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RESEARCH ARTICLE

Adaptive and risk-sharing strategies for sustainable rice farming in flood-prone coastal Central Java

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Abstract

Rice farming in flood-prone coastal areas faces increasing pressure from recurrent tidal flooding, land subsidence and saline intrusion, which threaten production stability and household livelihoods. This study examines how rice farming households in coastal Central Java respond to chronic flooding through a combination of on-farm adaptation strategies and risk sharing mechanisms. Using a mixed methods approach, the authors collected data from 200 rice farming households in Tugurejo (Semarang City) and Sayung (Demak Regency) through structured surveys, interviews, focus group discussions and field observations. Quantitative indicators of adaptation intensity and risk sharing reliance were complemented by qualitative analysis to capture everyday livelihood responses under persistent flood exposure. The results show that farmers primarily adopt reactive adaptation strategies focused on minimising losses rather than implementing anticipatory or technology-based measures. Informal and community-based risk-sharing mechanisms, particularly family support and collective action, play a central role in stabilising household livelihoods and coping with crop failure. These findings indicate that adaptation and risk-sharing function as complementary household responses to recurrent flooding, although persistent environmental pressures continue to constrain the long-term sustainability of rice farming. Strengthening the sustainability of coastal rice farming therefore requires integrated policy approaches that align flood-adaptive technologies, institutional support and formal risk management with existing community-based risk-sharing systems.

Keywords: coastal flooding; climate change adaptation; livelihood; rice farming; risk-sharing mechanisms

Introduction

Flood-related risks represent persistent threats to agricultural livelihoods in low-lying coastal regions, where changing biophysical conditions increasingly undermine smallholder-production systems. In Central Java, recurrent tidal inundation (*rob*), river overflows and extreme rainfall exacerbated by climate change have reshaped farming practices in coastal districts such as Tugurejo and Sayung in Demak Regency (1). These hydrometeorological disturbances not only damage standing crops and degrade soil quality, but also disrupt planting calendars, increase production uncertainty and reduce yield reliability. For rural households that depend heavily on rice as a primary staple and income source, recurrent flooding poses a sustained threat to food security and livelihood stability (2, 3).

Beyond direct biophysical impacts, flooding interacts with structural vulnerabilities. Farmers in Tugurejo and Sayung face increasing risks from saline water intrusion, land subsidence and sedimentation, all of which contribute to declining land productivity and rising production costs (4, 5). Studies across South and Southeast Asia demonstrate that climate hazards disproportionately affect households with limited adaptive capacity, typically characterised by small landholdings, low-asset ownership, high dependence on agriculture and weak institutional support (6, 7). Similar conditions prevail in coastal Central Java, where limited access to technology, inconsistent government interventions and the gradual loss of productive land constrain farmers ability to adjust farming systems in response to both seasonal flooding and long-term environmental change (8). As a result, flooding operates not merely as an environmental shock, but as a structural constraint that reproduces vulnerability over time.

Despite these persistent challenges, empirical work demonstrates that coastal rice farmers are not passive recipients of climate shocks. Households actively adopt a range of autonomous adaptation strategies including adjusting planting schedules, integrating flood-tolerant rice varieties, modifying water management practices and pursuing temporary livelihood diversification to buffer against repeated disturbance (3, 9). At the same time, informal community-based responses such as labour exchange, shared input use, kinship based financial support and rotating savings-and-loan arrangements function as everyday resilience mechanisms that enable households to cope with and recover from flood-induced shocks (6, 10). These practices highlight the central role of farmer agency and social capital in sustaining agricultural livelihoods under conditions of recurrent environmental stress.

However, the effectiveness and sustainability of these responses remain insufficiently understood in coastal Java, where recurrent inundation is shaped by the interaction of tidal flooding, land subsidence and socio-economic precarity. Existing studies have primarily focused on the biophysical impacts of flooding or infrastructure-based interventions, such as dikes, drainage systems and pumping facilities (4, 8), while paying limited attention to the

everyday livelihood strategies adopted by farmers to cope with chronic flooding. Moreover, adaptation strategies and informal risk-sharing mechanisms have generally been examined separately, with limited attention to how they coexist as complementary household responses to recurrent flood risk. Consequently, empirical evidence remains limited regarding how farmers combine agronomic adaptation and social support mechanisms to sustain rice-based livelihoods in flood-prone coastal environments. This study addresses this gap by jointly examining household adaptation strategies and informal risk-sharing arrangements in two flood-prone coastal areas of Central Java. Rather than treating these responses as separate processes, the study explores how they collectively contribute to sustaining rice-based livelihoods under recurrent flooding. This integrated perspective represents the principal novelty of the study and provides a more comprehensive understanding of household resilience in coastal farming systems.

This study aims to (1) identify household-level adaptation strategies to recurrent flooding, (2) analyse informal and semi-formal risk-sharing arrangements and (3) describe how agronomic adaptation and social responses interact in sustaining rice-based livelihoods in Tugurejo and Sayung. The findings contribute to the literature on coastal vulnerability, climate adaptation and livelihood resilience in Southeast Asia by providing empirical evidence on how adaptation and social risk-sharing jointly support household resilience under recurrent flooding. The findings also provide policy-relevant insights for developing integrated adaptation strategies that strengthen both formal adaptation interventions and community-based risk-sharing systems in flood-prone coastal agricultural areas.

Materials and Methods

Study area

This research was conducted in Tugurejo Village (Semarang City) and Sayung Subdistrict (Demak Regency) as shown in Fig. 1, both located along the northern coastal plain of Central Java. The area is characterised by low-lying elevations of 0–2 m above sea level, making agricultural land highly exposed to tidal flooding (*rob*), river overflow and saline intrusion from the Java Sea (1, 4, 11, 12). Seasonal rainfall is shaped by the monsoonal climate, with wet and dry periods becoming increasingly variable due to climate change (1, 2). Tugurejo lies along the western margin of the Semarang-Demak coastline, where flooding is further intensified by rapid land subsidence associated with groundwater extraction and geological compaction (5, 11).

In Sayung, exposure to tidal inundation is more persistent, with longer and deeper flood events that frequently submerge agricultural parcels for extended periods of the planting season (9, 12). Both locations experience compounded stressors, including soil salinisation, declining irrigation water quality and shrinking arable land, which collectively reduce productivity and increase input costs for irrigation, fertiliser and pest management (4, 8, 13). Rice farming remains the primary livelihood for most households, which rely largely on family labour and traditional cultivation practices (2, 9). The combined effects of sea-level rise, land subsidence and recurrent inundation have compelled farmers to adjust cropping calendars, shorten growing periods and increasingly diversify income sources as coping strategies (3, 7, 10). These characteristics make Tugurejo and Sayung suitable sites for examining household adaptation and risk-sharing responses under chronic flood conditions.

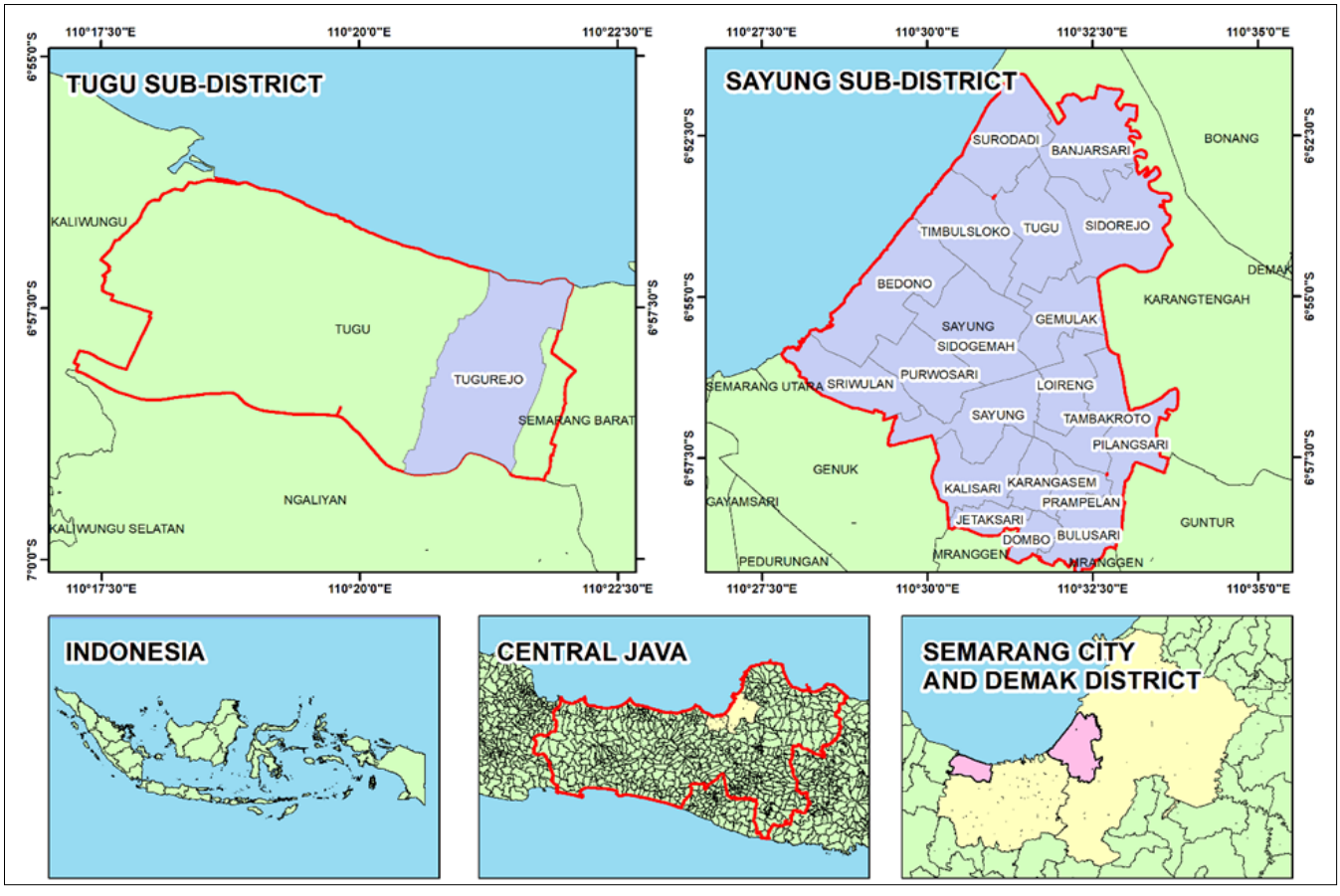


Fig. 1. Study area showing Tugurejo (Semarang) and Sayung (Demak) in Central Java, Indonesia. **Source:** Authors elaboration using administrative boundary data from the Geospatial Information Agency of Indonesia (Badan Informasi Geospasial, BIG), prepared using QGIS.

Data collection

Data collection followed a mixed methods field design commonly applied in climate change adaptation and rural livelihood studies (14), combining household surveys, qualitative interviews and field observations. Data were collected through a single integrated field survey conducted across two study sites. Primary data were obtained from rice farming households in Tugurejo and Sayung using stratified random sampling based on flood exposure intensity and the spatial position of farmland, an approach recommended for heterogeneous hazard environments (15). A total of 200 rice farming households were surveyed, consisting of 100 households from Tugurejo Village and 100 households from Sayung Subdistrict.

A structured household questionnaire was administered to document household adaptation practices, risk-sharing arrangements and farmers' perceptions of their effectiveness. The instrument captured four analytical dimensions: (a) socio-economic and farm characteristics; (b) flood exposure indicators, including frequency, duration, water depth and incidence of complete crop failure; (c) adaptive responses, covering agronomic, managerial and livelihood strategies, as well as changes in yield stability and production costs; and (d) risk sharing participation, measured through frequency of involvement, type and value of shared resources, timing of support and reciprocity among members. Responses to adaptation and risk-sharing indicators were measured using a five-point Likert scale to capture farmers perceptions of adaptation practices, risk-sharing arrangements and institutional support. In addition, indicators of livelihood sustainability were recorded, including income stability, continuity of rice cultivation and reliance on distress coping measures (16–18). The questionnaire was pre-tested to enhance validity and reliability prior to full implementation (19).

Qualitative data were generated through semi-structured interviews with village officials, farmer-group leaders and agricultural extension officers to obtain institutional and historical perspectives on flood risk management and farmer support systems (17, 19). Focus group discussions were conducted to explore collective norms, social capital and coordination mechanisms underlying informal risk sharing practices (17). In addition, systematic field observations documented land conditions, water management practices and visible flood impacts, strengthening empirical triangulation across data sources (19, 20).

Data analysis

A mixed-methods approach was adopted to capture the multidimensional dynamics of adaptation and risk sharing among coastal rice farmers. Structured household surveys were administered to farming households selected through stratified random sampling to reflect variation in flood exposure, livelihood reliance and field location (2, 3, 9). This design enabled systematic comparison across household types while ensuring adequate representation of highly and moderately inundated zones (21). Complementary qualitative data were collected through key informant interviews with village authorities, farmer-group leaders and agricultural extension workers, as well as focus group discussions (FGDs) that elicited community-level narratives and shared practices (6, 9, 10).

Survey responses were analysed using descriptive statistics, including frequencies, percentages and mean scores, to summarise socio-economic characteristics, flood exposure, adaptation strategies, risk-sharing mechanisms and perceptions of institutional support. These descriptive analyses were used to identify dominant patterns of household responses to recurrent flooding across the study sites. Qualitative data from interviews and focus group discussions (FGDs) were transcribed and subjected to thematic analysis following the six-step coding protocol proposed by Braun and Clarke (22), allowing the identification of recurrent themes related to knowledge exchange, cooperation, institutional support and livelihood resilience. Integration of quantitative findings with qualitative themes facilitated triangulation and provided a comprehensive interpretation of how agronomic adaptation and social responses contribute to sustaining rice-based livelihoods under recurrent flooding conditions (6, 10, 14).

Results

Socio-economic characteristics of rice farmers in flood-prone coastal areas

Table 1 presents the socio-economic characteristics of rice farming households in flood-prone coastal areas. The results indicate that the majority of household heads are older than 60 years (50.91 %), followed by those aged 40–60 years (47.27 %), suggesting an aging farming population. In terms of education, most respondents have elementary level education (49.09 %), whereas 43.64 % had attained high school education or above. Employment patterns show that although farming remains the primary occupation, many households also engage in additional livelihood activities, particularly fishing and other non-farm occupations, indicating livelihood diversification. Farming experience is generally high, reflecting strong dependence on rice cultivation as a long-term livelihood. The socio-economic profile of rice farming households reflects structural conditions commonly associated with climate vulnerability in coastal agrarian systems. Most respondents are smallholder farmers operating limited landholdings in low-lying areas prone to recurrent inundation, with relatively low levels of formal education that may limit the adoption of new agricultural technologies and access to agricultural extension information.

Household income structures showed a high reliance on rice farming, although a growing proportion of households reported engagement in on-farm or off-farm activities. This pattern suggests a gradual shift toward livelihood diversification as a response to increasing production uncertainty, consistent with findings in other flood-prone coastal regions (17, 18). Asset ownership remained relatively limited, particularly with respect to farm machinery and household savings, reinforcing condition of limited adaptive capacity under repeated climate stress (20). Overall, these characteristics indicate that vulnerability among coastal rice farmers is not merely exposure driven, but deeply rooted in socio-economic structure, where small land size, limited capital and dependence on a single staple crop intersect to constrain long term resilience (19).

The demographic structure of the sample indicates a predominance of elderly farmers, with more than half of household heads aged above 60 years. This age composition has important implications for adaptive capacity, as older farmers tend to rely on established practices and exhibit lower propensity to adopt new technologies under risk. Although a substantial share of respondents attained at least secondary education, this educational advantage may not necessarily translate into effective adaptation because of limited asset ownership and continued dependence on agriculture.

Table 1. Socio-economic characteristics of rice-farming households in flood-prone coastal areas

Characteristic	Category	Frequency (n)	Percentage (%)
Age of household head (years)	< 40	4	2
	40–60	95	47.50
	> 60	101	50.50
	Total	200	100.00
Education level of household head	Illiterate	15	7.5
	Elementary	98	49.00
	High school and above	87	43.50
	Total	200	100.00
Employment category	Farmer	84	42
	Farmer + Fisherman	25	12.50
	Farmer + Others	91	45.50
	Total	200	100.00
Farming experience (years)	≤ 20	64	32.00
	21–40	102	51.00
	> 40	34	17.00
	Total	200	100.00

The combination of small land size, aging labour and restricted capital access reinforces the structural nature of vulnerability and shapes subsequent adaptation and risk-sharing behaviour observed in the study area.

Flood exposure and production risk in coastal rice farming

As shown in Table 2, rice production in the study area is characterised by chronic rather than episodic exposure to flooding. The majority of farmers reported experiencing inundation in almost every production cycle, with both tidal flooding and river overflow contributing to prolonged waterlogging of fields. Similar patterns of recurrent inundation have been widely documented in subsiding Asian coastal plains (22, 23). This persistent exposure translated into substantial production risk. Yield outcomes were highly variable across seasons and a significant proportion of households reported experiencing partial or complete crop failure due to recurrent flooding. Even in seasons without total loss, farmers faced declining productivity and increasing production costs due to soil salinisation, nutrient leaching and post-flood pest and disease outbreaks, consistent with findings from other flood-prone rice systems (24, 25).

Comparative analysis across exposure categories indicates that households cultivating land in areas with higher flood intensity experienced significantly lower yield stability and a higher incidence of failed harvests. These findings support the argument that flooding in coastal environments functions as a structural constraint on rice-based livelihoods rather than as an occasional environmental disturbance (23, 26). Consequently, rice farmer in Tugurejo and Sayung experience flooding as a recurrent and structurally embedded risk that continuously shapes their farming decisions and livelihood strategies. Field-level evidence indicates that most households experience multiple inundation events within a single planting season, primarily associated with tidal flooding (*rob*) and overflow from adjacent drainage channels.

Table 2. Flood exposure and production risk of rice-farming households in Tugurejo and Sayung

Indicator	Tugurejo (Semarang)	Sayung (Demak)
Flood frequency (events/season)	2–3	3–5
Inundation duration (days/event)	5–12	7–20
Maximum water depth (cm)	20–50	30–60
Average rice yield (t/ha)	4.2–4.8	2.5–3.6
Incidence of crop failure (%)	20–30	30–45
Production cost increase (%)	15–25	20–35

In Tugurejo, farmers reported on average 2–3 flood events per season, with inundation lasting approximately 5–12 days per event. In Sayung, exposure was more severe, with 3–5 events per season and longer submergence periods of 7–20 days, often accompanied by saline intrusion. Maximum water depth commonly ranged between 20–60 cm, exceeding the tolerance threshold of conventional rice varieties. These hydrological conditions translated into substantial production risk. Average rice yields in moderately exposed plots ranged between 4.2–4.8 t ha^{-1}, whereas in highly exposed areas yields declined to 2.5–3.6 t ha^{-1}. Complete crop failure was reported by approximately 30–45 % of households in Sayung and 20–30 % in Tugurejo during the last three production seasons. In addition, farmers consistently reported increasing production costs due to replanting, additional fertiliser application and pest management following flood events. These results demonstrate that flooding in the coastal zone of Central Java operates as a structural constraint on rice-based livelihoods, progressively eroding yield stability and economic viability.

Adaptive strategies adopted by rice farmers

Rice farmers in flood-prone coastal Central Java adopt a range of adaptive strategies with varying levels of intensity across technical, infrastructural and social dimensions (Table 3). Overall, the distribution of mean scores indicates a clear preference for strategies that rely on existing household and social resources rather than anticipatory or technology-based measures, a pattern commonly observed in smallholder farming systems exposed to recurrent flooding (27, 28). Social-based coping mechanisms dominate farmers' responses, as reflected by the highest mean score for reliance on family support during crop failure (AS8; mean = 4.19). Elevated housing or farm storage facilities (AS7; mean = 3.09) also exhibit relatively high adoption levels, suggesting that farmers prioritise the protection of physical assets under recurrent tidal flooding conditions. Similar tendencies toward asset-protection and loss-minimisation strategies have been reported in other flood-prone coastal and deltaic agricultural regions, where farmers focus on safeguarding livelihoods rather than modifying production systems (29, 30).

In contrast, anticipatory technical strategies show low adoption. Adjustment of planting calendars (AS1; mean = 1.09) and storage of agricultural inputs and food reserves (AS6; mean = 1.51) record the lowest mean scores, indicating limited engagement in forward-looking risk management practices. Moderate adoption levels are observed for infrastructural adjustments, including

Table 3. Adaptive strategies adopted by rice farmers in flood-prone coastal areas

Adaptive strategy	Indicator code	Mean score	Adaptation level
Adjustment of planting calendar	AS1	1.09	Low
Use of flood/salinity-tolerant rice varieties	AS2	2.21	Moderate
Improvement of bunds and drainage systems	AS3	2.70	Moderate
Livelihood diversification (non-farm or off-farm activities)	AS4	2.43	Moderate
Reliance on farmer groups or cooperatives	AS5	2.13	Moderate
Storage of inputs and food reserves	AS6	1.51	Low
Elevated housing or storage facilities	AS7	3.09	Moderate-High
Reliance on family support during crop failure	AS8	4.19	High

improvements in bunds and drainage systems (AS3; mean = 2.70), as well as livelihood diversification into non-farm or off-farm activities (AS4; mean = 2.43). Reliance on farmer groups or cooperatives (AS5; mean = 2.13) also falls within a moderate range, suggesting the presence of collective mechanisms with limited intensity, as similarly documented in coastal rice farming contexts with partial institutional support (31). The overall pattern observed in Table 3 is broadly consistent with previous studies in flood-prone rice farming systems, which report stronger reliance on social and reactive adaptation strategies compared to anticipatory or technology-driven measures (31, 32).

Risk-sharing mechanisms among rice farming stakeholders

Beyond on-farm adaptation, rice farmers in flood-prone coastal Central Java engage in a variety of risk-sharing mechanisms involving households, farmer groups, community networks and formal institutions. These mechanisms function as social and economic buffers that help mitigate the impacts of flood-induced crop losses and income instability, a pattern widely observed in climate-vulnerable smallholder systems (33). Farmers perceptions of different risk-sharing arrangements based on a five-point Likert scale are summarised in Table 4. The results indicate pronounced variation in the strength of risk-sharing mechanisms across informal, semi-formal and formal arrangements. Informal family-based financial support (RS6) records the highest mean score (4.85), classified as a very strong mechanism. This is followed by community-based collective action (RS3; mean = 3.94) and mutual assistance among farmers (RS1; mean = 3.75), both categorised as strong. These findings highlight the central role of social capital and kinship networks in absorbing climate-induced shocks, consistent with evidence from flood-prone rice-growing regions in Indonesia, Vietnam and Bangladesh (33, 34).

Semi-formal mechanisms exhibit moderate levels of effectiveness. Support from farmer groups or cooperatives (RS2; mean = 3.21) and access to credit during crop failure (RS5; mean = 2.66) are perceived as moderately strong, suggesting the presence of organised collective and financial arrangements, although their use remains limited. Government emergency assistance (RS7) also falls within the moderate category (mean = 2.45), indicating that state support is recognised but not consistently relied upon by farmers. Similar patterns have been reported in other coastal agricultural systems, where institutional assistance complements but does not replace informal risk-sharing practices (34). In contrast, formal risk-sharing instruments demonstrate weak performance. Agricultural insurance schemes (RS4) register the lowest mean score (1.47), reflecting minimal participation and low perceived usefulness among rice farmers in the study area. Limited uptake of insurance has been widely attributed to administrative complexity, affordability constraints and low trust in formal institutions, particularly in highly exposed coastal environments (35).

While Table 4 captures farmers perceived strength of different risk-sharing mechanisms, Table 5 illustrates how these mechanisms operate in practice by distributing risk across multiple actors and livelihood components. The table shows that production and income risks are not borne solely by farmers but are shared among household members, farmer groups, informal lenders and, to a limited extent, formal institutions. Informal mechanisms primarily absorb short-term income shocks through family transfers and reciprocal labour arrangements, whereas semi-formal mechanisms distribute risk through delayed repayments, collective labour mobilisation and shared access to resources. In contrast, formal institutions play a marginal role in risk absorption, reinforcing farmers reliance on socially embedded arrangements rather than market-based or state-led instruments.

Overall, the results reveal a clear dominance of informal and community-based risk sharing mechanisms over formal institutional instruments. Risk-sharing in flood-prone coastal rice farming is therefore primarily sustained through socially embedded networks rather than formal financial or insurance systems, underscoring the importance of social capital in maintaining household resilience under recurrent flooding conditions (33, 35, 36).

Role of social institutions in supporting rice farmers under tidal flooding

Social institutions play a critical role in shaping how rice farmers respond to and recover from recurrent tidal flooding in coastal areas. These institutions encompass farmer groups, local government bodies, extension services, market actors and irrigation related organisations. Farmers perceptions of the roles played by these institutions in supporting adaptation and recovery processes, measured using a five-point Likert scale are depicted in Table 6. Substantial variation in the perceived effectiveness of social

Table 4. Farmers perceived strength of risk-sharing mechanisms

Risk-sharing mechanism	Indicator code	Mean score	Strength of mechanism
Mutual assistance among farmers	RS1	3.75	Strong
Support from farmer groups	RS2	3.21	Moderate
Community-based collective action	RS3	3.94	Strong
Formal agricultural insurance schemes	RS4	1.47	Weak
Access to credit during crop failure	RS5	2.66	Moderate
Informal family-based financial support	RS6	4.85	Very strong
Government emergency assistance	RS7	2.45	Moderate

Table 5. Structure and perceived distribution of risk-sharing mechanisms

Risk-sharing mechanism	Main actors involved	Type of risk absorbed	Form of contribution	Relative risk burden on farmers	System character
Mutual assistance among farmers (RS1)	Farmers, neighbours	Labour and income loss	Labour sharing, informal lending	Medium	Informal
Support from farmer groups/ cooperatives (RS2)	Farmer groups, cooperatives	Input and production risk	Collective inputs, group support	Medium	Semi-formal
Community-based collective action (RS3)	Community members	Production and recovery risk	Joint labour, collective recovery	Medium-Low	Informal
Agricultural insurance schemes (RS4)	Insurance providers, government	Production loss	Compensation claims	High	Formal
Access to credit during crop failure (RS5)	Informal lenders	Liquidity risk	Credit access	Medium-High	Semi-formal
Informal family-based financial support (RS6)	Family/kinship networks	Income and consumption risk	Cash transfers, in-kind support	Low	Informal
Government emergency assistance (RS7)	Government agencies	Short-term livelihood shock	Cash/food aid	Medium	Formal

institutions in supporting rice farmers facing recurrent tidal flooding in coastal Central Java are revealed in Table 6. Overall, the distribution of mean scores indicates that institutions facilitating market access and knowledge dissemination are perceived as more effective than those providing formal financial protection or risk mitigation. Market institutions, including rice mills and traders, record the highest mean score (SI6; mean = 4.85), classified as very strong. This finding underscores the critical importance of market access in enabling farmers to stabilise income following flood-induced production losses, particularly through rapid crop sales and price negotiation (37–43).

Knowledge-oriented institutional support also demonstrates a strong role. Access to coastal agriculture adaptation training provided by extension services or related organisations (SI3; mean = 3.94) is perceived as strong, highlighting the importance of technical guidance and information dissemination in enhancing farmers' adaptive capacity (44, 45). Assistance from farmer groups or cooperatives (SI1; mean = 3.75) likewise registers a strong role, indicating that collective institutions contribute to coordination, information exchange and limited mutual support among farmers.

In contrast, institutions associated with formal financial protection exhibit weaker performance. Access to credit or assistance during crop failure (SI4; mean = 1.47) records the lowest mean score, reflecting limited availability, accessibility and perceived usefulness of formal financial mechanisms in addressing climate-induced production shocks. Other institutional dimensions, including support from village or local government (SI2; mean = 3.21), institutional support for post-flood recovery (SI5; mean = 2.66) and accessibility of irrigation and pump services (SI7; mean = 2.45), fall within the moderate category. Taken together, the results suggest that institutional support in flood-prone coastal rice farming is uneven, with a stronger emphasis on market facilitation and training than on formal risk-sharing and financial protection (45).

Discussions

Flood risk as a structural constraint in coastal rice farming

These findings confirm that flooding in the coastal lowlands of Central Java is no longer an episodic environmental disturbance, but a structurally embedded risk shaping both production outcomes and livelihood trajectories. The high frequency and prolonged duration of inundation observed in Tugurejo and Sayung, together with substantial yield decline and recurrent crop failure, indicate chronic exposure similar to that reported in other subsiding Asian delta regions. Unlike seasonal flooding in inland areas, coastal flooding in these locations results from the combined effects of tidal inundation, land subsidence and saline intrusion, which progressively degrade soil quality and irrigation water, thereby reducing the biological and economic productivity of rice farming (46, 47). The yield gap between moderately and highly exposed plots identified in this study illustrates how hydrological stress translates into persistent productivity loss rather than short-term shock.

Socio-economic conditions further reinforce this structural vulnerability. The predominance of elderly farmers, limited productive assets and heavy dependence on rice farming constrain households' capacity to invest in adaptive technologies or diversify production systems. Similar relationships between age, asset ownership and adaptive capacity have been widely reported in climate-vulnerable agricultural systems (24, 27). Consequently, flood risk in Tugurejo and Sayung is shaped not only by recurrent biophysical hazards but also by persistent socio-economic constraints. This supports the concept of a "risk-locked" livelihood system, in which repeated flood exposure, high sensitivity and limited adaptive capacity continually reinforce household vulnerability over time.

Table 6. Role of social institutions in supporting rice farmers in flood-prone coastal areas

Institutional support dimension	Indicator code	Mean score	Institutional role
Assistance from farmer groups or cooperatives	SI1	3.75	Strong
Support from village or local government	SI2	3.21	Moderate
Access to coastal agriculture adaptation training	SI3	3.94	Strong
Access to credit or assistance during crop failure	SI4	1.47	Weak
Institutional support for post-flood recovery	SI5	2.66	Moderate
Availability of markets and marketing facilities	SI6	4.85	Very strong
Accessibility of irrigation and pump services	SI7	2.45	Moderate

Effectiveness of adaptive strategies under recurrent flooding

Although rice farmers in flood-prone coastal Central Java adopt a variety of adaptive strategies, the effectiveness of these measures under recurrent tidal flooding remains uneven. Strategies requiring low financial investment and relying on existing social or household resources tend to be more widely adopted, whereas anticipatory and technology-oriented measures show limited effectiveness in practice. Strategies aimed at asset protection, such as elevated housing or storage facilities, demonstrate relatively higher adoption levels, suggesting that farmers prioritise safeguarding physical assets over production-oriented adaptation. This reflects a rational response to repeated flooding events, where minimising loss becomes more feasible than preventing exposure. Similar patterns have been reported in other flood-prone coastal agricultural systems, where farmers focus on damage control rather than risk prevention due to persistent environmental uncertainty (31, 32).

In contrast, planting calendar adjustments and input storage are less widely adopted because recurrent flooding reduces the reliability of these anticipatory strategies. Although farmers recognise their potential benefits, prolonged inundation and unpredictable flood timing often undermine their effectiveness (27, 29). Despite these constraints, farmers in the study area do not remain passive. Consistent with adaptation theory in smallholder systems, households employ a portfolio of agronomic and livelihood strategies to buffer production risk. However, the effectiveness of these strategies is inherently partial and conditional. While measures such as varietal selection and temporal adjustment may reduce yield loss under moderate inundation, the magnitude and duration of flooding in highly exposed zones, particularly in Central Java frequently exceed the tolerance limits of available technologies. The persistence of high crop failure rates and rising production costs suggests diminishing marginal returns to on-farm adaptation when structural drivers of flooding remain unaddressed. Similar dynamics have been observed in coastal rice systems in Bangladesh and Vietnam, where farmer-led adaptation improves short-term resilience but cannot fully compensate for accelerating hydrological change (31, 32). Livelihood diversification plays a more robust role in stabilising household income, yet it also reflects a gradual disengagement from rice as a reliable economic base. This transition aligns with the concept of everyday adaptation, in which farmers continuously reconfigure livelihood portfolios in response to chronic risk rather than in anticipation of discrete climatic shocks (33).

Integrating adaptation and risk-sharing for sustainable rice farming

The dominance of informal and community-based risk sharing mechanisms observed in this study is consistent with findings from flood-prone and climate-vulnerable agricultural systems worldwide. In contexts characterised by recurrent environmental shocks and limited institutional reach, social capital functions as a critical form of informal insurance, enabling households to smooth consumption and recover from production losses (37). Family-based financial support emerges as the most robust mechanism, underscoring the central role of kinship networks in absorbing climate-induced shocks. Such arrangements offer rapid, flexible and trust-based assistance, which is particularly valuable under conditions of sudden crop failure caused by tidal flooding. Similar patterns have been documented in coastal rice systems in Southeast Asia, where family and community networks compensate for the absence or inadequacy of formal insurance and credit markets (38, 39).

Community-based collective action and mutual assistance among farmers also play a significant role in distributing risk. These mechanisms facilitate labour sharing, informal lending and joint recovery efforts following flood events. However, while effective in the short term, their capacity is inherently limited when shocks are widespread and covariate in nature, as recurrent flooding affects entire communities simultaneously rather than isolated households. By linking farmers perceptions (Table 4) with the structural distribution of risk (Table 5), the findings demonstrate that risk-sharing mechanisms function as a secondary layer of resilience rather than a substitute for adaptation. Although on-farm adaptation strategies aim to reduce physical exposure and production losses, Table 5 indicates that economic risks persist and are redistributed across households and community actors when adaptation measures fail. This asymmetric interaction suggests that technical adaptation alone is insufficient under conditions of chronic tidal flooding, reinforcing farmers dependence on informal risk sharing arrangements to sustain livelihoods.

The weak performance of formal agricultural insurance highlights a persistent institutional gap in climate risk management for smallholder farmers. Administrative complexity, low trust and misalignment between insurance design and farmers risk profiles have been widely identified as barriers to adoption in developing country contexts (39–41). As a result, formal mechanisms remain peripheral, reinforcing farmers dependence on social capital and informal arrangements documented in Table 5.

This study extends existing adaptation literature by empirically demonstrating that agronomic adaptation and informal risk sharing operate asymmetrically rather than synergistically in flood-prone coastal rice systems. Rather than jointly enhancing productivity, risk sharing mechanisms primarily function to stabilise livelihoods after production losses occur.

This imbalance indicates that current adaptation pathways remain largely reactive and defensive. Rather than enabling productivity enhancement or long-term transformation, adaptation and risk-sharing function mainly as coping strategies that sustain livelihoods under chronic stress. This pattern aligns with the concept of “everyday adaptation,” in which farmers continuously adjust livelihood arrangements in response to persistent risk rather than discrete climate shocks (42, 43).

These findings suggest that policy interventions focusing solely on technical adaptation or the expansion of agricultural insurance are unlikely to be effective unless they are aligned with existing informal risk-sharing structures. Strengthening climate resilience in flood-prone coastal areas therefore requires an integrated approach that combines flood-adaptive technologies, institutional trust-building and support for community-based risk sharing networks.

Institutions as enablers and constraints in flood-prone rice farming

The findings demonstrate that social institutions play a differentiated and uneven role in supporting rice farmers under recurrent tidal flooding. The strong performance of market-related institutions highlights the centrality of output markets in post-disaster recovery, where the ability to sell remaining or salvaged harvests quickly becomes a key livelihood strategy. In highly flood-exposed environments, market access functions as an informal stabilisation mechanism, allowing farmers to partially offset income

losses even when production declines. Similar patterns have been observed in other flood-prone coastal regions, where markets substitute for absent or ineffective formal insurance and compensation schemes (43–45). The relatively strong role of training and extension services further indicates that knowledge-based institutional support contributes meaningfully to farmers' adaptive capacity. Extension-led dissemination of flood-tolerant practices, planting adjustments and risk management techniques has been widely recognised as a critical component of climate adaptation in smallholder rice systems (39, 42). However, while knowledge provision enhances farmers ability to adjust practices, its effectiveness remains constrained when not accompanied by sufficient material resources, infrastructure investment, or financial support.

Moderate perceptions of farmer groups and local government involvement suggest that collective and public institutions provide a partial but incomplete safety net. Farmer organisations facilitate coordination, information sharing and limited mutual assistance, yet their capacity to buffer repeated flooding shocks remains restricted by limited financial resources and institutional authority (38). Similarly, local governments may offer emergency or post-flood assistance, but such interventions are often reactive, short-term and insufficient to address the cumulative impacts of recurrent tidal flooding.

The weakest performance of formal credit and assistance programs highlights a persistent institutional gap in climate risk management. Limited access to affordable credit, low participation in formal assistance schemes and weak institutional trust constrain farmers ability to recover and reinvest following flood-induced losses. This pattern is consistent with broader evidence from developing country agricultural systems, where formal financial institutions struggle to serve smallholders exposed to high climatic uncertainty and production risk (44–47). Overall, the results indicate that social institutions currently support adaptation and recovery in fragmented rather than integrated ways. While markets and knowledge systems function relatively effectively, the absence of strong financial and risk-sharing institutions limits the transition from short-term coping toward long-term resilience. Strengthening institutional integration, linking extension services, farmer organisations, market actors and formal financial mechanisms remains essential for enhancing the sustainability of rice farming in flood-prone coastal areas.

Policy implications for flood-prone coastal agriculture

The results underscore the need for integrated policy approaches that move beyond fragmented interventions by strengthening formal risk sharing instruments while building upon existing informal mechanisms. Enhancing the accessibility and credibility of agricultural insurance, expanding cooperative-based financing and simplifying administrative procedures are essential to complement household and community level strategies rather than attempting to replace them. At the same time, policy interventions must recognise that informal risk sharing is not a failure of development, but a rational and adaptive response to structural vulnerability in flood-prone coastal environments. Integrating local social capital into formal adaptation planning can enhance policy effectiveness, institutional trust and implementation legitimacy.

However, strengthening risk management alone will not be sufficient unless accompanied by broader interventions that address the structural drivers of recurrent tidal flooding. Investments in flood-control infrastructure, sustainable water management and climate-resilient agricultural systems should therefore be integrated with community-based adaptation initiatives. Such an approach offers greater potential to strengthen the long-term resilience and sustainability of rice-based livelihoods in flood-prone coastal areas.

Limitations

This study has several limitations that should be acknowledged. First, the analysis is based on cross-sectional data collected from two flood-prone coastal areas in Central Java, which may limit the generalisability of the findings to other coastal regions with different environmental and socio-economic conditions. Second, the assessment of adaptation strategies, risk-sharing practices and institutional support relied primarily on farmers self-reported responses, which may be subject to recall bias and individual perceptions. Finally, this study focused on describing household adaptation strategies, informal and semi-formal risk-sharing arrangements and institutional support, without examining their long-term effectiveness or causal relationships. Future research could adopt longitudinal designs and comparative studies across different coastal regions to better understand how adaptation and risk-sharing evolve under changing climate conditions.

Conclusion

This study shows that rice farming in flood-prone coastal areas of Central Java is shaped by chronic and structurally embedded flood risk rather than by occasional climatic shocks. Recurrent tidal flooding, land subsidence and saline intrusion consistently reduce yield stability, increase production costs and constrain farmers capacity to sustain rice-based livelihoods in Tugurejo and Sayung. Flood risk in this context operates as a long-term structural constraint that limits the effectiveness of farm level responses and reinforces socio-economic vulnerability among smallholder households. The findings reveal an asymmetric pattern of risk management. On-farm adaptation strategies are adopted at low to moderate intensity and are largely reactive, focusing on loss minimisation rather than anticipatory or transformative change. In contrast, informal and community-based risk sharing mechanisms, particularly family support and collective action play a more prominent role in stabilising household livelihoods after crop failure. The higher reliance on risk-sharing compared to adaptation indicates that farmers respond to recurrent flooding primarily through social redistribution of losses rather than through effective reduction of production risk. While these mechanisms enhance short-term resilience, they do not address the underlying drivers of vulnerability.

These results highlight the limitations of fragmented adaptation policies that emphasise technical solutions or formal insurance alone. Strengthening the sustainability of coastal rice farming requires integrated approaches that align flood adaptive technologies, institutional support and formal risk management with existing community-based risk sharing systems. Without such integration and without addressing the structural causes of recurrent flooding, rice farming in coastal Central Java is likely to remain locked in a cycle of coping rather than long-term resilience.

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Authors' contributions

PM conceived and designed the study, coordinated the research process, conducted data analysis and drafted the manuscript. AF contributed to data collection, data processing and assisted in the interpretation of the results. FNF participated in data collection, literature review and supported manuscript revision. JM contributed to the study design, performed statistical analysis and critically reviewed the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

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