



Rising Strong in a Drowning Land: Women's Leadership at the Helm of Transformative Coastal Resilience and Inclusive Climate Governance

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Abstract. Coastal regions in Indonesia are undergoing profound biophysical and social transformations driven by land subsidence, tidal flooding, and accelerated shoreline loss. Sriwulan Village in Demak Regency exemplifies a “drowning landscape,” where permanent inundation converges with entrenched social and gender inequalities. This study presents one of the first empirically grounded coastal resilience frameworks to position women’s leadership not as a complementary social component, but as a central institutional and governance mechanism for Nature-Based Solutions and climate adaptation. Using a mixed-methods approach that combines household surveys, focus group discussions, spatial and remote-sensing analysis, Livelihood Vulnerability Index assessment, and gender-focused analysis guided by the Gender Analysis Pathway and the Gender Equality and Social Inclusion framework, the research identifies persistent gaps in access, mobility, participation, and disaster information. Simultaneously, it documents strong yet largely informal leadership roles held by women in community preparedness, early warning, and environmental stewardship. The study delivers a gender-responsive Coastal Resilience Master Plan that integrates Nature-Based Solutions, a women-centered early warning system, and institutional arrangements that formalize women’s leadership within local climate governance. The findings demonstrate that embedding women’s leadership at the core of adaptation systems enhances adaptive capacity, strengthens governance effectiveness, and enables transformative pathways toward equitable and resilient coastal futures.

Keywords: Climate Governance, Coastal Resilience, Gender Equality and Social Inclusion (GESI), Livelihood Vulnerability Index, Women’s Leadership.

1 Introduction

In recent decades, land subsidence, coastal erosion, and intensifying hydrometeorological extremes. Low-lying coastal plains and deltaic systems are particularly vulnerable, as even modest increases in relative sea level can trigger cascading impacts on settlements, infrastructure, food systems, and livelihoods. These risks are especially pronounced in the Global South, where rapid socioeconomic transformation, governance constraints, and social inequalities intersect with accelerating climate pressures [1–3].

Indonesia’s northern coast of Java represents one of the most extreme global manifestations of compounded coastal risk. While the global mean sea level rise currently averages approximately 3 to 4 mm per year, relative sea level rise along the Java coast is amplified several times over by severe anthropogenic land subsidence driven by excessive groundwater extraction, sediment starvation, and coastal urbanization [4–6]. In several locations, subsidence rates exceed 5 to 10 cm per year, rendering conventional hard engineering responses, such as sea walls and embankments, ineffective and, in some cases, accelerating maladaptation [7–9]. Consequently, large areas have transitioned from episodic flooding to chronic and permanent inundation, fundamentally transforming coastal landscapes and undermining long term habitability.

Within this regional context, Demak Regency in Central Java has emerged as a critical hotspot of coastal

degradation. Sriwulan Village exemplifies this trajectory, experiencing daily tidal flooding locally known as rob, deteriorating drainage and sanitation systems, declining freshwater quality, and progressive land loss. Importantly, these hazards are not sudden onset disasters but slow onset cumulative processes that erode livelihoods and social systems over time. Such chronic exposure remains insufficiently addressed by conventional disaster risk reduction frameworks, which are largely designed for discrete and event-based hazards [10].

The social impacts of these coastal transformations are deeply gendered. A substantial body of literature demonstrates that climate risks are shaped by gendered power relations, differentiated access to resources, mobility constraints, and unequal participation in decision-making processes [11–14]. In coastal communities, women, particularly those from low-income households, often experience heightened vulnerability due to caregiving responsibilities, limited evacuation mobility, and restricted access to formal disaster information and institutional support [9,15]. However, prevailing research and policy approaches continue to frame women primarily as passive recipients of climate risk rather than as active agents of adaptation and resilience.

This study shifts the coastal adaptation paradigm from infrastructure-focused protection to leadership-driven resilience by demonstrating that women's leadership, integrated with Nature-Based Solutions, is a core driver of climate adaptation. Using Sriwulan Village as a strategic case study, the research proves that ecological success heavily relies on gender-responsive governance and social ownership. Bridging theory and practice, the study translates these empirical insights into actionable tools: a Gender-Responsive Coastal Resilience Master Plan and a community-centered mobile early warning system for the Global South.

2 Theoretical And Conceptual Framework

2.1 Gender, Power, and Climate Risk

Climate change is not a gender neutral phenomenon. Feminist political ecology and gender and development scholarship have long demonstrated that climate risks are mediated through socially constructed power relations that shape access to resources, decision-making authority, mobility, and exposure to hazards [16–18]. In coastal contexts, these inequalities are often intensified by livelihood precarity, informal land tenure, and limited institutional presence, producing differentiated vulnerability across gender, age, and socioeconomic groups.

However, contemporary gender and climate literature increasingly challenges vulnerability-only framings that depict women solely as victims of climate change. Instead, scholars emphasize women's agency, leadership, and situated knowledge as critical yet underutilized assets for adaptation and resilience building [19,20]. Women often occupy central roles in household risk management, social networking, environmental stewardship, and informal governance structures, particularly in contexts where formal institutions are weak or absent [21].

This study adopts this agency-oriented perspective, positioning women not as beneficiaries of resilience interventions but as leaders and co-producers of climate solutions. Leadership is understood here not merely as formal authority but as relational influence exercised through social organization, knowledge sharing, collective action, and moral legitimacy within communities [22]. This conceptualization is especially relevant in chronic disaster settings such as tidal flooding and land subsidence, where everyday adaptive practices and long-term social coordination are more decisive than emergency response alone.

2.2 Gender Responsive Disaster Risk Reduction and Inclusive Governance

The framework further draws on gender responsive disaster risk reduction and inclusive governance theories, which emphasize that equitable participation in decision-making processes directly influences the effectiveness and sustainability of risk reduction measures [23,24]. International policy instruments, including the Sendai Framework for Disaster Risk Reduction, explicitly recognize gender equality and inclusive governance as priorities, yet empirical implementation remains limited, particularly at local levels [25].

Gender responsive disaster risk reduction extends beyond sex disaggregated data collection. It requires systematic analysis of gender roles, power relations, and structural barriers across all phases of the disaster risk management cycle, including risk assessment, preparedness, response, recovery, and long-term adaptation [26]. Tools such as the Gender Analysis Pathway and the Gender Equality and Social Inclusion framework provide structured methodologies to identify gaps in access, participation, control over resources, and benefit distribution [27].

2.3 Nature-Based Solutions as Socio-Ecological Systems

Nature Based Solutions are increasingly promoted as cost-effective and multifunctional approaches to climate adaptation, particularly in coastal environments where mangroves, wetlands, and vegetated shorelines can attenuate

waves, reduce erosion, and enhance ecosystem services [28–30]. However, emerging scholarship cautions that NbS outcomes are not determined solely by ecological performance but are deeply shaped by governance arrangements, land tenure, and social inclusion [31].

This research adopts a socio-ecological systems perspective, viewing NbS as co-produced interventions that link ecological restoration with social organization and institutional support. In this framework, mangrove conservation and coastal green infrastructure are not treated as isolated technical measures but as collective practices that require sustained community stewardship, legitimacy, and leadership.

Women's leadership is theorized as a catalytic force within NbS implementation. Women often possess intimate knowledge of coastal ecosystems through daily livelihood activities and caregiving roles, positioning them as effective stewards of long-term environmental management [32]. When women are excluded from planning and governance, NbS risk becoming externally imposed, weakly maintained, or socially contested. Conversely, when women lead, NbS can strengthen both ecological resilience and social cohesion.

2.4 Transformative Coastal Resilience

The concept of resilience employed in this study aligns with transformative rather than absorptive or adaptive interpretations. Transformative resilience emphasizes the capacity of systems to reconfigure underlying structures that produce vulnerability, including governance arrangements, power relations, and development pathways [9,33,34]. This perspective is particularly relevant in subsiding coastal regions where returning to pre-disaster conditions is neither possible nor desirable.

2.5 Study Area: Sriwulan Village, Demak Regency



FIGURE 1. Location of Sriwulan Village within Demak Regency, Central Java, Indonesia, showing low-lying coastal morphology and proximity to the Java Sea as reported by Susilorini, et.al. [35]

Sriwulan Village is situated along the northern coastline of Demak Regency, Central Java, Indonesia, within a rapidly subsiding and tidally dominated coastal plain that borders the Java Sea (Figure 1). The village occupies former agricultural and aquaculture land formed by unconsolidated Holocene alluvial and marine sediments, rendering it highly susceptible to land subsidence, tidal flooding (rob), and shoreline retreat. These biophysical characteristics, combined with intensive groundwater abstraction and declining sediment supply, have accelerated relative sea-level rise far beyond global averages.

3 Methodology

3.1 Research Design and Analytical Approach

This study employed a mixed-methods, transdisciplinary research design to capture the complex interactions between coastal hazards, social vulnerability, governance structures, and women's leadership in Sriwulan Village, Demak Regency. The methodological approach integrates quantitative spatial and socio-economic analysis with qualitative participatory and institutional assessment, enabling both empirical rigor and contextual depth. The research was structured in four interlinked phases:

- a. baseline risk and vulnerability assessment,
- b. gender-responsive socio-institutional analysis,

- c. co-production of adaptation solutions, and
- d. validation and knowledge mobilization.

This sequential yet iterative design ensured that empirical findings directly informed applied outputs, namely the “Gender-Responsive Coastal Resilience” Master Plan and the Mobile “Flood and Tidal Early Warning System”, while remaining grounded in community realities and governance constraints.

3.2 Study Population and Sampling Strategy

The study population comprised households, community leaders, women’s groups, local economic actors, and institutional stakeholders in Sriwulan Village. A stratified purposive sampling strategy was adopted to ensure representation across gender, age, livelihood type, and exposure to flood and tidal risks.

Quantitative household surveys targeted flood-prone neighborhoods, particularly RW 2 and RW 8, which experience recurrent inundation exceeding 150–190 cm during peak tides. Special emphasis was placed on women-headed households, elderly residents, and caregivers, reflecting their heightened exposure and adaptive responsibilities. Qualitative participants for focus group discussions and in-depth interviews were selected based on leadership roles, experiential knowledge of flooding, and involvement in community-based initiatives such as waste banks, mangrove planting, and disaster preparedness groups.

3.3 Data Collection Methods

Primary and Secondary Data Collection. Data collection integrated comprehensive primary and secondary sources. Primary data were obtained through structured household surveys, gender-segregated focus group discussions (FGDs), and in-depth stakeholder interviews to map vulnerabilities, women’s leadership dynamics, and community adaptation strategies. Meanwhile, secondary data from government agencies (e.g., BPS and BMKG), spatial planning documents, and academic literature provided institutional and historical context to validate the empirical findings.

Spatial and Environmental Analysis. Spatial analysis formed a core methodological component of the study. Multi-temporal satellite imagery, village land records, and participatory mapping outputs were integrated using geographic information systems to assess shoreline change, land loss, flood extent, and infrastructure exposure. Participatory mapping sessions were conducted with community members, particularly women, to ground-truth spatial data and identify critical assets, evacuation routes, and frequently inundated zones. This approach ensured that spatial outputs reflected lived experience rather than solely remote sensing interpretations. The resulting maps directly informed the zoning, infrastructure recommendations, and Nature-Based Solutions proposed in the Master Plan.

Analytical Significance of the Study Area. The convergence of rapid land loss, chronic tidal flooding, failing infrastructure, groundwater-induced subsidence, and strong yet under-recognized women’s leadership renders Sriwulan Village an analytically critical case for studying transformative coastal resilience. Unlike contexts dominated by short-term disaster shocks, Sriwulan exemplifies a slow-onset disaster regime where resilience depends on long-term governance reform, inclusive leadership, and socio-ecological integration. By embedding high-resolution spatial analysis with gender-responsive institutional assessment, this study positions Sriwulan as a living laboratory for testing Nature-Based Solutions integrated with women-led climate governance. The empirical insights derived from this setting directly inform the development of the Gender-Responsive Coastal Resilience Master Plan and provide transferable lessons for other subsiding coastal regions in Indonesia and the Global South.

Livelihood Vulnerability Index (LVI). To quantify socio-economic vulnerability, the study applied the Livelihood Vulnerability Index, adapted to the coastal and gendered context of Sriwulan Village. The LVI integrates indicators across exposure, sensitivity, and adaptive capacity, including livelihood diversity, health access, water security, social networks, and disaster preparedness. Gender-disaggregated analysis was conducted to identify differential vulnerability patterns between men and women, as well as among women of different age groups and household structures. The LVI results provided an empirical basis for prioritizing interventions targeting women-headed households and informal economic sectors disproportionately affected by flooding.

Gender Analysis Pathway and GESEI Framework. A central methodological innovation of this study lies in the systematic application of the Gender Analysis Pathway (GAP) in conjunction with the Gender Equality and Social Inclusion (GESEI) framework. This analytical process examined gendered differences in access to resources and services, participation in decision-making, control over assets and information, and distribution of benefits from adaptation interventions. The analysis revealed structural gaps in early warning access, evacuation planning, and infrastructure design, while simultaneously highlighting women’s leadership roles in informal risk governance. These insights were operationalized in both the Master Plan and the mobile application, ensuring that outputs were not merely gender-sensitive but gender-responsive.

Co-Production of Solutions and Intervention Design. Rather than treating communities as research subjects, the study adopted a co-production approach, engaging women and local stakeholders as partners in solution design. Iterative workshops were conducted to refine Nature- Based Solutions, infrastructure priorities, evacuation strategies, and application features. Women's inputs were particularly influential in shaping mangrove restoration strategies, placement of green infrastructure, and the usability of the early warning system. This process enhanced local ownership and increased the likelihood of sustained implementation beyond the research period.

Validation, Ethics, and Knowledge Mobilization. Validation workshops were held to present preliminary findings and draft outputs to community members and institutional stakeholders. Feedback was systematically incorporated into final deliverables, ensuring accuracy and legitimacy. Ethical considerations included informed consent, confidentiality, and gender-sensitive facilitation practices. The research adhered to principles of inclusivity and respect, particularly in engaging vulnerable groups. Knowledge mobilization was embedded throughout the methodology, culminating in the dissemination of findings through policy briefs, training sessions, and integration into local and regional planning processes. This ensured that the research generated not only academic contributions but tangible governance and resilience outcomes.

Methodological Contribution. By integrating spatial analysis, vulnerability indexing, gender analysis, and participatory co-production within a single coherent framework, this methodology advances applied disaster research beyond conventional assessment- driven studies. It demonstrates how gender-responsive leadership can be empirically identified, analytically structured, and operationalized into concrete adaptation tools for coastal resilience.

4 Results And Discussion

4.1 Biophysical Transformation: Flooding, Subsidence, and Land Loss

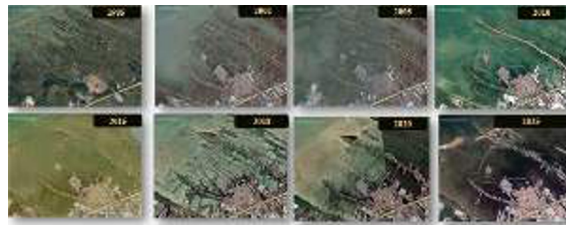


FIGURE 2. Coastal land loss in Sriwulan Village and Demak Regency, illustrating permanent inundation of 374.17 ha at the village scale and 2,116.54 ha at the regency scale (1985–2025) as reported by Susilorini, et.al. [35,36]

Figure 2 depicts the magnitude and spatial configuration of coastal land loss in Sriwulan Village and across Demak Regency, documenting permanent inundation of 374.17 ha at the village scale and 2,116.54 ha at the regency scale over the period 1985–2025, as reported by Susilorini et al. [35,36]. Derived from an integrated spatial analysis that combines multi-temporal satellite imagery, village land administration records, and participatory mapping with local communities, these findings provide a robust empirical foundation for understanding the accelerating biophysical transformation of the northern Java coastline.

At the local scale, the analysis confirms that 374.17 hectares of land within and immediately surrounding Sriwulan Village have undergone irreversible conversion from terrestrial to marine environments, with losses concentrated in former rice fields and aquaculture ponds. These areas, once central to household livelihoods and local food systems, are now permanently submerged, signifying not merely environmental degradation but the erasure of productive socio-ecological space. At the broader regency scale, cumulative land loss of 2,116.54 hectares reveals that Sriwulan's experience is embedded within a systemic pattern of coastal retreat affecting multiple settlements along the Demak shoreline. This convergence of local and regional trends underscores the structural nature of the hazard, driven by the compounded effects of land subsidence, sea-level rise, and altered coastal hydrodynamics.

Temporal analysis of shoreline positions illustrates a progressive inland migration of the coastline, accompanied by fragmentation and spatial isolation of settlement clusters. What were previously episodic flood events associated with extreme tides or storms have evolved into chronic, daily tidal inundation, fundamentally altering the functional relationship between land and sea. Flood extent mapping further demonstrates that the most severe impacts are concentrated in RW 2 and RW 8, where maximum tidal water levels reach up to 193 cm, routinely submerging residential areas, road networks, and drainage infrastructure. In these zones, tidal flooding has become a persistent

background condition rather than an exceptional event.

Overlay analysis of infrastructure and inundation patterns reveals a profound reconfiguration of everyday space. Critical access roads now operate as de facto tidal channels during high tides, severely constraining mobility, disrupting economic activity, and impeding emergency response and evacuation. Drainage systems, originally designed for surface runoff, are rendered ineffective under backflow conditions, further entrenching standing water and sanitation risks. These dynamics exacerbate existing vulnerabilities and disproportionately affect women, older adults, and children, for whom mobility limitations and care responsibilities intensify exposure to daily flood impacts. Collectively, these findings demonstrate that Sriwulan Village is no longer confronting a temporary or cyclical flood risk but is experiencing a structural transformation of the land–sea interface. The conversion of once-productive land into permanent open water marks a transition from hazard exposure to territorial loss, with cascading implications for spatial planning, governance, livelihoods, and social cohesion. This condition demands a fundamental rethinking of coastal resilience, shifting from short-term, emergency-oriented responses toward long-term, anticipatory, and transformative adaptation strategies that address both biophysical change and the social dimensions of vulnerability. In this context, Sriwulan emerges not only as a site of crisis but as a critical laboratory for advancing gender-responsive and nature-based approaches to coastal resilience under accelerating climate change.

Tidal Flooding Dynamics and Infrastructure Exposure. Hydrodynamic observations and community reporting integrated into the project’s spatial database indicate that tidal flood depths in Sriwulan reach up to 193 cm during peak high tides, particularly in RW 2 and RW 8, where elevation is lowest, and drainage capacity is severely compromised [35]. The road networks, drainage channels, and residential areas are regularly inundated, disrupting daily mobility, access to education and health services, and emergency evacuation routes [36].

The analysis confirms that existing gray infrastructure, including embankments and drainage channels, is structurally inadequate and functionally mismatched to the scale and dynamics of relative sea-level rise. Drainage channels frequently act as conduits for seawater intrusion rather than discharge systems, exacerbating standing water conditions [36].

Groundwater Dependence, Subsidence, and Sanitation Stress. Household surveys and technical assessments show that most residents continue to rely on groundwater extracted from wells at depths of approximately 30–40 meters, both for domestic use and small-scale livelihoods [35,36]. This dependence contributes to ongoing aquifer compaction and land subsidence, reinforcing a feedback loop between water insecurity and flood exposure. Sanitation mapping conducted as part of the Master Plan reveals that a significant proportion of households lack functional septic systems. This research observed that the wastewater is often discharged directly into drainage channels or coastal waters, heightening environmental degradation and public health risks, particularly for women, children, and elderly residents who remain in inundated areas throughout the day.

Socio-Demographic Patterns and Gendered Vulnerability. Demographic analysis highlights pronounced gendered and age-based vulnerability. Male out-migration for employment has resulted in a village population dominated by women, elderly persons, and children, particularly in the most flood-prone zones. While this demographic shift increases care burdens and mobility constraints, it also reveals strong informal leadership structures led by women through savings groups, waste banks (Bank Sampah), food processing collectives, and disaster preparedness networks [9,36]. Participatory mapping and focus group discussions documented in the Final Report of this research demonstrate that women play a central role in disseminating flood warnings, organizing evacuations, managing household-level adaptation, and maintaining mangrove planting initiatives [9]. These findings informed the design of the Gender-Responsive Mobile Early Warning System as explained in the document [37] and the next sub-section.

Livelihood Vulnerability and Socio-Economic Stressors. The Livelihood Vulnerability Index (LVI) analysis indicates high overall vulnerability, driven predominantly by exposure and sensitivity components. Households located in permanently inundated zones exhibit sharply reduced livelihood diversity as rice cultivation and aquaculture have become unviable due to salinity intrusion and standing water. Water insecurity emerged as a critical stressor. Survey results show that most households rely on groundwater wells at depths of 30–40 m, despite declining water quality and rising extraction costs. This dependence contributes to ongoing land subsidence, reinforcing a feedback loop between environmental degradation and vulnerability. Sanitation indicators further elevate vulnerability scores. A substantial proportion of households lack functional septic systems, resulting in direct wastewater discharge into drainage channels and coastal waters. Women reported disproportionate health and care burdens, particularly during prolonged inundation periods, reinforcing gendered patterns of risk and responsibility.

Gender-Responsive Coastal Resilience Master Plan. One of the central empirical and applied outcomes of this research is the Sriwulan Village Gender-Responsive Coastal Resilience Master Plan, which translates gender analysis and climate risk assessment into a spatially explicit, implementable adaptation framework. The Master Plan moves beyond conventional coastal engineering approaches by integrating Nature-Based Solutions (NbS), women’s

leadership, and inclusive governance into a single planning instrument tailored to a chronically inundated coastal settlement.

Master Plan Structure and Spatial Logic. The Master Plan is structured around a multi-layered spatial framework that aligns hazard exposure, socio- economic vulnerability, and gendered access to infrastructure. Spatial analysis identifies zones of permanent inundation, chronic tidal flooding, and relative safety, which are then overlaid with settlement patterns, road networks, drainage channels, and community facilities. This zoning forms the basis for differentiated intervention strategies, including coastal greenbelts, adaptive settlement upgrading, and evacuation-oriented infrastructure improvements. The plan explicitly prioritizes Nature-Based Solutions as the first line of defense. Mangrove restoration zones, sediment-trapping vegetated buffers, and rehabilitated coastal wetlands are proposed along the most exposed shoreline segments. These interventions are designed not only to attenuate wave energy and reduce tidal flooding but also to restore ecosystem services that support local livelihoods, particularly women-led aquaculture processing and small- scale fisheries. In this sense, ecological restoration is treated as both a biophysical and socio-economic resilience strategy.

Gender Analysis Pathway as a Planning Engine. A key innovation of the Master Plan is the operationalization of the Gender Analysis Pathway (GAP) as a core planning engine rather than a supplementary social assessment. Findings from gender-disaggregated surveys, participatory mapping, and livelihood vulnerability analysis are directly embedded into spatial and programmatic decisions. For example, locations of evacuation routes, communal shelters, and access roads are informed by women’s daily mobility patterns, caregiving responsibilities, and safety concerns identified during field engagement. Women’s leadership is institutionalized through proposed community governance mechanisms embedded in the Master Plan. These include women-led disaster preparedness units, stewardship roles in mangrove conservation areas, and formal representation of women’s groups in village-level disaster risk reduction and spatial planning forums. This approach repositions women from perceived “vulnerable beneficiaries” to strategic actors shaping resilience outcomes.

Integration with Early Warning Systems and Governance. The Master Plan is designed to function synergistically with the Gender-Responsive Flood and Tidal Early Warning System, ensuring that spatial planning, preparedness, and real-time risk communication reinforce one another. Safe zones, evacuation routes, and critical facilities identified in the Master Plan are directly referenced within the Early Warning System interface, strengthening coherence between planning and emergency response. From a governance perspective, the Master Plan provides a policy-ready instrument aligned with district and provincial spatial planning frameworks. Its structure enables vertical integration into regional coastal management strategies while retaining strong community ownership at the village level. This dual orientation enhances the feasibility of implementation and long-term sustainability.

Transformative Contribution. The results demonstrate that the Master Plan functions not merely as a technical document but as a transformative governance tool. By embedding gender analysis, NbS, and participatory planning into spatial decision-making, it redefines coastal resilience as a process of social-ecological transformation rather than short-term risk mitigation. The Sriwulan Master Plan thus offers a replicable model for other low-lying coastal communities facing compound climate risks, particularly where gender inequalities intersect with environmental degradation. Hence, the empirical findings were translated into actionable planning interventions. Table 1 synthesizes the linkages between key components of the Gender-Responsive Coastal Resilience Master Plan, the primary coastal risks they address, and the gendered insights generated through the Gender Analysis Pathway. The table demonstrates how differentiated vulnerability and leadership capacities identified among women in Sriwulan Village informed the design of targeted spatial, ecological, technological, and governance interventions, and how these interventions are expected to generate measurable resilience, inclusion, and governance outcomes. By explicitly mapping risks to gender-responsive planning responses, the table illustrates the operational logic through which women’s leadership is institutionalized as a strategic driver of transformative coastal resilience rather than a supplementary social consideration.

TABLE 1. Linkages Between Master Plan Components, Coastal Risks, Gender Insights, and Expected Impacts

Master Plan Component	Primary Coastal Risks Addressed	Gender Analysis Pathway (GAP) Insights	Expected Impacts on Resilience and Governance
		Women and elderly residents	Reduced exposure through risk-
Gender-Responsive Spatial Zoning and Risk-Based Land Use Planning	Coastal Green Infrastructure)	Gender-Responsive Flood and Tidal Early Warning System (EWS)	Diversification and Adaptive Economic Zones
Nature-Based Solutions (Mangrove Restoration and	Gender-Safe Evacuation Routes and Shelter Planning	Livelihood	Water, Sanitation, and Drainage Improvement (Climate-Resilient WASH)

Institutionalization of Women's Leadership in Village Disaster Governance	Permanent land loss; chronic tidal flooding; settlement fragmentation	disproportionately remain in permanently inundated zones due to male out-migration and caregiving responsibilities	sensitive zoning; improved safety for women and dependents; enhanced legitimacy of spatial planning through inclusive participation
Community Capacity Building and Knowledge Mobilization	Shoreline erosion; wave overtopping; ecosystem degradation	Women possess strong experiential knowledge of coastal ecosystems and lead informal mangrove stewardship initiatives	Increased ecological durability of NbS; strengthened community ownership; integration of livelihoods and ecosystem services
	Deep tidal flooding (up to 193 cm); infrastructure submergence; limited mobility	Women face mobility constraints during evacuation due to caregiving roles and safety concerns	Improved evacuation efficiency; reduced physical risk for women, children, and elderly; safer access to emergency services
	Sudden tidal surges; delayed risk communication; information asymmetry	Women act as trusted local information brokers but lack access to formal early warnings	Enhanced preparedness and anticipatory action; increased women's confidence and leadership in disaster response
	Loss of agriculture and aquaculture livelihoods; salinity intrusion	Women manage household economies and informal safety nets amid livelihood collapse	Increased adaptive capacity; reduced economic vulnerability; strengthened women-led local economies
	Standing water; sanitation failure; public health risks	Women bear disproportionate care burdens related to water access and sanitation management	Improved health outcomes; reduced care burden; enhanced dignity and safety in flood-prone environments
	Fragmented governance; weak coordination; exclusion from decision-making	Women lead preparedness and response informally but are underrepresented in formal institutions	Strengthened disaster risk governance; alignment with SDG 5.5 and Sendai Priority 2; sustainable leadership pathways
	Limited risk awareness; weak adaptive learning	Women serve as key agents of social learning and knowledge transfer	Long-term resilience through adaptive governance; increased institutional trust and social cohesion

4.2 Early Warning Systems for Inclusive Flood Preparedness

A gender-responsive Early Warning System (EWS) can substantially improve flood preparedness and community inclusion by addressing the social and informational asymmetries that often limit the effectiveness of conventional, technically driven warning mechanisms. In flood-prone coastal contexts such as Sriwulan Village, early warning is not merely a matter of hazard detection but of whether warnings are accessible, intelligible, trusted, and actionable across diverse social groups, particularly women, older adults, and low-literacy users. The development and pilot implementation of a Progressive Web App (PWA)-based EWS in this study demonstrates how integrating gender considerations into system design can transform early warning from a one-way information broadcast into a participatory resilience platform [37]. The EWS can be accessed by the link <https://sriwulan.web.id/> and have user-interface as presented by Figure 3.

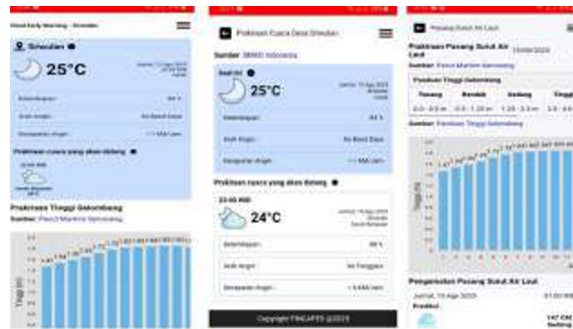


FIGURE 3. The User-Interface of the EWS (Home, Weather, Seawater Level)

The EWS was co-developed and tested collaboratively with local women’s groups, ensuring that system architecture, content, and visual design reflected everyday risk experiences and communication practices. By integrating real-time data from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) on rainfall intensity and sea-level height, the system provides timely and anticipatory alerts, delivering flood warnings up to eight hours before predicted high tides. Crucially, these alerts are communicated through simplified text and icon-based notifications, enabling rapid comprehension under stressful conditions and reducing dependence on technical jargon that often excludes non-specialist users.

Beyond hazard notification, the system embeds preparedness within spatial and social contexts. Interactive flood maps visualize inundation-prone areas and clearly delineate safe evacuation routes, enabling households to translate warnings into concrete movement decisions. This spatial functionality is particularly important for women, who often manage evacuation logistics for children, older family members, and people with disabilities. The inclusion of a community chat function further strengthens horizontal and vertical communication, allowing residents to share real-time observations, coordinate responses, and directly engage with local authorities and disaster management actors. In doing so, the EWS shifts early warning from a top-down, institution-centered model toward a community-anchored communication ecosystem.

The pilot test conducted between June and August 2025 provides empirical evidence of the system’s effectiveness in enhancing both preparedness and inclusion. Of the 85 active users, 61% were women, indicating that the system successfully reached a demographic group often marginalized in digital disaster communication. User feedback reveals that 78% of participants found the alerts clear and understandable, while 69% actively used the evacuation map features, suggesting that the system supported both cognitive and behavioral aspects of preparedness. Most notably, 92% of women users reported increased confidence in their preparedness, underscoring the role of accessible information in strengthening perceived agency and decision-making capacity [9].

User feedback played a critical role in refining the system’s inclusivity. Iterative improvements, including enhanced color contrast, bilingual display options, and the expanded use of visual icons, were introduced to accommodate users with low literacy, age-related visual limitations, and diverse linguistic backgrounds. These adaptations illustrate that gender-responsive EWS design is not a static checklist but an adaptive learning process, responsive to user experience and grounded in principles of equity and accessibility.

Overall, the PWA-based, gender-responsive EWS demonstrates that early warning systems can serve as more than technical instruments for hazard detection. When designed through participatory processes and informed by gender

analysis, they become platforms for social inclusion, collective learning, and empowerment, strengthening not only the timeliness of flood response but also the capacity of communities, particularly women, to act as informed leaders in disaster preparedness and climate adaptation. A high-impact summary table that clearly highlights the strengths, innovations, and outcomes of the gender-responsive Early Warning System (EWS) is presented as Table 2.

TABLE 2. Key Strengths and Outcomes of the Gender-Responsive Early Warning System (EWS)

Dimension	Design Feature / Evidence	Key Strengths	Implications for Preparedness and Inclusion
Participatory Design	Co-developed with local women’s groups throughout design and testing phases	Ensures relevance to everyday risk experiences and local communication practices	Strengthens trust, uptake, and women’s ownership of disaster preparedness processes
Timeliness of Warning	Real-time integration of BMKG rainfall and sea-level data; alerts issued up to 8 hours before predicted high tides	Moves preparedness from reactive to anticipatory	Enables households to plan evacuation, secure assets, and coordinate care responsibilities
Accessibility of Information	Simplified text, visual icons, improved color contrast, bilingual display	Reduces exclusion related to literacy, age, and language barriers	Broadens access to early warning for women, older adults, and low-literacy users
Actionable Spatial Guidance	Interactive flood maps and clearly marked safe evacuation routes	Translates warnings into concrete, place-based action	Enhances evacuation efficiency, especially for women managing dependents
Two-Way Communication	Community chat linking residents, women leaders, and officials	Shifts early warning from one-way alerts to participatory communication	Improves situational awareness, peer support, and coordination during flood events
Preparedness Outcomes	69% of users accessed evacuation maps during pilot	Demonstrates practical use beyond information receipt	Indicates behavioral engagement with preparedness tools
Gender Inclusion	61% of active users were women	Confirms effective reach to a traditionally underserved group	Positions women as informed actors and decision-makers in disaster response
Perceived Preparedness	92% of women reported increased preparedness confidence	Strengthens psychological readiness and agency	Enhances women’s leadership roles in household and community-level response
Iterative Adaptation	User feedback led to interface and language improvements Safety guidance and eco-literacy	Embeds learning and flexibility into system design Links early warning with	Ensures long-term usability and sustainability of the EWS Supports long-term risk reduction
Knowledge Integration	resources embedded in the app	broader risk awareness and NbS principles	beyond immediate flood events

4.3 Gender Analysis Pathway

From Differential Vulnerability to Leadership Assets. Application of the Gender Analysis Pathway (GAP) constitutes a central empirical result of this study. The GAP synthesizes sex-disaggregated survey data, focus group discussions, and institutional interviews to systematically assess gendered differences in access, participation, control, mobility, and benefit distribution across the disaster risk reduction cycle.

The analysis reveals persistent structural gaps: women have limited access to formal early warning information, minimal representation in village-level disaster decision-making forums, and constrained mobility during flood events due to caregiving responsibilities and safety concerns. These gaps directly increase women’s exposure and adaptive burden.

At the same time, the GAP documents robust informal leadership capacities exercised by women. Women act as primary information brokers at the neighborhood scale, coordinate household-level evacuation, manage food security during flooding, and lead community-based initiatives such as waste banks and mangrove stewardship groups. These leadership roles are relational, practice-based, and continuous, operating outside formal institutional recognition.

By explicitly mapping both vulnerability gaps and leadership assets, the GAP reframes women from passive risk bearers to central governance actors. This reframing represents a key empirical and conceptual contribution, demonstrating that gender-responsive resilience depends not only on reducing vulnerability but on institutionalizing existing leadership capacities.

Institutional and Governance Misalignment. Institutional analysis highlights a significant misalignment between local risk realities and prevailing governance frameworks. Existing spatial plans and sectoral policies prioritize gray infrastructure while insufficiently addressing land subsidence, long-term habitability, and gender inclusion.

Coordination between village authorities, district agencies, and disaster management institutions remains fragmented. Early warning dissemination relies heavily on top-down channels that do not align with community-level communication practices identified through the GAP.

Nevertheless, stakeholder workshops reveal emerging openness among local authorities to participatory planning and Nature-Based Solutions, particularly when supported by empirically grounded, gender-responsive evidence. This institutional receptiveness created a critical entry point for co-produced adaptation outputs.

Translation of Empirical Findings into Applied Outputs. The integration of empirical findings through the Gender Analysis Pathway culminated in three interrelated applied outputs: a context-specific GAP as a governance instrument, a Gender-Responsive Coastal Resilience Master Plan, and a Gender-Responsive Mobile Flood and Tidal Early Warning System, as presented by Table 3.

TABLE 3. Linking Empirical Findings, GAP Insights, and Applied Outputs

Empirical Findings	Gender Analysis Pathway Insights	Applied Outputs
Permanent land loss (374.17 ha village; 2,116.54 ha regency)	Women disproportionately remain in inundated zones due to male out-migration	Risk zoning and relocation-sensitive planning in Master Plan
Chronic tidal flooding up to 193 cm	Women experience constrained mobility and safety risks during evacuation	Gender-responsive evacuation routes and warning protocols
High livelihood vulnerability and care burden	Women manage household adaptation and informal safety nets	Livelihood diversification and women-led NbS stewardship
Limited access to formal early warnings	Women act as trusted local information brokers	Mobile early warning system with two-way communication
Weak institutional coordination	Informal women’s leadership fills governance gaps	Institutionalization of women’s roles in Master Plan

Integrated Impact and Theoretical Contribution. The results demonstrate that vulnerability in Sriwulan Village is not solely a function of environmental exposure but is fundamentally shaped by governance structures and gendered power relations. By elevating the Gender Analysis Pathway as both a methodological and policy instrument, the study advances a transformative model of coastal resilience in which women’s leadership functions as a structural driver rather than a supplementary consideration.

The integration of GAP-driven analysis with spatial risk assessment and co-produced solutions contributes to resilience theory by empirically demonstrating how informal leadership can be translated into institutionalized governance mechanisms. This finding extends existing scholarship on Nature-Based Solutions and gender-inclusive adaptation by providing an operational pathway from analysis to implementation.

4.4 Gender Analysis Pathway as a Global Architecture for Transformative Coastal Resilience

Gendered Coastal Risk in the Context of Global Climate and Disaster Governance. The empirical findings presented in previous sections demonstrate that flood and tidal disaster risks in Sriwulan Village are deeply gendered and structurally produced. Women face disproportionate exposure due to caregiving responsibilities, restricted mobility, and limited access to formal disaster information, yet simultaneously act as primary agents of preparedness, early response, and environmental stewardship. This paradox reflects a broader global challenge identified in disaster risk reduction and climate governance frameworks: those most affected by climate risks are often excluded from decision-making processes.

Within the Sendai Framework for Disaster Risk Reduction (2015–2030), Priority 1 emphasizes understanding disaster risk through disaggregated data, while Priority 2 calls for inclusive disaster risk governance. However, as evidenced in Sriwulan, gender considerations frequently remain peripheral or symbolic in implementation. The findings, therefore, underscore a critical gap between global commitments and local practice, positioning gender not as a cross-cutting issue but as a foundational governance variable shaping risk production and resilience outcomes.

The Gender Analysis Pathway as an Integrative Methodological Architecture. The Gender Analysis Pathway (GAP) is advanced here as a methodological architecture that operationalizes global normative frameworks into locally actionable instruments. Unlike conventional gender mainstreaming approaches that often function as add-on assessments, the GAP embeds gender analysis within the core logic of research design, spatial planning, technological development, and policy formulation.

Conceptually, the GAP aligns with Sendai Priority 1 by generating gender-disaggregated risk data through surveys, participatory mapping, and livelihood vulnerability analysis. It advances Sendai Priority 2 by translating this evidence into governance mechanisms that institutionalize women's leadership. Simultaneously, it supports Sendai Priority 4 by strengthening preparedness and response through gender-responsive early warning systems.

In relation to the Paris Agreement, the GAP responds to Article 7 on adaptation by integrating gender-responsive approaches into local climate resilience planning. Rather than framing adaptation as infrastructure-heavy interventions, the GAP emphasizes governance capacity, social inclusion, and locally led adaptation, consistent with emerging interpretations of transformative adaptation under the Paris framework.

Conceptual Framework Aligned with Sendai–SDGs–Paris Agreement. Addressing chronic tidal flooding and land subsidence in highly vulnerable coastal settings requires more than technical risk reduction measures; it demands a governance framework capable of identifying structural inequalities, redistributing decision-making power, and translating local knowledge into institutionalized resilience actions. In Sriwulan Village, where climate hazards intersect with entrenched gender disparities, conventional disaster risk reduction approaches have proven insufficient to capture differentiated vulnerabilities, informal leadership roles, and the lived realities of women navigating daily inundation. To respond to these gaps, this study advances the Gender Analysis Pathway (GAP) as a unifying methodological and governance framework that connects gender-responsive risk analysis with applied resilience outputs and long-term transformative impacts.

The conceptual framework presented in Figure 3 synthesizes global policy commitments with locally grounded analytical processes. It explicitly aligns the Sendai Framework for Disaster Risk Reduction, the Sustainable Development Goals (SDGs), and the Paris Agreement with the Gender Analysis Pathway, positioning GAP not only as a research tool but as an operational bridge between international normative agendas and place-based adaptation practice. This integration addresses a critical gap in the disaster and climate governance literature, where gender considerations are often acknowledged rhetorically but remain weakly embedded in implementation pathways. At the core of the framework is the Gender Analysis Pathway, which constitutes the analytical engine of the study. GAP integrates gender-disaggregated risk analysis, participatory vulnerability mapping, Livelihood Vulnerability Index (LVI) assessment, and institutional and governance analysis. Together, these components reveal how exposure, sensitivity, and adaptive capacity are unevenly distributed across gender and social groups, while simultaneously identifying women's leadership capacities that are often overlooked in formal governance structures. By systematically linking gendered vulnerability with institutional access and decision-making power, GAP operationalizes Sendai Priority 1 on understanding disaster risk and directly advances SDG 5 on gender equality.

Building on these analytical insights, the framework demonstrates how GAP findings are translated into three interrelated applied outputs. First, a Gender-Responsive Coastal Resilience Master Plan integrates inclusive zoning, gender-safe evacuation routes, and Nature-Based Solutions to address both physical and social dimensions of risk. Second, a Gender-Responsive Flood and Tidal Early Warning System enhances preparedness through accessible information, safe reporting mechanisms, and coordinated evacuation support tailored to women's needs. Third, a Women's Leadership Model for Disaster Resilience formalizes women's roles in preparedness, response, and recovery through capacity building and governance inclusion. Collectively, these outputs operationalize Sendai Priority 2 on strengthening disaster risk governance and contribute directly to SDGs 11 and 13 on sustainable cities and climate action.

The final tier of the framework captures the transformative impacts generated through the interaction of gender analysis and applied interventions. These include inclusive climate and disaster governance, institutionalized women's leadership, enhanced effectiveness and durability of Nature-Based Solutions, and strengthened community resilience in the face of chronic coastal hazards. This impact layer aligns with Sendai Priority 4 on preparedness and "Build Back Better" and with Article 7 of the Paris Agreement, which emphasizes adaptation that is locally led, inclusive, and responsive to vulnerable populations. Importantly, feedback loops embedded in the framework illustrate iterative learning and adaptive governance, underscoring that resilience is not a fixed outcome but a dynamic process shaped by continuous knowledge mobilization and social transformation.

Figure 3 illustrates the integrated conceptual framework linking global policy architectures to locally grounded gender-responsive resilience action. The framework is structured across three interconnected tiers: (i) the Gender Analysis Pathway, comprising gender-disaggregated risk analysis, participatory vulnerability mapping, Livelihood Vulnerability Index assessment, and institutional analysis; (ii) applied outputs, including a gender-responsive coastal resilience master plan, a gender-responsive flood and tidal early warning system, and a women's leadership model for disaster resilience; and (iii) transformative impacts, encompassing inclusive climate governance, institutionalized women's leadership, strengthened community resilience, and durable Nature-Based Solutions. Arrows and feedback loops depict the translation of global commitments under the Sendai Framework, SDGs, and Paris Agreement into iterative, locally led adaptation and disaster risk reduction processes.

Institutionalizing Women's Leadership as a Governance Innovation. The applied outputs discussed in the previous sections demonstrate how the GAP enables the formal recognition and institutionalization of women's leadership without eroding its community legitimacy. The Coastal Resilience Master Plan integrates women's spatial knowledge, caregiving roles, and risk perceptions into zoning regulations, evacuation planning, and Nature-Based Solutions design. This directly advances SDG 5.5, which calls for women's full and effective participation in leadership and decision-making. The early warning system further operationalizes Sendai Priority 4, enhancing preparedness through accessible, trusted, and gender-responsive communication mechanisms. By embedding women's social networks into warning dissemination and evacuation coordination, the system improves response effectiveness while strengthening social cohesion.

Gender-Responsive Nature-Based Solutions within Climate Adaptation Frameworks. This research found that Nature-Based Solutions achieve greater ecological durability and social acceptance when governed through gender-responsive frameworks. Women's leadership in mangrove restoration ensured long-term maintenance, alignment with livelihoods, and community ownership. This finding contributes to SDG 13 and SDG 15 (Life on Land) by demonstrating that ecological restoration and social equity are mutually reinforcing. Within the Paris Agreement context, these findings support the shift toward locally led adaptation, emphasizing that adaptation effectiveness depends not only on ecological design but also on inclusive governance structures capable of sustaining long-term stewardship.

Transformative Adaptation through Methodological Design. This study advances the argument that transformative adaptation emerges through methodological design choices rather than isolated interventions. By structuring the GAP to systematically link evidence, outputs, and impacts, the research demonstrates how gender equity can be embedded within adaptation pathways, reshaping power relations and governance practices incrementally yet durably. The Sriwulan case illustrates that transformation is achievable even in highly vulnerable settings when women's leadership is recognized as a strategic asset rather than a social consideration. This insight contributes to global debates on transformation by providing a concrete, replicable model for aligning local adaptation with international climate and disaster frameworks.

4.5 Global Relevance and Transferability

Beyond Sriwulan Village, the GAP framework offers a transferable methodology for coastal and deltaic regions facing slow-onset hazards worldwide. Its explicit alignment with the Sendai Framework, SDGs, and the Paris Agreement positions it as a practical tool for governments, development agencies, and climate finance mechanisms seeking to operationalize gender commitments into measurable resilience outcomes.

Policy-to-Framework Alignment: Sendai–SDGs–Paris Crosswalk. To strengthen policy relevance and enhance global transferability, this study explicitly maps the Gender Analysis Pathway (GAP) and its applied outputs against the Sendai Framework for Disaster Risk Reduction (2015–2030), the Sustainable Development Goals (SDGs), and the Paris Agreement. While these global frameworks consistently emphasize gender equality and inclusivity, operational guidance on how to implement these principles at the local scale remains limited. This research addresses that gap by providing a concrete, evidence-based implementation

pathway. Table 4 presents a policy crosswalk demonstrating how GAP functions as a bridging architecture between global commitments and local action in Sriwulan Village.

TABLE 4. Policy-to-Framework Crosswalk Linking GAP, Applied Outputs, and Global Frameworks

GAP Component / Applied Output	Sendai Framework Priority	Relevant SDGs	Paris Agreement Alignment	Empirical Evidence from Sriwulan
Gender-disaggregated risk data, participatory mapping, LVI analysis	Priority 1: Understanding Disaster Risk	SDG 5 (5.1, 5.5); SDG 11 (11.5); SDG 13 (13.1)	Article 7.1 – Understanding climate vulnerability	Revealed gendered exposure, mobility constraints, and livelihood vulnerability (Section 5.1)
Identification of informal women’s leadership and governance gaps (GAP diagnostic stage)	Priority 2: Strengthening Disaster Risk Governance	SDG 5 (5.5); SDG 16 (16.7)	Article 7.5 – Participatory, gender-responsive adaptation	Women as de facto leaders in preparedness and response, but excluded from formal governance (Section 5.2)
Gender-Responsive Coastal Resilience Master Plan	Priority 2 & 3: Governance and Risk Reduction Investment	SDG 11 (11.3, 11.b); SDG 13 (13.2)	Article 7.2 – Strengthening adaptive capacity	Integration of women’s spatial knowledge into zoning, evacuation routes, and NbS (Section 5.4)
Gender-Responsive Flood and Tidal Early Warning System	Priority 4: Enhancing Preparedness and “Build Back Better”	SDG 9 (9.c); SDG 11 (11.5); SDG 13 (13.1)	Article 7.7 – Early warning and preparedness	Improved accessibility, trust, and coordination through gender-responsive design (Section 5.5)
Women’s Leadership Model for Disaster Resilience	Priority 2 & 4: Governance and Preparedness	SDG 5 (5.5); SDG 10 (10.2); SDG 16 (16.7)	Article 7 – Locally led adaptation	Formalization of women’s roles as planners, coordinators, and NbS stewards
Gender-responsive Nature-Based Solutions (mangrove restoration)	Priority 3: Investing in DRR for resilience	SDG 13; SDG 14; SDG 15	Article 7.6 – Ecosystem-based adaptation	Increased ecological durability and community ownership through women-led stewardship
Knowledge mobilization and policy recommendations	Priority 2: Risk governance	SDG 17 (17.16, 17.17)	Article 12 – Capacity-building and knowledge sharing	Translation of findings into policy briefs and local regulations

Interpretive Value of the Crosswalk. This crosswalk demonstrates that the Gender Analysis Pathway is not an auxiliary gender tool, but a core operational mechanism for implementing global disaster and climate frameworks at the local scale. Unlike many adaptation studies that reference Sendai, SDGs, or the Paris Agreement normatively, this research shows how each commitment is activated through specific methodological steps and applied outputs.

Critically, the table illustrates that: (1) Sendai priorities are fulfilled through evidence-based, inclusive governance mechanisms rather than post-disaster response alone; (2) SDG 5 (Gender Equality) is operationalized across planning, technology, and environmental management, not isolated to social programming; and (3) Paris Agreement adaptation commitments are enacted through locally led, gender-responsive governance and Nature-Based Solutions, aligning with emerging best practices in climate finance and adaptation policy.

Scientific and Policy Contribution. By explicitly and systematically mapping empirically grounded findings onto the Sendai Framework, the Sustainable Development Goals, and the Paris Agreement, this study makes three substantive contributions to the disaster risk reduction and climate adaptation literature. First, it moves beyond normative assertions of gender inclusion by operationalizing global gender commitments within concrete disaster risk reduction and adaptation processes. Through the Gender Analysis Pathway, abstract policy principles are translated into measurable indicators, actionable planning instruments, and governance mechanisms that directly shape preparedness, early warning, and resilience-building interventions.

Second, the study introduces a replicable policy crosswalk model that demonstrates how locally generated gender-disaggregated evidence can be aligned with multiple global frameworks simultaneously. This cross-scalar integration offers a practical methodological template for other coastal and deltaic regions facing compound risks from subsidence, sea-level rise, and socio-economic marginalization. Rather than treating international agreements as parallel or fragmented agendas, the proposed crosswalk enables coherent, mutually reinforcing implementation across disaster risk reduction, climate adaptation, and sustainable development domains.

Third, and most critically, the findings reframe women's leadership from a perceived social co-benefit to a core strategic pillar of climate resilience and disaster governance. By evidencing how women's leadership enhances risk communication, strengthens institutional coordination, and improves the effectiveness and legitimacy of Nature-Based Solutions, the study challenges technocratic and gender-neutral resilience paradigms. Women emerge not as passive beneficiaries of adaptation interventions, but as central agents shaping resilience outcomes, governance quality, and long-term sustainability.

Taken together, this alignment elevates Sriwulan Village beyond the status of a localized case study. Instead, it positions Sriwulan as a living laboratory for operationalizing the convergence of the Sendai Framework, the SDGs, and the Paris Agreement through gender-responsive governance. The insights generated offer transferable lessons for coastal regions globally, demonstrating how transformative resilience can be achieved when global policy commitments are enacted through locally led, gender-informed institutional innovation.

4.6 Future Research Directions

While this study establishes the Gender Analysis Pathway (GAP) as a robust framework for gender-responsive coastal resilience, several avenues for future research warrant further exploration. First, comparative and multi-sited studies across coastal and deltaic regions are essential to assess the scalability and contextual adaptability of the GAP under diverse socio-political, ecological, and governance conditions. Prior research highlights that adaptation pathways are highly context-dependent, shaped by institutional capacity, cultural norms, and political economy, underscoring the need for cross-context validation of gender-responsive methodologies [38–40].

Second, longitudinal research designs are critical to evaluate the durability of institutionalized women's leadership and the long-term effectiveness of gender-responsive Nature-Based Solutions and early warning systems. Existing studies emphasize that slow-onset hazards such as land subsidence and chronic tidal flooding require sustained governance and adaptive learning over time, rather than short-term project-based interventions [41,42]. Longitudinal evidence would enable assessment of whether governance transformations achieved through GAP persist under accelerating climate stress.

Third, future research should examine the integration of gender-responsive analytical pathways into climate finance and national adaptation planning processes. Although international frameworks increasingly mandate gender inclusion, empirical studies show that gender considerations are often weakly embedded in budgeting, monitoring, and evaluation mechanisms [43–45]. Investigating how GAP-informed planning can influence investment decisions, climate finance accountability, and adaptation effectiveness would significantly advance policy-relevant scholarship.

Finally, the rapid expansion of digital technologies in disaster risk reduction presents new research opportunities. Future studies should assess how gender-responsive design principles embedded in early warning systems influence trust, risk perception, and behavioral responses, particularly among women and other marginalized groups. Emerging evidence suggests that technology can either reduce or reproduce social inequalities depending on governance and design choices [46–49]. Rigorous evaluation of gender-responsive digital systems is therefore essential for equitable and effective disaster preparedness.

5 Conclusion

This study demonstrates that coastal resilience under conditions of chronic tidal flooding and land subsidence depends not only on technical adaptation but on governance transformation that addresses structural inequalities. Evidence from Sriwulan Village, Demak Regency, shows that disaster risk and adaptive capacity are strongly shaped by gendered exposure, access to resources, and leadership, positioning gender-responsive governance as a central component of effective climate adaptation.

Spatial analysis indicates that 374.17 hectares of land in and around Sriwulan Village have been permanently inundated, while cumulative land loss across Demak Regency has reached 2,116.54 hectares between 1985 and 2025. Flooding has shifted from episodic events to daily tidal inundation, with water levels reaching up to 193 centimeters, disrupting mobility, livelihoods, and access to essential services. Household-level evidence confirms disproportionate impacts on women, particularly through increased unpaid care responsibilities and livelihood precarity.

Quantitative results demonstrate the effectiveness of gender-responsive interventions. The pilot Early Warning System engaged 85 active users, 61 percent of whom were women. Evaluation results show that 78 percent found alerts clear and understandable, 69 percent used evacuation maps, and 92 percent of women reported increased confidence in flood preparedness.

Methodologically, this study advances the Gender Analysis Pathway as a replicable framework that translates gender-disaggregated evidence into applied planning, technology, and governance outputs. By explicitly aligning with the Sendai Framework, the Sustainable Development Goals, and the Paris Agreement, the Sriwulan case illustrates how women's leadership can be institutionalized as a strategic pillar of transformative coastal resilience.

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