facilities sustained damage, affecting the education of 15,500 children and communities' access to medical services. Water supply systems were contaminated or physically damaged. The comprehensive nature of infrastructure impacts illustrates how disasters cascade across systems, with failures in one domain amplifying impacts in others [47].

Long-term development implications prove profound. The displacement of 151,000 families creates protracted recovery challenges, including housing reconstruction, livelihood restoration, and continuity of social services. Agricultural land damage—113 hectares of rice fields destroyed—threatens food security in affected regions. Economic losses exceeding $20 billion across the three provinces represent substantial setbacks to development progress. The impacts of educational disruption and psychological trauma on human capital will manifest over extended periods. Recovery trajectories will depend critically on whether reconstruction incorporates risk reduction measures or recreates pre-existing vulnerabilities [48-51].

Existing Mitigation Efforts and Persistent Gaps

Existing flood mitigation measures across Sumatra emphasize structural approaches, such as dams, reservoirs, embankments, and drainage systems, designed to contain or channel floodwaters. River normalization projects attempt to restore channel capacity degraded by sedimentation. Some urban areas have piloted nature-based solutions, including Jakarta's vertical drainage and the expansion of green open space under Governor's Instruction 52/2020. However, persistent gaps undermine effectiveness. Most critically, interventions concentrate on downstream engineering without addressing upstream watershed degradation—treating symptoms while ignoring causes. This approach proves fundamentally inadequate when watershed deforestation eliminates the natural flood-regulation capacity that no amount of downstream infrastructure can replicate [52,53].

Policy and planning instruments include Indonesia's National Action Plan for Climate Change Adaptation (RAN-API) and regional disaster management plans mandating preparedness activities. However, implementation reveals substantial weaknesses. Research documents partial implementation, insufficient integration across sectors, limited community participation in planning processes, inadequate budget allocation relative to stated priorities, and the absence of systematic monitoring and evaluation frameworks to track outcomes. The disconnect between policy commitments and operational implementation reflects broader governance challenges, including capacity constraints, competing priorities, and limited political will for prevention investments that generate benefits only when disasters do not occur [54].

Multi-stakeholder initiatives demonstrate both potential and limitations. Collaborative governance models in cities like Jakarta, Surabaya, and Denpasar have facilitated coordination among government agencies, NGOs, and community organizations. NGO-supported community-based disaster management programs have enhanced preparedness in some localities. However, challenges persist, including organizational silos that hinder information sharing, communication gaps among stakeholders, uneven capacity among actors, and fragmented efforts lacking strategic coordination. Scaling successful pilot programs to provincial or national levels requires addressing these systemic barriers through institutional reforms, capacity-building investments, and the formalization of collaborative mechanisms with clear mandates and resources [55-58].

Analysis: Synthesis and Answering Research Objectives

Critical Lessons Learned from November 2025 Flash Floods

Five critical lessons emerge from the synthesis of literature, disaster documentation, and expert analyses. First, ecosystem-based disaster risk reduction proves non-negotiable for sustainable flood mitigation in watershed contexts. Technical flood-control infrastructure, divorced from upstream forest conservation, fundamentally fails when extreme rainfall encounters degraded watersheds lacking natural water-retention capacity. The November 2025 disaster demonstrates that decades of deforestation created conditions in which no feasible amount of downstream engineering could prevent catastrophic flooding, given the rainfall intensity. This lesson necessitates reframing flood management from primarily an infrastructural challenge to an integrated watershed management approach that requires forest protection and restoration as a prerequisite for all other interventions [59].

Second, climate change adaptation requires systemic transformation rather than incremental adjustments. Attribution studies confirming climate change's role in intensifying Cyclone Senyar, combined with projections showing a 322-402% increase in flood risk by 2050, establish that historical approaches calibrated to past climate conditions are inadequate for emerging threats. Adaptation must be mainstreamed across all development sectors—spatial planning, infrastructure design, agricultural practices, and urban development—with substantial resource allocation commensurate with the scale of projected impacts. Current adaptation financing proves grossly insufficient relative to need, requiring fundamental shifts in budget priorities and development paradigms [60].

Third, multi-level governance coordination proves critical for translating policy into effective action. The detection-action gap during November 2025—where early warnings existed but failed to trigger a protective response—exemplifies coordination failures with lethal consequences. The literature on collaborative governance emphasizes that complex disasters require vertical coordination among national, provincial, and local authorities and horizontal coordination across sectors, including environment, public works, health, and emergency management. Current institutional arrangements feature unclear mandates, inadequate communication protocols, and limited coordination mechanisms. Addressing these deficits requires institutional reforms, including memoranda of understanding that clarify roles, joint operational procedures, regular coordination meetings, and shared information systems [13].

Fourth, community resilience requires genuine participation and empowerment rather than top-down programming. Research consistently demonstrates that communities with active disaster preparedness programs grounded in local knowledge and participatory planning exhibit superior response capacity compared to those subjected to externally imposed interventions. However, meaningful participation demands resources, capacity building, and institutional space for community voice in decision-making. Current approaches often feature token consultation rather than genuine empowerment. Effective community resilience-building requires long-term investment in organizational capacity, disaster education that integrates local and scientific knowledge, participatory risk assessment and planning, and community-controlled resources that enable local action [61].

Fifth, early warning systems require end-to-end functionality spanning detection through community action. Technological detection capacity, while necessary, proves insufficient without effective dissemination that ensures all populations receive warnings through culturally appropriate channels, public understanding that enables correct interpretation of warning messages, and community response capability, including evacuation routes, shelter arrangements, and institutional coordination. The November 2025 experience revealed failures across multiple components—dissemination compromised by infrastructure damage, limited public understanding of appropriate protective actions, and unclear institutional responsibilities for coordinating evacuation. Strengthening early warning systems requires investment across all components, with particular attention to last-mile dissemination and community preparedness [22].

Causal Pathways and Interconnections

The November 2025 disaster resulted from the convergence of multiple causal pathways whose interactions amplified impacts beyond any single factor's contribution. The environmental-climate-disaster nexus illustrates critical feedbacks: deforestation reduces water retention capacity and accelerates surface runoff; increased runoff generates soil erosion, removing remaining organic matter and further degrading infiltration capacity; degraded soils provide diminished resistance to extreme rainfall; climate change intensifies extreme precipitation events; the combination of extreme rainfall and degraded watersheds produces catastrophic flooding. This feedback dynamic means that vulnerability escalates nonlinearly—each increment in forest loss generates a proportionally larger increase in flood risk as protective thresholds are crossed [62-65].

The governance-development-risk nexus reveals political economy dimensions. Short-term economic incentives favor forest conversion to plantations and mining operations, generating immediate revenue and employment. However, these activities create long-term disaster vulnerability with costs externalized to society through flood damage, loss of life, and development setbacks. Weak governance enables this externalization [34].

Inadequate enforcement of environmental regulations, spatial planning failures permitting development in hazardous areas, and the absence of mechanisms requiring risk assessments for land use decisions. The resulting pattern—privatized short-term benefits and socialized long-term costs—proves politically difficult to disrupt despite recognition of unsustainability [36].

The nexus of socio-economic vulnerability creates poverty-disaster traps. Economic marginalization drives settlement in flood-prone areas due to land affordability or livelihood requirements. Limited financial resources prevent households from implementing adaptation measures. When disasters strike, marginalized populations suffer disproportionate impacts due to housing quality, location in the highest-risk zones, and limited access to emergency assistance. Post-disaster recovery proves difficult without capital for rebuilding, potentially leading to distressed asset sales or predatory lending that deepen poverty. Breaking these cycles requires addressing structural inequality alongside disaster risk reduction—through social protection programs, livelihood diversification, equitable land access, and inclusive recovery policies that ensure vulnerable populations benefit rather than fall further behind [66].

Effectiveness of Current Disaster Risk Reduction Frameworks

Assessment of Indonesia's implementation of the Sendai Framework reveals mixed progress across the four priority areas. Priority 1 (understanding disaster risk) has advanced through improved hazard mapping, vulnerability assessments, and risk information systems. However, gaps remain in the comprehensiveness, resolution, and accessibility of risk information, particularly at the local level. Priority 2 (strengthening disaster risk governance) shows significant weaknesses, evidenced by coordination failures, enforcement gaps, and capacity deficits documented in the November 2025 response. The institutional architecture is structured through BNPB and BPBDs, but its functionality remains limited by resources, capacity, and political commitment [67].

Priority 3 (investing in disaster risk reduction for resilience) represents perhaps the most substantial gap. Analysis of disaster-related expenditures reveals an overwhelming emphasis on post-event emergency response and reconstruction relative to prevention and mitigation investments that could reduce the occurrence and impacts of disasters. This allocation pattern reflects political incentives that favor visible response activities over prevention, yielding benefits only in disasters that do not occur. Additionally, DRR investments often emphasize structural measures like flood walls rather than addressing underlying drivers, including watershed degradation and climate vulnerability. Reorienting investment toward comprehensive risk reduction, including ecosystem restoration, nature-based solutions, early warning systems, and community preparedness, requires fundamental shifts in budget priorities and decision-making criteria [68].

Priority 4 (enhancing disaster preparedness and Build Back Better recovery) shows improvement in preparedness planning, with most jurisdictions now having emergency response plans. However, the quality and currency of these plans vary substantially. However, the Build Better concept remains incompletely implemented. Post-disaster reconstruction typically emphasizes speed over transformation, with pressure to restore normalcy leading to the recreation of pre-existing vulnerabilities. Lessons from successful BBB implementations emphasize the need for: rapid post-disaster assessments; identifying vulnerability factors to address during reconstruction; participatory recovery planning; ensuring that affected communities shape decisions; integrating disaster risk reduction into building codes and spatial plans; and medium-term recovery timeframes that balance urgency with quality [69-72].

Uptake of nature-based solutions in Indonesia remains limited despite growing recognition of their potential. Pilot projects in Jakarta, Surabaya, and Denpasar demonstrate feasibility and multiple co-benefits, including flood risk reduction, biodiversity enhancement, urban heat island mitigation, and recreational opportunities. Economic assessments from comparable contexts show that NBS achieve positive benefit-cost ratios of 3.5 to 5.6 when co-benefits are valued, compared with negative ratios for conventional infrastructure that considers only flood damage reduction. However, barriers to scaling include: limited awareness among decision-makers of NBS potential, higher perceived upfront costs and longer payback periods than grey infrastructure, lack of technical capacity for NBS design and maintenance, absence of financing mechanisms suited to NBS characteristics, and institutional inertia favoring conventional engineering approaches. Overcoming these barriers requires: demonstration projects that document NBS effectiveness in Indonesian contexts; capacity building for practitioners and officials; development of design standards and guidelines; innovative financing, including green bonds and ecosystem service payments; and policy reforms mandating the consideration of NBS in all flood management planning [73].

Community-based disaster management demonstrates effectiveness when adequately supported but faces sustainability challenges. Programs featuring NGO partnerships, adequate budgets, strong local leadership, and integration with existing community structures show measurable improvements in disaster preparedness, early warning system functionality, and response capacity. However, many CBDM initiatives remain donor-dependent and lack sustainability when external funding ends. Additionally, suboptimal socialization results in uneven coverage, with many vulnerable communities lacking active programs. Institutionalizing and scaling CBDM requires formal integration into government disaster management frameworks with dedicated budget lines, capacity building for local facilitators and community volunteers, development of standardized training curricula and materials, and monitoring and evaluation systems that track program coverage and effectiveness [23].

Conclusion

The November 2025 flash floods that devastated Aceh, North Sumatra, and West Sumatra represent not merely a natural disaster but a foreseeable catastrophe resulting from decades of policy failures, environmental degradation, and inadequate disaster risk reduction investments. This qualitative literature review synthesizing evidence from peer-reviewed research, expert analyses, and disaster documentation reveals that disaster magnitude resulted from convergence of four primary factors: systematic destruction of forest ecosystems in upper watersheds eliminating natural flood regulation capacity, climate change-intensified extreme rainfall associated with Tropical Cyclone Senyar, governance failures including weak enforcement and coordination deficits, and inadequate early warning system dissemination combined with limited community preparedness.

Critical lessons emphasize that sustainable flood mitigation in watershed contexts requires ecosystem-based approaches integrating forest conservation and restoration as prerequisites for downstream interventions. Technical flood-control infrastructure proves fundamentally inadequate when watersheds lack natural water-retention capacity. Climate change adaptation necessitates systemic transformation, with substantial resource allocation aligned with projected risk escalation rather than incremental adjustments. Multi-level governance coordination is essential for translating policy into practical action and requires institutional reforms to address communication protocols, role clarity, and accountability mechanisms. Community resilience building demands genuine participation and empowerment rather than top-down programming, with long-term investments in capacity, disaster education, and community-controlled resources. Early warning systems require end-to-end functionality across detection, dissemination, public understanding, and response capability rather than isolated technological investments.

An assessment of Indonesia's disaster risk reduction frameworks reveals mixed implementation of the Sendai Framework priorities. While understanding of risk has improved through enhanced mapping and evaluation, governance weaknesses persist, including coordination failures and capacity deficits. Investment allocation overwhelmingly favors post-disaster response over prevention and mitigation, reflecting political incentives and institutional inertia. Build Back Better principles remain incompletely operationalized in recovery practice. Nature-based solutions show promise, as demonstrated by pilot projects, but face barriers to scaling, including awareness gaps, perceived cost differentials, technical capacity limitations, and institutional preferences for conventional engineering. Community-based disaster management proves effective when adequately supported but faces sustainability challenges that require formal integration into government frameworks.

This research contributes to disaster risk reduction scholarship by demonstrating the critical importance of integrated approaches addressing environmental, governance, and social dimensions simultaneously. Reducing flood vulnerability demands confronting underlying drivers, including watershed degradation and climate change, rather than merely treating symptoms through engineering. The analysis provides evidence-based guidance for policymakers addressing Indonesia's escalating flood risk, with policy recommendations organized across immediate, medium-term, and long-term horizons emphasizing ecosystem restoration, hybrid infrastructure approaches, governance reforms, early warning enhancement, and community resilience investments.

Future research priorities include: longitudinal studies tracking watershed restoration impacts on flood risk reduction at landscape scales, comparative cost-benefit analyses of grey versus green versus hybrid infrastructure approaches accounting for full lifecycle and co-benefits, implementation science examining barriers and enablers for scaling successful pilot programs, climate change scenario planning for flood risk under different emission pathways and adaptation strategies, and participatory action research co-designing solutions with affected communities. Addressing Indonesia's flood vulnerability challenge requires sustained commitment to evidence-based policy, adequate resource allocation, strengthened institutional capacity, and genuine integration of disaster risk reduction into development planning across all sectors.

Policy Recommendations

Immediate Priority Actions (0-2 Years)

Emergency Response and Early Recovery

The immediate post-disaster period demands coordinated action to prevent recovery failures that recreate vulnerabilities. Establish an integrated disaster recovery coordination mechanism across Aceh, North Sumatra, and West Sumatra, with a single lead agency (BNPB) and clear roles for regional BPBDs, sectoral ministries, NGOs, and community organizations, drawing on Central Sulawesi, where unified coordination improved recovery outcomes. Implement debris recycling programs that convert disaster waste into reconstruction materials, recognizing that 80% of debris in Central Sulawesi is recyclable, providing cost-effective inputs while generating local employment. Conduct participatory vulnerability assessments in all affected districts, identifying high-risk populations requiring relocation and ensuring community participation in site selection and planning to avoid conflicts that derailed some previous relocations.

Governance and Institutional Strengthening

Clarify and formalize coordination mechanisms among BNPB, provincial BPBDs, and line ministries through memoranda of understanding that specify: roles and responsibilities for disaster prevention, preparedness, response, and recovery; information-sharing protocols, including frequency and formats; joint operational procedures for emergency response; and dispute-resolution mechanisms. Establish emergency task forces at the provincial level to resolve land tenure issues and facilitate resettlement, as land conflicts constitute significant barriers to recovery and require legal expertise and political authority to settle. Conduct rapid institutional capacity assessments of BPBDs in the three provinces, followed by targeted capacity-building to address specific deficits in disaster risk assessment methods, early warning system operations, emergency operation center management, and recovery planning.

Early Warning System Enhancement

Deploy additional rain gauges, stream gauges, and real-time monitoring stations in upper watersheds, particularly in remote mountainous areas where monitoring gaps currently exist, ensuring data transmission redundancy through satellite and cellular networks. Develop multi-channel warning dissemination protocols that integrate SMS alerts, radio broadcasts, mosque loudspeakers, sirens, and community-based networks to ensure redundancy when infrastructure fails, specifying trigger thresholds and message content for different hazard levels. Implement standardized early warning training programs for BPBD personnel, focusing on: interpretation of meteorological forecasts, recognition of hydrological threshold exceedance, decision-making on warning triggers, and inter-agency coordination during emergencies.

Medium-Term Strategic Interventions (2-5 Years)

Ecosystem Restoration and Watershed Management

Launch a large-scale watershed restoration program prioritizing upper catchments of Batang Toru, Krueng Aceh, Kampar, and other critical rivers with targets of 100,000 hectares reforested within five years, using native species appropriate to elevation and soil conditions, employing local communities in nursery operations and planting activities, generating livelihoods while restoring ecosystems. Establish a moratorium on all new forest conversion permits in upper watershed areas pending comprehensive environmental impact assessments that account for downstream flood risk, with permits only granted when assessments demonstrate no significant increase in flood vulnerability and include mandatory mitigation measures. Implement payment for ecosystem services (PES) schemes compensating upstream communities for forest conservation, financed through water tariffs on downstream urban users and industries, with payment levels sufficient to provide livelihood alternatives to forest conversion.

Restore riparian buffers and floodplain connectivity through river corridor management plans specifying: minimum buffer widths based on stream order and flood return periods, prohibition of structures in active floodways, removal of encroachments where feasible with compensation and alternative site provision, and reconnection of rivers to floodplains enabling natural water storage during high-flow events. The scientific evidence demonstrates that riparian vegetation reduces flow velocity, promotes infiltration, and provides habitat for aquatic species, generating multiple ecosystem service benefits beyond flood regulation alone.

Spatial Planning and Land Use Reform

Revise regional spatial plans (RTRW) for Aceh, North Sumatra, and West Sumatra provinces, incorporating: high-resolution flood hazard maps developed using LiDAR topographic data and hydrological modeling, climate change projections adjusting return period estimates for 2050 conditions, mandatory disaster risk assessment for all major development proposals with transparent approval criteria, and a mechanism for regular plan updates as risk information improves. Implement flood zoning regulations that prohibit development in high-risk floodways and active channels, limit density, require elevation/flood-proofing in moderate-risk areas, and establish preferential development zones in low-risk locations. Enforcement requires building permit processes that verify compliance, inspection programs that ensure construction matches permits, and sanctions for violations, including stop-work orders and structure removal.

Establish green infrastructure mandates for urban and peri-urban development, including: rainwater harvesting systems for buildings above minimum size thresholds, permeable pavement for parking areas and pedestrian surfaces, bioswales and vegetated buffer strips for stormwater management, and retention ponds integrated into development landscapes. Jakarta's experience with Governor's Instruction 52/2020 demonstrates the feasibility of these approaches in Indonesian contexts, though consistent enforcement remains challenging. Create land-use incentives, including tax reductions for developments incorporating nature-based flood-mitigation features, expedited permitting for projects demonstrating superior environmental performance, and recognition programs highlighting exemplary projects.

Infrastructure Investment: Hybrid Grey-Green Approach

Adopt hybrid infrastructure strategy combining conventional engineering with nature-based solutions: upgraded drainage systems sized for climate change-adjusted design storms, detention basins providing temporary water storage during peak flows, flood walls protecting critical facilities where elevation proves infeasible, wetland restoration and constructed wetlands providing natural water treatment and storage, urban forests and street tree programs increasing pervious surface area, and green roofs reducing building stormwater contributions. Economic assessment demonstrates that hybrid approaches optimize cost-effectiveness while providing co-benefits, including carbon sequestration, biodiversity habitat, urban heat island mitigation, and recreational opportunities that pure grey infrastructure cannot deliver.

Prioritize critical infrastructure resilience through: seismic and flood-resistant design standards for schools, hospitals, emergency operation centers, and evacuation shelters; transportation network redundancy ensuring alternate routes when primary corridors fail; and distributed systems for power, water, and telecommunications reducing vulnerability to single-point failures. The November 2025 experience, in which infrastructure damage hampered emergency response, demonstrates that resilient critical infrastructure is a prerequisite for effective disaster management. Invest in redundant power and telecommunications systems, ensuring emergency communication during disasters through: backup generators for vital facilities with fuel reserves for extended operation, satellite communication terminals not dependent on terrestrial networks, and battery-powered emergency broadcast systems.

Community-Based Disaster Risk Reduction

Scale community-based disaster preparedness programs to all flood-prone sub-districts with: organizational support for local volunteer networks, including training and equipment, facilitation of participatory hazard mapping and evacuation planning grounded in local knowledge, conduct of regular evacuation drills and simulation exercises, and prepositioning of emergency supplies in community-accessible locations. Research demonstrates that CBDP effectiveness depends on sustained support rather than one-time interventions, requiring multi-year commitments from implementing agencies.

Integrate local and indigenous knowledge into disaster risk assessments and early warning systems through: participatory mapping sessions documenting traditional flood indicators and historical events, establishment of community advisory committees providing input on early warning protocols, incorporation of cultural practices and social networks into communication strategies, and recognition of community knowledge holders in disaster management institutions. The integration of scientific and local knowledge enhances both system accuracy and community ownership, improving warning response rates. Implement inclusive disaster education programs addressing diverse needs across age, gender, disability status, and language groups: school-based curricula integrating disaster education across subjects, community workshops using culturally appropriate pedagogies and languages, accessible materials in formats including visual, audio, and tactile for persons with disabilities, and targeted programs for vulnerable populations including elderly, children, and persons with mobility limitations. Establish community disaster funds that provide grants for household-level mitigation, including: elevation of existing structures in high-risk areas where relocation is infeasible; purchase of emergency supplies and communication equipment; installation of rainwater harvesting systems and backup power; and subsidies for disaster insurance premiums for low-income households.

Long-Term Transformative Policies (5-10 Years)

Climate Change Adaptation Mainstreaming

Update National Action Plan for Climate Change Adaptation (RAN-API) with: ambitious flood risk reduction targets aligned with Sendai Framework goals, dedicated budget allocation of minimum 2% of national budget for adaptation reflecting projected risk escalation, sectoral adaptation plans for critical systems including agriculture, water resources, and urban development, and comprehensive monitoring framework tracking progress with publicly accessible dashboards promoting accountability. Current adaptation financing is grossly inadequate relative to projected increases in flood risk of 322-402% by 2050, necessitating a fundamental budget reorientation.

Mandate climate change impact assessments for all major development projects, including infrastructure construction, industrial zones, and urban expansion, with standardized methodologies accounting for multiple climate scenarios and time horizons, transparent criteria for project approval based on risk thresholds, a requirement that projects demonstrate net risk reduction or neutrality, and rejection authority for projects substantially increasing flood vulnerability regardless of economic benefits. Integrate disaster risk reduction and climate adaptation into national and regional development planning cycles (RPJMN at national level, RPJMD at provincial/district levels) through: mandatory DRR chapters in all development plans with quantified targets and budget allocations, performance indicators tracking DRR outcomes integrated into government evaluation systems, and cross-sectoral coordination mechanisms ensuring coherence across line agencies.

Legal and Regulatory Reforms

Strengthen enforcement provisions in forestry, water resources, and spatial planning laws, including criminal penalties for illegal deforestation and river encroachment with imprisonment for repeat offenders, administrative sanctions including permit revocation and rehabilitation cost recovery for development code violations, and civil liability provisions enabling disaster-affected communities to seek compensation from parties whose illegal activities contributed to disasters. Current weak enforcement reflects insufficient deterrence; meaningful penalties can shift cost-benefit calculations.

Amend Law 24/2007 to mandate minimum budget allocations for disaster risk reduction-distinct from emergency response—at both national and regional levels, with: phased implementation requiring 10% of disaster-related budgets for DRR in year 1 increasing to 30% by year 5, sanctions for non-compliance including budget transfer restrictions, and annual reporting requirements specifying DRR expenditures by category enabling tracking and transparency. Enact regional regulations formalizing multi-stakeholder disaster management platforms with: legal status enabling resource mobilization and coordinated action, representation requirements ensuring inclusive participation across government, NGOs, private sector, and communities, and secretariat functions providing technical and administrative support for platform operations.

Institutional Capacity Building

Establish a national training academy for disaster risk reduction, providing professional certification programs for BNPB/BPBD personnel covering risk assessment, early warning, emergency management, and recovery planning, continuing education courses updating skills as methodologies evolve, training for local government officials integrating DRR into sectoral responsibilities, and community leader programs building grassroots capacity for CBDP facilitation. Indonesia's disaster management institutions require systematic capacity development rather than ad hoc training.

Create dedicated disaster risk reduction units within key line ministries including Public Works (infrastructure resilience), Agriculture (climate adaptation), Environment (ecosystem restoration), and Education (disaster education curriculum), with: mandates to integrate DRR into all sectoral planning and budgeting, adequate staffing with technical specialists, authority to review and approve major projects based on risk criteria, and coordination protocols ensuring coherence with BNPB/BPBD strategies. Horizontal integration across sectors is essential given the cross-cutting nature of disaster risk.

Develop regional centers of excellence for disaster research and innovation in Sumatra leveraging university partnerships (Universitas Gadjah Mada, Universitas Syiah Kuala, Universitas Andalas) to: conduct applied research on disaster risk reduction effectiveness in local contexts, provide technical assistance to regional governments for risk assessments and planning, offer graduate education programs producing disaster management professionals, and facilitate knowledge exchange among practitioners, researchers, and policymakers.

Financing Mechanisms

Establish provincial disaster risk financing mechanisms, including: dedicated disaster funds capitalized through annual budget allocations providing rapid liquidity post-disaster without requiring emergency budget reallocations, catastrophe bonds transferring tail risk to capital markets with proceeds supporting immediate response, and parametric insurance schemes providing automatic payouts when trigger indicators (rainfall thresholds, stream gauge levels) are exceeded, enabling fast response without lengthy claims processes. Indonesia has pioneered several disaster financing innovations at the national level; expanding them to regions would enhance resilience.

Create green bonds and blended finance instruments specifically for watershed restoration and nature-based infrastructure projects, with revenue streams from ecosystem service beneficiaries (water utilities, tourism operators) providing bond repayment, concessional capital from development finance institutions improving project economics, and technical assistance facilities supporting project preparation and implementation, addressing capacity constraints that often impede NBS scaling. Implement ecosystem service payment schemes at watershed scale with downstream beneficiaries—urban water utilities, industries, and agricultural water users—compensating upstream communities for conservation that protects water quantity and quality, with payments sufficient to provide livelihood alternatives to forest conversion and managed through transparent systems that ensure equitable distribution.

Monitoring, Evaluation, and Learning

Develop comprehensive disaster risk indicators and a reporting system to track progress on Sendai Framework targets at national, provincial, and district levels, including: disaster mortality and affected populations; economic losses as a percentage of GDP; critical infrastructure damage; and DRR investment levels, with public dashboards enabling civil society monitoring and accountability. Mandate post-event learning reviews (after-action reports) for all significant disasters with standardized protocols for data collection during the response phase, structured debriefing sessions with all involved agencies and communities, documentation of successes and failures with causal analysis, and formal mechanisms ensuring findings inform policy updates and training curricula. Establish longitudinal research programs tracking watershed restoration impacts, infrastructure performance, and community resilience over extended periods (10-20 years) to: generate robust evidence on intervention effectiveness under diverse conditions, enable adaptive management based on monitoring data, and contribute to the international knowledge base on disaster risk reduction in tropical contexts.

References

1. Salma (2025) UGM Expert: Severe Sumatra Flash Floods Driven by Upper Watershed Forest Degradation, Universitas Gadjah Mada News Report.

2. Dhanya D (2026) Why Deforestation Is Turning Aceh's Floods into Deadly Disasters. Tempo English: Environment.

3. Human Initiative (2026) Situation Report #4 - Floods and Landslides in Aceh Province, North Sumatra, and West Sumatra - Thursday, 4 December 2025. ReliefWeb Indonesia.

4. Jesi, Grehenson G (2026) Experts at Universitas Gadjah Mada Urge Reforestation and Watershed Rehabilitation to Prevent Flash Flood Disasters. UGM News Report.

5. Judijanto L (2026) Hydrometeorological And Watershed Drivers Of The November 2025 Floods In Aceh, North Sumatra, And West Sumatra Under Tropical Cyclones Senyar And Koto. Sjrs Shrine J Res Sci J Res Sci 3(2).

6. Hendrawan VSA, Rahardjo AP, Mawandha HG, Aldrian E, Muhari A, et al. (2025) Review article: Past and future climate–related hazards in Indonesia.

7. Nasri N, Nursaputra M, Arif AR, Dwiyani R, Chania L, et al. (2025) Ecological Disaster in Northern Sumatra: How Extreme Rainfall and Land-Cover Disturbance Triggered Widespread Flash Flooding. J Penelit Kehutan Wallacea 14(2): 111-121.

8. Meijaard E, Wafiy M, Ni'Mattulah S, Dennis R, Hadisiswoyo, P, et al. (2025) Extreme Rainfall Event in Sumatra Caused Critical Habitat Loss and Lethal Impacts to the Critically Endangered Tapanuli Orangutan.

9. Fathrio I, Satiadi D, Praja AS, Purwaningsih A, Sinatra T, et al. (2025) Assessment of atmospheric dynamics contributing to extreme rainfall and devastating floods in Bangka Belitung from 8 to 9 February 2016. Clim Dyn 63(11): 1-26.

10. Chaniago N (2026) Did deforestation worsen Sumatra disaster? Indonesia to trace timber, summon companies to explain. CNA: Channel News Asia- Asia.

11. Siregar k (2026) The real reasons Cyclone Senyar turned deadlier in Indonesia than elsewhere. Channel News Asia: Analysis.

12. Garner AJ, Samanta D, Weaver MM, Horton BP (2024) Changes to tropical cyclone trajectories in Southeast Asia under a warming climate. npj Clim Atmos Sci 7(1): 156.

13. Amil AC (2025) Collaborative Governance Mechanisms in Disaster Risk Reduction and Management in the Philippines: A Systematic Review. Proc 1st Int Conf Public Adm Scoial Sci (ICoPASS 2024) Univ Sultan Ageng Tirtayasa 1(1): 149-173.

14. GPDRR (2026) The Government of Indonesia hosts GP2022. Global Platform for Disaster Risk Reduction.

15. Chandra A, Acosta J, Howard S, Pines UL, Williams M, et al. (2011) Building community resilience to disasters: A way forward to enhance national health security. Rand health quarterly 1(1): 6.

16. Ramadhan C, Dina R, Nurjani E (2023) Spatial and temporal based deforestation proclivity analysis on flood events with applying watershed scale (case study: Lasolo watershed in Southeast Sulawesi, Central Sulawesi, and South Sulawesi, Indonesia). Int J Disaster Risk Reduct 93: 103745.

17. Arifanti VB, Basyuni M, Suharti S, Slamet B, Karlina E, et al. (2025) Assessing the environmental and socioeconomic impacts of mangrove loss in Indonesia: A synthesis for science-based policy. Forest Sci Technol 21(4): 430-446.

18. Das K (2026) Climate Change Is Making Cyclones More Intense and Long-lasting. Asian Scientist.

19. IFRC (2022) Disaster Recovery in Indonesia: A Legal and Policy Survey. Geneva.

20. Subiyakto R, Pujiyono B, Akhyary E, Poti J (2025) Collaborative Governance in Natural Disaster Mitigation in Karimun District, Kepulauan Riau Province, Indonesia. Environ Ecol Res 13(2): 304-311.

21. Muhammad IN, Sarpono S, Wibowo A, Setiawibawa R, Kurniadi A (2025) Linking Land Cover to Flood Vulnerability: A Study on Vegetation Indices and Urban Build-Up in Hazard Mapping. J Geogr Sci Educ 3(2): 229–240.

22. Tedjaprasadja L (2025) Early Warning System for Disaster Preparedness in Local Flood Management. J Divers Med Res Medicosph 2(6): 240–247.

23. Budiman, Amalinda F (2025) Strengthening Community-Based Disaster Preparedness: Strategies, Barriers, and Policy Implications. Resiliensi J Mitigasi dan Adapt Bencana 1(1): 1–15.

24. Syahimin AN (2023) Community Resilience and Disaster Preparedness: A Social Analysis of Vulnerability and Coping Mechanisms in Indonesian Villages. J Asian Multicult Res Soc Sci Study 4(4): 9–18.

25. Inácio M, Karnauskaitė D, Mikša K, Gomes E, Kalinauskas M, et al. (2022) Nature-Based Solutions to Mitigate Coastal Floods and Associated Socioecological Impacts. In: Handbook of Environmental Chemistry (1st edn.) Springer Science and Business Media Deutschland GmbH p. 35-58.

26. Ruangpan L, Vojinovic Z, Plavšić J, Curran A, Rosic N, et al. (2024) Economic assessment of nature-based solutions to reduce flood risk and enhance co-benefits. J Environ Manage 352.

27. Tanaka MK, Surminski S (2024) Nature-based solutions for flood management in Asia and the Pacific.

28. Dube E, Wedawatta G, Ginige K (2021) Building-Back-Better in Post-Disaster Recovery: Lessons Learnt from Cyclone Idai-Induced Floods in Zimbabwe. Int J Disaster Risk Sci (12)5: 700-712.

29. Mannakkara S, Wilkinson S, Francis TR (2014) Build Back Better' Principles for Reconstruction. In: Encyclopedia of earthquake engineering 343: 1.

30. Mezinska S, Kakuk P, Mijaljica G, Waligóra M, O'Mathúna DP (2016) Research in disaster settings: a systematic qualitative review of ethical guidelines. BMC Med Ethics 17(1): 62.

31. Pare G, Kitsiou S (2025) Methods for Literature Reviews. In: Handbook of e-Health Evaluation: An Evidence-based Approach.

32. Snyder H (2024) Designing the literature review for a strong contribution. J Decis Syst 33(4): 551-558.

33. Hopkins KG, Welles JS, Pindilli EJ, Noe GB, Claggett PR, et al. (2023) Societal benefits of floodplains in the Chesapeake Bay and Delaware River watersheds: Sediment, nutrient, and flood regulation ecosystem services. J Environ Manage 345: 18747.

34. Fiantis D, Minasny B, Ginting FI (2025) Sumatra's flood crisis: How deforestation turned a cyclonic storm into a likely recurring tragedy. The Conversation.

35. Bloomberg (2026) Climate change supercharged $20 billion Asia floods, study finds. The Japan Times: Environment -Climate Change.

36. Alhadi Z, Rahman A, Yusran R, Eriyanti F, Antomi Y, et al. (2025) Dynamics of Flood and Landslide Risk Governance Policy in Solok Regency, Indonesia. Int J Saf Secur Eng 15(6): 1197–1217.

37. Fitriyati N, Arifin HS, Kaswanto RL, Marimin (2024) Enhancing land use planning through integrating landscape analysis and flood inundation prediction Bekasi City's in 2030. Geomatics Nat Hazards Risk 15(1).

38. Suprayoga H (2020) Disaster Management in the Implementation of the 2030 Sustainable Development Goals in Indonesia. J Indones Sustain Dev Plan 1(1): 105-111.

39. El-Fitra I (2026) Analysis: Deforestation ignored as Sumatra faces its worst flood disaster," The Jakarta Post: Opinion Academia.

40. Henao Salgado MJ, Zambrano Nájera J (2022) Assessing Flood Early Warning Systems for Flash Floods. Front Clim 4.

41. Islam MM, Hasan M, Mia MS, Al Masud A, Islam ARMT (2025) Early warning systems in climate risk management: Roles and implementations in eradicating barriers and overcoming challenges. Nat Hazards Res 5(3): 523–538.

42. Zahri R, Md Ali AH, Rambat S, Ghazali NH, Ahmad Y, et al. (2025) Flood Early Warning Systems (FEWS) in Enhancing Disaster Risk Reduction and Community Resilience: A Systematic Review. IJLGC Int J Law Gov Commun 10(40): 425-445.

43. Downing TE, Patwardhan A (2002) Adaptation Planning Framework Technical Paper 3: Vulnerability assessment for climate adaptation.

44. Tripathi PK, Prabhakaran G, Gayathri NM, Nautiyal S (2025) Disaster Risk Reduction and Management. BR Publications.

45. Chen Z, Feng M, Johnson MF, Wright N, Weng Y (2026). Flash Floods in Mountainous Regions: Global Research Trends, Process Mechanisms, and Control Measures. EGUsphere p. 1-42.

46. Nichelatti E, Oppel A, Tagem A (2025) The rising tide: floods as drivers of income and welfare inequality in South Africa pp. 153.

47. OCHA (2025) Indonesia Humanitarian Coordination Platform (IHCP) Situation Report #1 - Floods, flash floods and landslides - Provinces of Aceh, North Sumatra, and West Sumatra (December 2, 2025).

48. Polri INP (2026) Death Toll Climbs in Aceh, North Sumatra and West Sumatra Disaster. INP Polri: National.

49. Mille J, Charlton D, de Ruiter MC, Stevens R, Haklay M, et al. (2025) Understanding energy system dynamics in a changing climate: Insights for first responders and risk managers. IScience 28(9): 113320.

50. Campos RE, Sevilla CS, Barbany CJM, Sauri BM, Peco GS, et al. (2025) Co-creating educational action to protect children after DANA floods in Spain. Sustainability 17(4): 1542.

51. Zabulis X, Partarakis N, Zidianakis E, Kaplanidi D (2025) A Critical Review of the Function of Intangible Cultural Heritage as a Driver for Social Resilience and Cohesion. Encyclopedia 5(4): 189.

52. Juliastuti Y, Wijayanti AAS, Gunawan E, Irwansyah S, Wulandari (2024) Nature-Based Solutions for Flood Mitigation in Metropolitan Areas. ETASR Eng Technol Appl Sci Res 14(6): 18896-18901.

53. de Groot L, Demeijer FA, Zweekhorst M, Urias E (2025) Multi-stakeholder networks in the higher education context: a configurative literature review of university-community interactions. J High Educ Policy Manag 47(4): 490-508.

54. UNDP (2022) Accelerating Climate Change Adaptation Investment Planning to Enhance Resilience in Indonesia.

55. Djalante R (2012) Adaptive governance and resilience: the role of multi-stakeholder platforms in disaster risk reduction. Nat Hazards Earth Syst Sci 12(9): 2923–2942.

56. Yilmaz MU (2025) Enhancing Sustainable Flood Risk Management Through a Novel Fuzzy Multi-Stakeholder Framework. Water Resour Manag 39(3): 1453-1480.

57. Vollmer M, Berchtold C, Anniés J (2025) Co-creating solutions for Disaster Risk Reduction in multi-country research projects–Opportunities and Challenges. Int J Disaster Risk Reduct 117: 105187.

58. Rokhideh M, Fearnley C, Budimir M (2025) Multi-Hazard Early Warning Systems in the Sendai Framework for Disaster Risk Reduction: Achievements, Gaps, and Future Directions. Int J Disaster Risk Sci 16(1): 103–116.

59. Salma (2026) Expert Urges Ecosystem-Based Conservation to Solve Ciliwung Watershed Crisis. UGM News Report.

60. Alam KA, Sagala S, Adysti RT, Wibowo HA, Abdullah AAA, et al. (2025) Policy Brief: Key Recommendations for Mitigating Future Urban Flood Risks in a Changing Climate: The March 2025 Greater Jakarta Flood Aftermath.

61. Rifai AI, Prasetijo, J Isradi M, Sari YA, Zolkipli MF (2025) Flood and landslide exposure awareness for mitigation of road network performance: a community-based approach. SINERGI 29(2): 411.

62. Li P, Sheng M, Yang D, Tang L (2019) Evaluating flood regulation ecosystem services under climate, vegetation and reservoir influences. Ecol Indic 107: 105642.

63. Pirasteh S, Gholami MD, Li H, Wang T, Zenner EK, et al. (2025) Social vulnerability: A driving force in amplifying the overall vulnerability of protected areas to natural hazards. Heliyon 11(4).

64. Majidi A, Hosseini SA (2025) Dynamic Adaptive Policy Pathways Approach to Manage Climate and Land Use Change-Induced Urban Flood Damages. J Flood Risk Manag 18(2): e70074.

65. Liu X, Liu X, Liu T, Yu M, Yang Y (2026) Seasonal migration of flood risk: Multi-ecosystem threshold triggering and adaptive management. Ecol Indic 182: 114557.

66. Giofandi EA, Tjahjono B, Rachman ML (2024) Understanding the impact of land use change on urban flood susceptibility mapping assessment: A review. J Degrad Min Lands Manag 11(3): 6025-6035.

67. UNDRR (2025) GAR 2025 Hazards: Floods.

68. Leuven J (2026) How can nature-based approaches help prevent flood disasters?. Haskoning-Enhancing Society Together: Newsroom.

69. WCDRR (2015) Issue Brief: Reconstructing after disasters: build back better. Sendai.

70. Demirci FS, Isik Z (2026) Developing a community responsive resilient contractor selection model for post-disaster reconstruction projects: a build back better approach. Eng Constr Archit Manag 33(2): 1702-1737.

71. Berry LL, Danaher TS, Keiningham T, Aksoy L, Andreassen TW (2025) Social Profit Orientation: Lessons from Organizations Committed to Building a Better World J Mark 89(2): 1-19.

72. Çetin S, Kirchherr J (2025) The Build Back Circular Framework: Circular Economy Strategies for Post-Disaster Reconstruction and Recovery. Circ Econ Sustain 5(3): 1689-1726.

73. DeAngeli E, Holmes B, Walls MA (2026) Nature-Based Solutions 101. Resources for the Future.