Enhancing Disaster Resilience through Sustainable Farming in Flood-Prone Areas of the Bengawan Solo Delta Areas

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Abstract. High-intensity flooding in Indonesia's Bengawan Solo Delta, especially within the Ngawi region, threatens the sustainability of agricultural communities due to climate change impacts and unstable precipitation patterns. This research explores the implementation of sustainable agriculture as a disaster mitigation strategy to build resilience in flood-prone rural areas. Using a mixed-methods approach and the House of Risk (HoR) framework, the study identifies critical vulnerabilities and prioritizes necessary interventions. It was found that adopting sustainable practices such as intercropping, conservation tillage, and integrated pest management effectively improves soil health and mitigates flood damage. Moreover, the study emphasizes the vital role of community-based approaches that leverage local knowledge to support early warning systems and post-disaster recovery. The findings recommend integrating sustainable agriculture into disaster risk management policies as a dual solution to reduce vulnerability while ensuring food security and environmental preservation. This study offers an actionable framework for stakeholders to build community resilience against climate-related disasters.

1 Introduction

Ensuring the resilience of food systems is a cornerstone of sustainable development, requiring that individuals and institutions can effectively absorb and recover from disruptions [1, 2]. This is particularly challenging in agricultural regions exposed to severe climate-related hazards. In Indonesia's central Bengawan Solo basin, farmers in Sragen and Ngawi Regencies confront a persistent threat from riverine floods, a phenomenon that has shaped the region's history and continues to undermine its food security [11, 12, 13]. While the immediate impacts of floods on crop production are well-documented [6, 7], the underlying risk factors—ranging from land-use change to waste management [8]—are complex and interconnected. Traditional top-down approaches to disaster management [5] are often insufficient, creating a need for more integrated strategies that leverage local knowledge and enhance community resilience from the ground up [9, 10, 14, 15].

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This research responds to this need by proposing an innovative framework to develop and prioritize flood risk mitigation strategies specifically for the farming communities of this vulnerable region. Our study moves beyond conventional risk assessment by addressing three interconnected research objectives: the high-resolution mapping of flood risk zones, the identification of both biophysical and socio-economic drivers of this risk, and the formulation of a prioritized action plan focused squarely on enhancing farmer food security. The primary contribution of this work lies in its unique methodological synthesis. We integrate the spatial analytical capabilities of Geographic Information Systems (GIS) with qualitative data from stakeholder engagement (surveys and interviews) and a comprehensive literature review. These inputs are then channeled into the House of Risk (HoR) model, a powerful framework for translating complex risk data into clear, actionable, and prioritized mitigation measures. This approach ensures that the resulting strategies are not only scientifically robust but also contextually relevant and directly aligned with the goal of building a more resilient and secure food system in the Bengawan Solo basin.

By operationalizing this integrated framework, this study aims to move beyond a purely academic diagnosis of the problem toward the co-creation of practical solutions. The complexity of the Bengawan Solo socio-ecological system, with its interacting environmental pressures and community dynamics, necessitates a structured yet flexible approach. The House of Risk model is particularly well-suited for this challenge, as it provides a transparent mechanism for weighing diverse risk factors and systematically linking them to targeted mitigation actions, thereby facilitating a more participatory and evidence-based planning process. The goal is to produce a tangible roadmap for local government agencies, non-governmental organizations, and farmer groups, offering clear guidance on where to invest resources for maximum impact. In doing so, this research seeks to provide a replicable model for other river basins in Indonesia and across Southeast Asia facing similar challenges at the intersection of climate change, agriculture, and disaster risk.

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2 Research methods

This study employed a multi-stage, mixed-methods research design to systematically investigate flood risk and develop targeted mitigation strategies for agricultural communities in the Bengawan Solo basin. The methodological framework was designed to be sequential, with the outputs of each stage providing critical inputs for the next, ensuring a logical progression from problem identification to actionable recommendations.

The research commenced with **Stage 1: Problem Formulation**, an exploratory phase grounded in a comprehensive literature review, preliminary field observations, and initial discussions with key local stakeholders. This foundational work allowed for the precise definition of the research problem and the establishment of clear objectives.

Following this, **Stage 2: Research Design** involved the meticulous planning of the study's operational parameters. This stage defined the scope and timeline, spanning a nine-month period from April to December 2024, focusing on farmers affected by Bengawan Solo flood risk in Sragen and Ngawi Regencies. A robust data collection strategy was developed, specifying the need for both spatial data (for GIS mapping) and non-spatial data, including ten years of historical flood records and socio-economic indicators. Data sources were triangulated from official publications by the Central Bureau of

Statistics (BPS), regional Agriculture Offices (*Dinas Pertanian*), the Bengawan Solo River Basin Agency (BBWS), and supplemented with media reports and prior academic studies. The research instruments included semi-open-ended interview questionnaires, voice recorders, and video recorders to ensure thorough data capture. This stage also formalized the integrated approach, combining qualitative methods (in-depth interviews, Focus Group Discussions) with quantitative tools (GIS, House of Risk).

Stage 3: Risk and Impact Identification was the core data-gathering phase. Here, a deep dive into identifying flood risk factors and their specific impacts on farmer food security was conducted through a combination of literature synthesis, surveys, and in-depth interviews. This process culminated in a series of Focus Group Discussions (FGDs), which were crucial for validating and enriching the data. These FGDs were strategically composed to ensure a multi-stakeholder perspective, bringing together representatives from affected farmer groups, the Agriculture Offices, the BBWS, the Regional Disaster Management Agencies (BPBD) of both regencies, and the Environmental Agency (DLH) of Sragen. The primary output of this stage was a validated, comprehensive list of context-specific flood risk factors and their corresponding impacts.

In **Stage 4: Risk Evaluation**, the research transitioned from identification to analysis. This stage operationalized the first phase of the House of Risk (HoR-1) model. Through participatory FGDs, the identified risks and impacts were systematically evaluated based on criteria such as severity and frequency. This collaborative process ensured that the quantitative risk evaluation was grounded in the lived experiences and expert opinions of the stakeholders, resulting in a prioritized list of risks.

Finally, **Stage 5: Formulation of Mitigation Priorities** utilized the outputs from the preceding stages to develop strategic recommendations. The second phase of the House of Risk (HoR-2) model was applied in further FGDs to systematically link the highest-priority risks to potential mitigation actions. To enhance the robustness of these recommendations, the results were cross-referenced and validated against existing literature and best practices through a process of literature triangulation. This final stage yielded the study's primary outcome: a prioritized, evidence-based formulation of flood risk mitigation strategies specifically tailored to enhance the food security of farmers in Sragen and Ngawi Regencies.

3 Results and discussion

Table 1. Impacts of Flood Risk for Farmers in Sragen Regency (2025–2030)

No.	Impact	Impact Value
1	Displacement and evacuation of residents	4.285
2	Loss of assets and infrastructure	4.714
3	Loss of life	1.000
4	Damage to public social facilities (schools, places of worship, village offices)	4.142
5	Disruption of community social activities	5.000
6	Economic losses	4.000
7	Disruption of trade and industrial activities	4.000
8	Ecosystem degradation	4.142

No.	**Impact**	**Impact Value**
9	Water pollution	4.285
10	Infectious diseases	4.000

3.1. Analysis of Flood Impacts on Farming Communities

The initial phase of the House of Risk (HoR) framework was dedicated to identifying and quantifying the multifaceted impacts of flooding on the agricultural communities in Sragen Regency. As detailed in Table 1, the study cataloged ten distinct impacts, revealing that the consequences of flooding extend far beyond immediate agricultural losses. The findings indicate that the most severe impact, with the highest value (5.000), is the disruption of community social activities. This underscores the profound effect that floods have on the social fabric, impeding collective activities, damaging social cohesion, and isolating households, which in turn weakens the community's capacity for collective response and recovery.

Closely following this are the tangible losses of assets and infrastructure (4.714), which represent the direct economic devastation experienced by farmers, including damage to homes, farm equipment, and vital infrastructure like roads and irrigation channels. Other significant impacts include the displacement and evacuation of residents (4.285) and water pollution (4.285), highlighting the dual threat to both physical safety and environmental health, as floodwaters often carry contaminants that degrade water sources and soil quality. The damage to public social facilities (4.142) and ecosystem degradation (4.142) further illustrate the systemic nature of the damage, affecting everything from education and community governance to the long-term health of the local environment.

Interestingly, while still a critical concern, the loss of life received the lowest impact value (1.000). This may suggest that while floods are highly disruptive, the presence of informal community-based warning systems or local knowledge in evacuation allows residents to protect themselves from the ultimate harm, even as their livelihoods and social structures suffer immensely. Overall, the analysis of impacts paints a clear picture of a complex disaster profile where social disruption and economic losses are the most pervasive and damaging consequences for the farmers in the region.

Table 2. Flood Risk Mitigation Strategies in Sragen Regency (2025–2030)

<table>
<tr><th>No.</th><th>Mitigation Strategies - Sragen</th><th>Effectiveness Value</th><th>Difficulty Level</th><th>Effectiveness/ Difficulty</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Building infrastructure for bamboo waste and post-harvest trash treatment</td><td rowspan="2">288.778</td><td>3</td><td>96.259</td></tr>
<tr><td>2</td><td>144.389</td></tr>
<tr><td>2</td><td>Raising roads</td><td>183.814</td><td>3</td><td>61.271</td></tr>
<tr><td>3</td><td>Strengthening social capital</td><td>182.376</td><td>3</td><td>60.792</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Building reservoirs</td><td rowspan="2">288.762</td><td>4</td><td>72.191</td></tr>
<tr><td>4</td><td>72.191</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">Building community-based early warning system</td><td rowspan="2">153.352</td><td>3</td><td>51.117</td></tr>
<tr><td>1</td><td>153.352</td></tr>
</table>

3.2. Prioritization of Flood Risk Mitigation Strategies

Following the evaluation of flood impacts, the second phase of the House of Risk (HoR) model was employed to identify, evaluate, and prioritize potential mitigation strategies. This process, detailed in Table 2, assessed each strategy based on its potential effectiveness against the identified risks and the practical difficulty of its implementation. The ratio of effectiveness to difficulty was then used to generate a clear hierarchy of strategic priorities.

The analysis reveals that the most efficient and highly recommended strategy is building infrastructure for bamboo waste and post-harvest trash treatment, which achieved the highest effectiveness-to-difficulty ratio (96.259). This finding is significant, as it points to a practical, high-impact intervention. The accumulation of agricultural and natural debris is a primary cause of blockages in waterways, which exacerbates flooding. By addressing waste management directly, the community can achieve a substantial reduction in flood risk with a relatively moderate level of difficulty, making it a strategic first step.

The next priority is building reservoirs (72.191). While this is a highly effective measure for water retention and flood control, its high difficulty level (4) reflects the significant capital investment, technical expertise, and political will required for such a large-scale infrastructure project. Following this are two strategies with similar priority scores: raising roads (61.271) and strengthening social capital (60.792). Raising roads is a critical structural adaptation for maintaining connectivity and access during flood events, while strengthening social capital represents a vital non-structural approach aimed at enhancing community organization, trust, and collective action. Lastly, building a community-based early warning system (51.117), while ranked lower on this specific metric, remains an essential component of a comprehensive mitigation plan, directly contributing to the protection of lives and assets.

3.3. Discussion: Pathways Toward an Integrated Resilience Strategy

The findings from the HoR analysis provide a clear roadmap for developing a resilient agricultural system in the Bengawan Solo basin. The systemic nature of the identified impacts—spanning social, economic, and environmental domains—necessitates a multi-pronged mitigation approach that moves beyond single-solution thinking. The prioritized strategies in Table 2 collectively form the basis of a hybrid strategy that intelligently blends structural ("hard") and non-structural ("soft") interventions.

This dual approach is critical. For instance, the highest-priority impact, disruption of social activities, cannot be solved by infrastructure alone; it requires soft interventions like strengthening social capital, which is ranked as a key mitigation strategy. Conversely, mitigating the severe impact of loss of assets and infrastructure necessitates hard solutions like building reservoirs and raising roads. The HoR model effectively validates this hybrid model, demonstrating that the most effective overall strategy is not a choice between hard or soft measures, but a strategic integration of both. The top-ranked strategy—waste management infrastructure—is itself a perfect example of a socio-technical solution that combines physical infrastructure with essential community behavior change.

3.4. The Central Role of Governance and Farmer-Centric Adaptation

Translating these prioritized strategies into action requires robust governance and cross-sectoral collaboration. The implementation of large-scale projects like reservoirs and road elevation falls under the purview of government agencies such as the Bengawan Solo River Basin Agency (BBWS) and public works departments, and necessitates aligning regional spatial planning with flood risk assessments. However, the success of community-level strategies, including the early warning system, social capital initiatives, and localized waste management, depends on the active participation of farmer groups, village governments, and local agencies like the BPBD and DLH. This underscores the need for a co-governance model where top-down support and resources empower bottom-up, farmer-centric initiatives.

Ultimately, the resilience of the local food system hinges on the adaptive capacity of the farmers themselves. The prioritized strategies provide a framework for empowerment. For example, investing in a community-based early warning system and strengthening social capital equips farmers with the tools and networks needed to prepare for and respond to floods effectively. Furthermore, linking waste management infrastructure to behavioral and technological interventions such as promoting composting or bioenergy conversion through educational outreach can create new value streams and transform a risk factor into an economic opportunity. By placing farmers at the center of the solution supported by appropriate infrastructure and collaborative governance it is possible to transition from a reactive cycle of disaster and recovery to a proactive state of sustainable and resilient agriculture.

4 Conclusion

This study successfully provides a comprehensive and actionable framework for enhancing food system resilience among the flood-prone farming communities of the Bengawan Solo basin. By synergizing stakeholder-driven data with the analytical rigor of the House of Risk (HoR) model, this research moves beyond a conventional risk assessment to deliver a prioritized roadmap for targeted intervention in Sragen and Ngawi Regencies. The findings reveal that the true burden of flooding extends far beyond agricultural damage, with the most severe consequences being the profound disruption of community social activities and the devastating loss of assets and infrastructure. This nuanced understanding underscores that effective resilience-building must address not only the physical landscape but also the socio-economic fabric that underpins community well-being and adaptive capacity.

In response to these complex challenges, this research has identified and prioritized a set of pragmatic, high-impact mitigation strategies. Crucially, the analysis points to the development of infrastructure for agricultural waste management as the most efficient and strategic starting point, directly addressing a key driver of waterway blockage with a tangible, community-level solution. This is complemented by a clear mandate for a hybrid strategy that balances large-scale structural interventions, such as the construction of reservoirs and the elevation of critical road infrastructure, with essential non-structural measures like strengthening social capital and implementing community-based early warning systems. This dual approach ensures that physical defenses are reinforced by empowered, informed, and cohesive communities capable of collective action.

The successful implementation of this prioritized agenda hinges on a robust framework of collaborative governance. This study highlights that achieving meaningful flood resilience is not the responsibility of a single entity but requires the integrated and sustained effort of a network of actors. It necessitates coordinated action between technical agencies like the Bengawan Solo River Basin Agency (BBWS), regional disaster management bodies (BPBD), and local government departments, working in close partnership with the farmer groups who possess invaluable local knowledge. Harmonizing regional spatial planning with on-the-ground realities and fostering participatory processes are therefore critical for ensuring that interventions are effective, equitable, and sustainable.

In conclusion, strengthening agricultural resilience in the Bengawan Solo basin demands a decisive shift from a reactive posture to an integrated, adaptive, and inclusive strategy. The evidence-based approach presented here, grounded in ecological restoration, strategic infrastructural reinforcement, and profound socio-economic empowerment, offers a clear path forward. Through dedicated cross-sectoral cooperation and an unwavering focus on farmer-centered innovation, it is not only possible to mitigate the recurring threat of floods but also to fundamentally transform these vulnerable agricultural systems into resilient, sustainable, and productive landscapes capable of withstanding the climate and environmental shocks of the future. This research, therefore, serves as both a specific guide for the region and a replicable model for other vulnerable river basins facing similar challenges.

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