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Sustainable Resilience in Flood-Prone Rice Farming: Adaptive Strategies and Risk-Sharing Around Tempe Lake, Indonesia

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Abstract: Recurrent flooding near Tempe Lake, Indonesia, exacerbated by climate change, presents significant challenges for rice-farming communities, threatening their livelihoods and food security. This study explores the adaptive strategies employed by farmers to mitigate flood-related risks and evaluates the role of institutional frameworks in risk-sharing mechanisms. Using a mixed-methods approach, we analysed primary survey data from 140 rice farmers and conducted interviews with irrigation pump operators. The study viewed 30 years of historical flood records to identify environmental patterns affecting agricultural practices. The findings indicate that farmers employ various adaptation strategies to enhance resilience, including irrigation technologies, risk-sharing agreements, and livelihood diversification. Informal co-operative structures play a crucial role, with landowners covering 50% of production costs and farmers receiving 60% of profits after deducting operational expenses. However, flood-related income disruptions and shifting environmental conditions threaten long-term sustainability. This study emphasizes the need to formalize risk-sharing agreements, promote flood-resistant crop adoption, and improve water management infrastructure to address these challenges. Additionally, policies should support the development of community-led co-operative models and flexible contract structures, as well as training and access credit to ensure fair compensation for climate-induced losses. Integrating institutional support, technological advancements, and community-driven adaptation strategies can enhance economic stability, strengthen food security, and ensure the long-term viability of rice farming in flood-prone regions.

Keywords: vulnerability; partnerships; agricultural practices; livelihoods; institutional support

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1. Introduction

Risk is often defined as the negative consequence arising from an activity or decision, and it can encompass both immediate and long-term threats faced throughout life [1–3]. Climate change and environmental degradation drive flooding, a significant risk in Tempe Lake [4,5]. The community around the lake must actively engage in adaptation efforts to avoid or minimize losses caused by these floods [6–9]. The looming threat of flooding,

intensified by environmental degradation, presents a constant peril for the residents [4,10]. As a result, the community's adaptation strategies, such as diversifying livelihoods and adopting flood-resistant practices, are essential to mitigate the risks and build resilience against recurring floods [7–9,11–13].

Tempe Lake possesses immense potential due to its rich natural resources, which have historically provided the foundation for both agricultural and fishing activities that sustain local communities. Several studies have emphasized the importance of these resources in maintaining food security and supporting livelihoods. Rice farming plays a crucial role, as the fertile lands around the lake are highly suitable for rice cultivation, allowing farmers to meet their subsistence and income needs [14,15]. Fishing is equally important, contributing a significant portion of protein to the local diet and providing a critical source of income [16].

Tempe Lake plays an essential role in supporting the livelihoods and maintaining the ecological balance of the surrounding communities, which rely predominantly on farming and capture fisheries for their income. Despite the inherent risks associated with these activities (such as flood-related failures in rice farming during both growing seasons), their complementary nature has allowed the community to create a distinctive way of life. Rice farming faces significant challenges due to floods that disrupt the growing season, either at the beginning or end, often resulting in crop failure [17,18]. These intertwined challenges reflect the complexity of the community's livelihood system, emphasising the critical need for resilient strategies to safeguard and sustain their unique way of life.

In addition to its economic use, Tempe Lake functions as an essential water catchment zone, collecting water from multiple rivers and precipitation. This unique function allows the lake to fulfil several critical responsibilities for supporting human existence. It functions as a water system regulator, a groundwater provider, a flood control device, a micro-climate regulator, and a habitat for various flora and fauna [19]. The lake supports aquaculture and serves as a tourist and relaxation destination. These diverse responsibilities contribute to ecological balance and the sustainability of dependent populations' livelihoods [20,21].

Despite the challenges posed by frequent flooding, people continue to live near the lake due to its economic and food security benefits. Researchers have found that communities in flood-prone areas like Tempe Lake have adopted effective adaptation strategies, including income diversification and flood-resistant rice varieties, to mitigate the impacts of environmental hazards [9,22]. Strong social networks and community collaboration further strengthen this adaptive capacity, enhancing resilience and providing a safety net during times of crisis [23–25]. Consequently, the economic and cultural ties to the lake and these resilience strategies explain why people remain in the region despite the recurrent floods.

Numerous studies highlight the impact of climate change on agriculture, particularly in developing countries, emphasizing droughts, floods, and institutional adaptation strategies to mitigate risks [11,26,27]. While institutional arrangements help distribute flood-related risks equitably [21,28–31], limited research focuses on risk analysis and livelihood sustainability for communities near lakes, a gap this study addresses in Indonesia. Flooding, a natural occurrence in Tempe Lake, significantly shapes rice farming, posing major challenges for farmers [32,33]. Despite these obstacles, institutional frameworks play a crucial role in sustaining rice farming and community adaptation. Local communities continue their activities amid floods, employing engineering solutions, infrastructure improvements, and policy-driven adaptations [34–37]. Floods disrupt farming, damage property, and affect social interactions, leading to financial instability despite occasional benefits [38,39]. Climate change further threatens rice farming through floods, droughts, and pest outbreaks, but improved farming techniques and technical knowledge enhance resilience [40–43].

Experts increasingly recognize institutional resilience as a key factor in determining smallholder farmers' ability to adapt to climate-induced risks, especially in flood-prone

agricultural systems. [44,45]. Recent research underscores the role of informal institutions, co-operatives, and social capital in strengthening adaptation strategies. These entities enable farmers to collectively manage risks and sustain agricultural production during extreme weather events [46,47]. In the context of Southeast Asian lake-based farming systems, studies on the Mekong Delta (Vietnam), Tonle Sap Lake (Cambodia), and Chao Phraya River Basin (Thailand) highlight inspiring community-driven risk-sharing mechanisms. Here, farmers rely on informal lending networks, collective land-use agreements, and co-operative irrigation management to mitigate the impacts of flooding [48–50].

In Indonesia, studies on climate resilience in lake-based agricultural communities underscore the vital role of traditional institutions. They suggest that localized governance structures are critical in managing flood risks and ensuring food security [51,52]. For instance, research on Sienreng and Lake Tempe illustrates how these institutions have facilitated profit-sharing agreements between farmers, landowners, and irrigation service providers, creating informal safety nets during periods of environmental stress [52,53]. However, despite these adaptive mechanisms, policy misalignment and weak institutional coordination have been identified as key challenges in integrating local knowledge into formal adaptation frameworks [54]. Similar institutional barriers have been observed in lake-based farming communities in Myanmar and Laos, where government-led flood mitigation efforts often fail to align with smallholder farmers' autonomous adaptation strategies [55,56].

Moreover, emerging climate governance frameworks emphasize the importance of polycentric and flexible institutional arrangements to enhance resilience in highly climate-sensitive agricultural landscapes [44,57]. Research on climate-smart agricultural finance in Southeast Asia suggests that public-private partnerships, microfinance institutions, and digital financial inclusion initiatives can significantly improve rural farmers' access to credit, crop insurance, and risk-reduction strategies [57,58]. These insights reinforce the need for context-specific interventions integrating formal governance structures with local resilience-building initiatives in flood-prone rice-farming regions like Tempe Lake.

Despite extensive research on climate change adaptation in agriculture, particularly in developing countries, a limited exploration of risk-sharing mechanisms and transformative strategies for the livelihood sustainability of communities living near lakes remains. While previous studies have focused on technological and social adaptation, the role of institutional frameworks in regulating profit-sharing and risk-distribution systems, especially in flood-prone regions like Tempe Lake in Indonesia, remains underexplored. Additionally, research on integrating adaptation strategies such as income diversification and flood-resistant practices with local institutions and community collaboration is scarce. The potential for combining agriculture and freshwater aquaculture as a sustainable livelihood approach also lacks in-depth analysis. This study aims to bridge these gaps by examining institutional mechanisms that support risk-sharing, contributing to the broader discourse on agricultural sustainability in flood-prone areas.

This study aims to analyse the role of institutional frameworks in regulating profit-sharing and risk-sharing mechanisms among farmers, landowners, and irrigation pump enterprises in flood-prone areas around Tempe Lake. It seeks to assess the impact of recurrent flooding on agricultural productivity and the socio-economic livelihoods of rice farming communities while exploring the potential integration of agriculture and freshwater aquaculture as a sustainable livelihood strategy. Additionally, the study proposes strategies for strengthening local institutions and improving risk-sharing mechanisms to enhance the resilience of farming communities facing recurrent floods. Through these objectives, the research contributes to a deeper understanding of institutional resilience and adaptive strategies in flood-prone agricultural systems.

This study provides valuable insights into how institutional frameworks and risk-sharing mechanisms can strengthen the resilience of agricultural communities in flood-prone areas like Tempe Lake. By examining how institutional arrangements affect the distribution of risks and benefits among key stakeholders—farmers, landowners, and irrigation pump operators—the research enhances the understanding of how these systems help mitigate the adverse effects of frequent flooding on farming productivity and community livelihoods. The findings can potentially inform policies and strategies promoting sustainable farming in vulnerable regions. Additionally, this study contributes to climate adaptation research by highlighting the importance of institutional resilience, co-operative farming, and financial inclusion in mitigating the impacts of climate-related agricultural risks.

2. Research Methods

2.1. Study Sites

Tempe Lake was chosen for this study due to its unique vulnerability to biannual flooding caused by heavy rainfall and the overflow of the Walanae and Bila rivers. Climate change has intensified these events, threatening agricultural productivity and the livelihoods of farming communities. Rice farming, the region's primary livelihood, is particularly at risk, with frequent crop failures jeopardising food security and economic stability. Despite these challenges, the lake remains a vital resource, supporting agricultural and fishing activities essential to the community's survival.

This study examines Tempe Lake to explore how communities adapt to recurrent floods through innovative risk-sharing and adaptive strategies. The region's informal partnerships among farmers, landowners, and irrigation operators offer key insights into collaborative climate risk mitigation. With its socio-economic importance and resilient communities, Tempe Lake provides a valuable case for understanding sustainable agricultural practices in flood-prone areas and informing strategies to enhance resilience globally.

Figure 1 illustrates the location of Tempe Lake in Wajo District, South Sulawesi, Indonesia. Positioned in the district's lowlands, the lake serves as a natural catchment for rainfall and river inflows, primarily from the Walanae and Bila rivers. Its connection to nearby water bodies like Sidenreng and Labulang Lakes enhances its ecological and hydrological importance in the region.

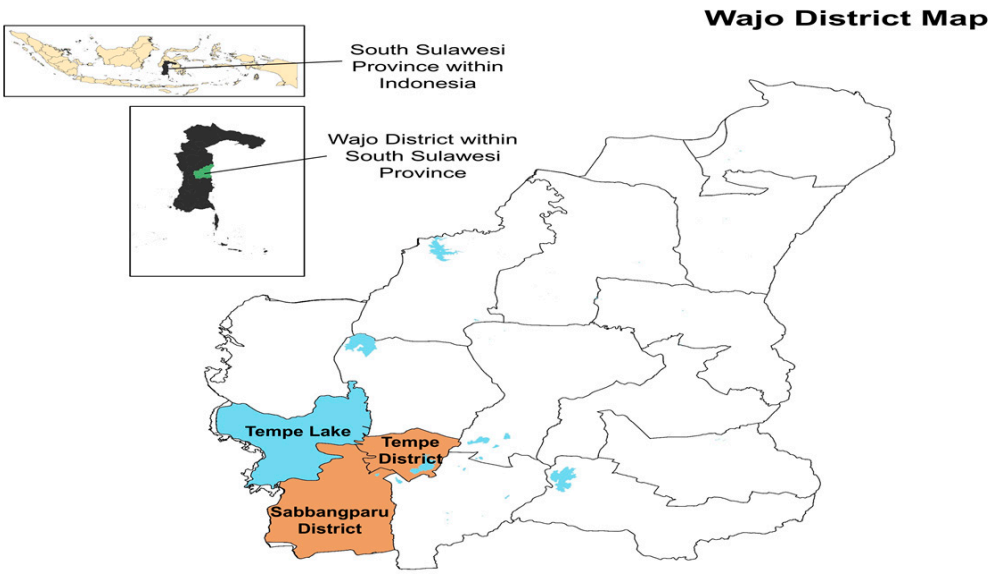

Figure 1. Situation of the study sites: Sabbangparu and Tempe subdistricts within Wajo district, South Sulawesi, Indonesia [59,60].

2.2. Data Collection

This study employs a multifaceted research approach integrating primary and secondary data collection to enhance livelihood sustainability in flood-prone regions like Tempe Lake. It aims to develop a comprehensive understanding of flood risk management by examining agricultural practices, institutional frameworks, and adaptive strategies.

By combining household surveys, stakeholder interviews, and historical flood data, the study provides a holistic perspective on farmers' socio-economic and environmental challenges. The research team collected primary data through household surveys of 140 purposively selected rice farmers from the Sab-Bangparu and Tempe sub-districts in Wajo District, South Sulawesi, Indonesia, chosen for their high flood exposure.

Additionally, stakeholder interviews with irrigation pump entrepreneurs provided insights into water management and risk mitigation. A 30-year water level dataset from the Watershield Council of Walanae River, Pompengan Makassar, was analysed to assess flood patterns and their impact on agriculture.

These sub-districts were selected due to their strategic role in rice farming and vulnerability to recurrent flooding, making them ideal for studying adaptation strategies and risk-sharing mechanisms. The study provides valuable insights into the sustainability and resilience of rice farming systems in flood-prone regions through rigorous sampling and multi-source data analysis.

In addition to household surveys, the study gathered expert perspectives from two irrigation pump entrepreneurs who are key stakeholders in the local farming ecosystem. These entrepreneurs provided valuable insights into irrigation systems, which are crucial in mitigating flood risks, improving water management, and supporting rice production. Their inclusion helped broaden the study's understanding of infrastructural and institutional support mechanisms influencing farmers' adaptation strategies.

By integrating rigorous sampling methods, multi-source data collection, and context-specific analysis, this research offers valuable insights into the sustainability and resilience of rice farming systems in flood-prone regions like Tempe Lake.

2.3. Data Analysis

The data analysis, which primarily focuses on qualitative methods, serves to provide a comprehensive understanding of the farmers' experiences. The study conducted a descriptive analysis of historical flood data and rice yield records, identifying patterns of productivity fluctuations in relation to flood timing. Summary statistics, including mean, standard deviation, and coefficient of variation, were computed to measure the extent of yield variability. When combined with farmers' narratives on adaptation, these statistical measures provide an empirical foundation. This approach allows for a more structured understanding of how flooding impacts agricultural productivity, capturing both the measurable and perceived dimensions of flood-induced agricultural challenges.

The analysis is robust and well-triangulated, integrating multiple data sources to validate qualitative findings. Self-reported production losses—a key aspect of our analysis—were systematically cross-referenced with quantitative productivity data from farmer records and irrigation reports. This allowed us to assess the alignment between perceived and actual yield variations. Additionally, key informant interviews with local agricultural officers enriched our understanding of the broader institutional responses and risk-sharing mechanisms in place. These insights provided valuable context to the statistical findings, offering a more nuanced interpretation of adaptive strategies.

Rather than relying on regression or correlation models, we strengthened our analysis through qualitative triangulation to capture the complexity of farmer responses by the following stages:

- Cross-validation of narratives from farmers, landowners, and irrigation pump operators to identify recurring themes in flood response strategies.
- Comparison with historical flood records to situate individual and community-level experiences within broader environmental trends; and
- Thematic analysis of risk-sharing agreements to uncover structural patterns in farmer collaboration and adaptation without imposing rigid quantitative assumptions on social interactions.

The multi-source qualitative approach is essential, as it ensures that our findings reflect the diverse and context-specific ways farmers navigate environmental and economic uncertainties. By integrating descriptive statistical measures—mean, standard deviation, and coefficient of variation—with rich qualitative narratives, our analysis provides a comprehensive understanding of adaptation, capturing its structural and behavioral patterns. This provides a holistic understanding of risk-sharing structures and agricultural resilience in flood-prone rice-farming regions.

Employing qualitative analysis enhances this study by capturing the complex social and economic dynamics of risk-sharing and adaptation in flood-prone rice farming communities. It provides rich, firsthand insights into farmers' experiences, adaptive strategies, and decision-making processes. Presenting findings in a narrative format ensures clarity and accessibility for policymakers, researchers, and local stakeholders. The flexibility of this approach allows researchers to explore emerging themes and refine inquiries based on participant responses, generating more contextually relevant and nuanced insights. This adaptability strengthens the study's contribution to understanding institutional resilience, risk-sharing frameworks, and sustainable agricultural practices in Tempe Lake.

3. Results and Discussion

3.1. Challenges of Sustainable Livelihoods in Flood-Prone Areas

The observable rainfall patterns within the catchment area significantly influence the hydrological dynamics of Tempe Lake, leading to potential flood risks. The heightened fluctuations and surges in rainfall, attributed to the impacts of climate change, introduce uncertainties that pose considerable threats to the agricultural industry. These variations, coupled with an increasing trend in rainfall intensity, serve as crucial indicators of risk development.

Twenty-three tributaries span the two main watersheds, the Bila and Walanae Rivers, which play a crucial role in the region's hydrology. The Bila River flows directly into Tempe Lake, while the Walanae and Cenranae Rivers merge and continue their course toward Bone Bay through the Cenranae River [16,61]. However, during periods of heavy rainfall, the water flow dynamics change significantly. The narrow channel and low elevation of the Cenranae River cause an overflow, diverting excess water into Bone Bay andempe Lake [62]. The region's topography and water flow patterns drive this cyclical movement, which exacerbates flooding, especially around Tempe Lake, underscoring the need for improved water management strategies.

Three interconnected lakes—Sidenreng Lake in Sidrap District, Taparang Lapompaka Lake, and Labulang Lake in Soppeng District—link with Tempe Lake during flood events, further amplifying the hydrological complexity of the region. This intricate network of water bodies, coupled with the limited drainage capacity of the Cenranae River leading to Bone Bay, significantly increases the risk of flooding during periods of heavy rainfall. These factors and accelerated sedimentation in Tempe Lake contribute to increased erosion and siltation within the lake ecosystem [63]. As a result, understanding and managing these interconnected water systems is essential for mitigating the adverse impacts of flooding and supporting the sustainable livelihoods of the Tempe Lake community.

Figure 2 illustrates a shift in the timing of peak flooding over the observed periods, a finding with significant implications for our understanding of hydrological changes. Between 1991 and 2000, the highest flood level occurred in July, reaching 6.77 m sal. However, during the subsequent periods of 2001–2010 and 2011–2018, the flood peak shifted earlier to June, with water levels of 6.21 m sal and 6.56 m sal, respectively. Conversely, the lowest water levels were recorded in September and October. In October, water levels dropped to 4.31 m sal in 1991–2000 and 4.27 m sal in 2011–2018, while the lowest recorded level in 2001–2010 occurred in September at 3.93 m sal. These variations indicate notable temporal shifts in flood dynamics over the decades, underscoring the urgent need for further research and policy action to address these changes.

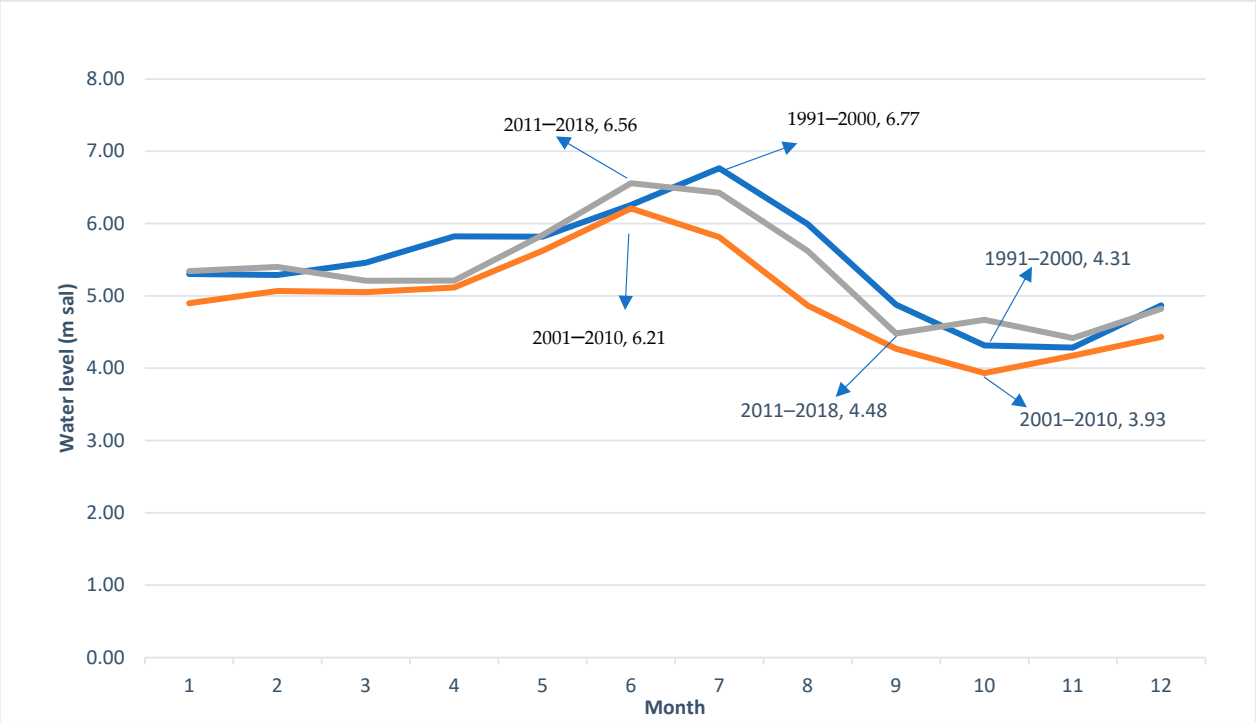

Figure 2. The average level of water in Tempe lake (m sal). Source: Balai Besar Wilayah Sungai Pompengan Jeneberang, Ministry of Public Works, Makassar, 2022.

Climate change strongly influences the observed variations in water levels, mainly through the intensification of rainfall patterns. Increased frequency and intensity of rainfall contribute to greater water flow from the river watershed into Tempe Lake, thereby elevating the risk of flooding. Factors such as climate change, global warming, and ecosystem degradation in the watershed area are critical in exceeding the lake's capacity, triggering flooding events [64,65]. As Feinstein (2018) highlights, rainfall rates are a key indicator for predicting and understanding these flooding occurrences, making them crucial for future mitigation efforts [66].

As climatic and environmental elements progress, monitoring and evaluating rainfall rates is crucial for forecasting and managing flood occurrences in Tempe Lake. Numerous studies highlight the essential influence of precipitation patterns on flood dynamics. The rising global temperatures exacerbate the hydrological cycle, resulting in more frequent and severe rainfall events [67]. Similarly, climate change causes changes in regional meteorological patterns, increasing flood risks in vulnerable areas such as watersheds [68]. To alleviate the effects of rainfall fluctuations on river levels and adjacent ecological systems, effective flood management measures rely on precise monitoring. By identifying these trends and tackling the root causes, such as watershed degradation and global warming, stakehold-

ers can formulate targeted actions that mitigate the enduring effects of climate-induced fluctuations in water levels [69].

For their livelihoods, the community surrounding Tempe Lake relies heavily on agriculture and fishing, with rice farming being the primary agricultural activity and fishing playing a crucial role in the fishing sector. Previous studies have shown that both sectors form the backbone of the local economy [70,71]. However, in 2016, the construction of a weir significantly altered these traditional practices. The community built the weir to regulate and maintain water levels at 4–5 m above sea level, covering an area of approximately 10,000 hectares, with the intention of mitigating flooding and enhancing water management [71]. While it has helped control water levels, research indicates that it has also disrupted the natural flow of the lake, negatively affecting rice cultivation and fish breeding cycles [72]. These disruptions have led to substantial changes in income-generating activities, with households facing increased uncertainty in their primary livelihoods. Consequently, the new environmental and economic realities have forced many to adopt alternative strategies [52]. This shift underscores the complex trade-offs between infrastructure development and local livelihoods in rural communities dependent on natural resources.

The construction of the weir permanently submerged a significant portion of Tempe Lake's previously dry-season agricultural land, drastically altering the farming landscape. This shift has forced many farmers to adapt by switching to water-resistant crops, such as flood-tolerant rice varieties or vegetables, while others have had to abandon farming entirely [73]. The regulation of water levels has disrupted traditional agricultural practices, reducing the availability of arable land and intensifying challenges related to food security and income generation [74,75]. Other communities have shifted their focus towards non-agricultural sectors, such as fishing, small-scale trade, or seasonal migration, in response to changing environmental conditions, aiming to secure income and ensure food security [76]. Overall, the drought's impact has redefined agricultural productivity in the region, necessitating widespread adaptation and diversification strategies among local farmers to sustain their livelihoods.

The fisheries sector has witnessed a decline in income, driven by two key factors leading to reduced fish catches. First, the weir construction has permanently inundated farmland, forcing many farmers to turn to fishing as an alternative livelihood. This influx of new fishermen has intensified competition for limited fish resources, increasing the sector's economic pressure. Research indicates that displacement due to infrastructure development, such as dams or weirs, often forces affected communities to switch to fishing, causing overfishing and economic strain as the labour pool grows disproportionately [77,78]. Second, non-sustainable fishing methods, including environmentally damaging gear and continuous fishing without designated off-seasons, have further depleted fish stocks. Unregulated fishing disrupts reproductive cycles by denying fish sufficient time to spawn, leading to a long-term population decline [79]. These unsustainable practices, coupled with the increasing number of fishermen, have significantly reduced fish stocks, threatening both the ecosystem and the livelihoods dependent on it.

The drought's unintended consequences reveal the complexity of environmental interventions, as they can solve some socio-economic issues while creating new vulnerabilities when environmental and social dynamics are overlooked [80–82]. Addressing these challenges requires a holistic approach that balances ecological conservation with the socio-economic needs of the community, ensuring sustainable resource management and long-term well-being for those affected.

The perspectives of farmers and fishermen around Tempe Lake provide a nuanced view of the ecological changes before and after 2016. Before this period, the water-covered

area during the dry season was minimal, which helped limit the population of predatory fish. Naturally embedded in mud and soil, fish eggs rely on seasonal water level fluctuations to hatch, contributing to ecological balance. However, the installation of the floating weir significantly altered this process by expanding the water body to 10,000 hectares. This larger area provided predatory fish with constant access to newly hatched fish, disrupting the existing ecological balance. The resulting increased predation pressure on juvenile fish has contributed to the degradation of fish populations, undermining the livelihoods of local fishermen.

Studies on similar hydrological interventions have shown that expanding water bodies can shift fish population dynamics, often favouring larger predatory species, which disrupt food chains and reduce biodiversity [83,84]. Furthermore, as observed in various freshwater ecosystems where habitat alterations have led to a decline in fish stock sustainability, seasonal water levels directly impact fish reproduction cycles [85,86]. These findings underscore the importance of carefully considering ecological impacts when designing infrastructure projects that alter natural water systems.

In contrast, the floating weir has brought substantial benefits to the agricultural sector by reducing the risks of crop failure due to flooding and drought. Before the weir's construction in 2016, rice farms around Tempe Lake faced significant challenges, for example, a lack of water during the dry season and frequent flooding during the rainy season, which increased the likelihood of crop failure. Since the weir's installation, farmers have been able to cultivate rice twice annually by using pump irrigation from the lake, except during periods of severe flooding. However, despite this improvement in water management, climate variability persists as a risk, leading many farmers to report lower yields compared to the pre-weir period. This suggests that while the drought has mitigated some challenges, other factors, such as unpredictable climate patterns, influence agricultural outcomes.

Studies on similar water management interventions show that infrastructure like weirs and dams can enhance agricultural productivity by stabilising the water supply. However, they often introduce new complexities, particularly in climate change. For instance, improved irrigation reduces vulnerability to drought. However, they can sometimes lead to over-reliance on artificial water sources, making agriculture more susceptible to changes in climate variability [87]. Moreover, long-term sustainability requires balancing ecological considerations with socio-economic outcomes, as poorly managed water interventions may exacerbate existing vulnerabilities [88,89].

Agriculturists near Tempe Lake earn an average income that exceeds the South Sulawesi minimum wage of IDR 2.9 million. During recurrent flood seasons, the erratic characteristics of rice cultivation and fishing result in significant revenue fluctuations, particularly among fishermen. Floods affecting farmers, lasting roughly one month from December to January and extending up to two months from July to August, provide challenges for farmers attempting to synchronize their two-yearly rice cropping seasons with the flood cycles. Although agriculture offers a more consistent income than the fishing industry, which is significantly susceptible to environmental changes, income inequalities remain throughout the community.

Research highlights that farming, particularly with irrigation infrastructure in place, tends to offer more consistent income than fishing, which is highly sensitive to weather and environmental factors [90,91]. The challenges of synchronising agricultural activities with unpredictable flood patterns are well-documented in regions where water management systems struggle to accommodate the timing and intensity of natural flood cycles [87,92,93]. This unpredictability contributes to the income variability seen in both sectors, despite the overall stability that agricultural activities can provide.

3.2. Social Characteritics of Households

The respondents represent a predominantly middle-aged farming community with diverse livelihood strategies. Most households engage in farming and fishing, reflecting the region's dependence on multiple income sources. Education levels are generally low, with a significant proportion having only elementary schooling or being illiterate. Household sizes vary, though smaller families are dominant. Farming experience is extensive, with many farmers having decades of practice, reinforcing their reliance on agriculture and fishing as a way of life. These characteristics highlight a strong connection between livelihood sustainability and generational experience in managing farming and fishing activities.

Table 1 highlights the social characteristics of respondents, showing a predominantly middle-aged farming community where 60% are between 40 and 60 years old. Most engage in farming and fishing (80%), while only 7.14% rely solely on farming. Education levels are low, with 53.57% having only elementary education and 16.43% being illiterate. Household sizes are generally small, with 53.57% having fewer than four members. Farming experience is extensive, with 46.42% having 10–30 years of experience and 43.57% over 30 years. These findings suggest that farming and fishing are deeply rooted livelihoods, sustained by experience but limited by low education and diversification opportunities.

Table 1. Social characteristics of farmer households around Tempe Lake.

Social Characteristics	Range (n = 140)			Total
Age (year)	<40	40–60	>60	
	30.00	60.00	10.00	100.00
Employment	Farmer	Farmer + fishermen	Farmer + fishermen + others	
	7.14	80.00	12.86	100.00
Household head education	Illiterate	Elementary	High school	
	16.43	53.57	25.00	100.00
Household size (people)	<4	4–6	>6	
	53.57	34.29	12.14	100.00
Farmer experience	<10 years	10–20 years	>30 years	
	5.00	46.42	43.57	100.00

Livelihood patterns in farming communities reflect a generational shift, where younger households engaged solely in farming have less experience and are less inclined to diversify into fisheries or other occupations. In contrast, older households with multiple livelihood sources—combining farming, fishing, and other activities—have extensive experience and view these practices as a way of life rooted in long-standing traditions. Similar trends are observed in flood-prone areas, where fishing-only households are more vulnerable than those with diversified agri-fishery incomes [94]. In the Mekong Delta, shifts in primary income sources highlight successful household adaptations to changing economic conditions, a promising sign for the future of farming communities [95]. Factors influencing livelihood diversification include age, education, household size, social networks, and institutional support [96]. Intergenerational livelihood changes are more evident than intra-generational shifts, with a growing transition towards non-farm sectors while maintaining ties to traditional work [97]. To strengthen resilience and reduce vulnerability, policies should focus on infrastructure development, skill-building programs, and targeted support for disadvantaged groups [94,97].

3.3. Livelihood Diversification as a Response to Flood-Induced Risks

The flood cycles in the Tempe Lake region create significant economic uncertainty. Agricultural income, while variable, demonstrates a relatively higher degree of stability compared to the fisheries sector. The unpredictability of fishery income is notably more pronounced, reflecting the sector's susceptibility to the timing and severity of floods, which disrupt fish availability and fishing activities. This contrast between the two income sources highlights local communities' broader challenge in maintaining consistent livelihoods. The flood cycles, which dominate the agricultural and fishery sectors, create substantial economic instability, making it difficult for households to plan and secure reliable income. As a result, efforts to improve the livelihoods of these communities must consider both the environmental dynamics of the region and the socio-economic impacts of income variability driven by floods.

The livelihood data in Table 2, analysed in the context of the flood cycle in Tempe Lake, illustrate the significant impact of environmental factors on household incomes. Agriculture, with an average income of IDR 14.739 Milion per household farmer, exhibits significant variability, as evidenced by its coefficient of variation of 103.24%. Flood cycles, which disrupt agricultural activities due to seasonal inundation, especially during the July–August and December–January periods, are mainly responsible for this variation. The flood cycles often force farmers to adjust their planting and harvesting schedules, resulting in inconsistent yields and fluctuating income levels.

Table 2. Variation of average household income from agriculture, fisheries, and other sources (in IDR000).

Description	Agriculture (IDR/Season)	Fishery (IDR/Month)	Others (IDR/Month)
Average	14,738.58	571.32	2967.87
Standard of Deviation	15,215.44	818.12	2532.81
Coefficient Variation (%)	103.24	143.24	85.40

Note: Income from agriculture IDR 2456.33/month.

Fisheries generate income with a high coefficient of variation of 143.24%. The high degree of variability highlights the delicate nature of fishing around Tempe Lake, as flood patterns directly influence fish availability. Floods can either hinder fishing activities or cause overfishing when water levels rise, further depleting fish stocks and leading to unpredictable income for fishermen. Other income sources, averaging IDR 2.968 million per month, also show variability, though to a lesser extent than agriculture or fisheries, with a coefficient of variation of 85.40%. Even though these income streams offer some stability, the flood cycles indirectly impact the broader economic conditions.

The study emphasizes the significant livelihood difficulties caused by the flood cycles in Tempe Lake. Agriculture offers greater consistency than fisheries, yet it is significantly susceptible to disruptions from seasonal floods, which hinder planting and harvesting timelines. Conversely, fisheries are more vulnerable to the region's erratic hydrology, with fish populations and harvest prospects varying according to flood patterns. This economic volatility underscores the pressing necessity for focused initiatives to alleviate the effects of flood cycles on the lives of individuals reliant on agriculture and fisheries.

The complex interaction between income disparities and resource use reflects the delicate balance within the community surrounding Tempe Lake. Local households rely heavily on the lake's resources for daily sustenance, highlighting the importance of sustainable development strategies that balance economic prosperity with environmental conservation. Research shows that interventions focussing on improving water management and support-

ing adaptive livelihood strategies can help communities better cope with environmental unpredictability [87]. Recognising these dynamics is crucial for designing effective policies that protect vulnerable populations while maintaining the region's ecological integrity [91].

The data in Table 2 reveal significant income disparities among households around Tempe Lake, primarily influenced by the region's flood cycles. While a portion of farmers earn above the regional minimum wage, the majority struggle with lower incomes due to challenges posed by unpredictable floods. These farmers face difficulties synchronising their agricultural activities with the flood patterns, leading to reduced yields and financial instability. The findings highlight the vulnerability of many households in the area and emphasize the need for targeted interventions to help farmers adapt to environmental conditions and secure more stable livelihoods.

Table 3 highlights the flood cycle's significant impact on farmers' income levels in Tempe Lake. A notable 36.98% of farmers earn above the regional minimum wage (RMW), suggesting they may have managed to mitigate the challenges posed by the floods through better resource management or favourable land conditions. However, most farmers earn less than the RMW, with 23.44% falling between 25.1% and 50% of the minimum wage and 9.38% earning less than 25% of the RMW. These lower income brackets reflect the severe vulnerability of farmers who struggle to synchronize their agricultural activities with unpredictable flood patterns, leading to reduced yields and unstable livelihoods.

Table 3. Percentage of respondents based on the rate of income.

Range of Income (Percentage of RMW)	Households	Percentage (%)
Above 100.0	59	36.98
75.1–100.0	28	17.71
50.1–75.0	20	12.50
25.1–50.0	38	23.44
Less or $\leq$25	15	9.38
	160	100.00

RMW = Regional minimum wage (UMR = Upah minimum regional).

The wide disparity in income levels around Tempe Lake illustrates how the region's flood cycles contribute to economic instability for the farming community. Farmers earning less are often affected by frequent crop failures, mainly due to their inability to effectively mitigate the impacts of flooding [85,86,98]. These households may lack access to crucial flood control measures such as irrigation systems, drainage infrastructure, or early warning systems, making them more vulnerable to environmental shocks. Studies have shown that households with limited resources are often more susceptible to the adverse effects of climate variability, which further widens the income gap between wealthier and poorer farmers [99,100]. The unpredictable nature of flooding not only disrupts agricultural cycles but also limits the ability of lower-income farmers to invest in adaptive strategies, perpetuating a cycle of poverty and vulnerability [100,101].

Addressing these disparities requires targeted interventions prioritising flood management infrastructure, education on climate-resilient farming practices, and financial support to help vulnerable households adapt to changing conditions. Research has demonstrated that integrated approaches to water management and livelihood diversification can significantly reduce the economic impact of floods on smallholder farmers [87,102]. Implementing such strategies around Tempe Lake could help reduce income inequality and promote greater resilience in the face of environmental challenges.

Tempe Lake is essential in providing nutritional support to lakefront inhabitants, especially for low-income families. The unimpeded access to fish and vegetables from the

lake offers a vital and consistent source of protein, vitamins, and minerals. This biodiverse ecosystem serves as a sustainable source of nutrition, fulfilling the community's dietary needs throughout the year. Residents attain a balanced nutritional intake with a diet that integrates stored carbs from rice with a plentiful supply of fish and vegetables. Resources from the lake improve food security and contribute to a balanced diet, thereby enhancing the health and well-being of the population [103,104].

The community's economic dynamics and adaptive practices around Tempe Lake highlight a complex relationship between income, food security, and environmental resources. The lake's multifaceted role underscores the community's resilience as it sustains livelihoods through these natural resources. Any effort to improve economic opportunities must align with environmental conservation, highlighting the critical importance of ecosystem preservation. By safeguarding this delicate ecosystem, the community can continue to adapt to the income variability they face while ensuring long-term well-being and sustainable livelihood [104,105].

Despite the resilience embedded in the community's agricultural traditions, income from the farm sector remains significantly lower than earnings in other industries. This income disparity is particularly pronounced compared to the local minimum wage, as underscored in regional economic assessments. The combination of low agricultural income and reliance on lake resources emphasizes the need for initiatives that address economic inequalities and protect the natural assets vital to the community's well-being [106]. Ensuring these initiatives support sustainable livelihoods is essential to maintaining the economy [104,107].

3.4. Adaptive Income Strategies and Risk-Sharing Frameworks

The agricultural landscape around Tempe Lake experiences extreme fluctuations and variations in production, reflecting the inherent risks of farming in this region. These fluctuations pose a significant threat to farmers, exposing them to the potential for crop failure due to increased production costs or losses resulting from flooding. Differences in crop timing and the proximity of farms to the lake exacerbate the profound impact of such risks.

The farmers surrounding the lake face a continual threat of reduced agricultural output, as variations in productivity significantly exceed fluctuations in production prices. The increased variability in productivity is mainly due to planting dates that frequently misalign with the erratic timing of floods. The challenge of forecasting these flood episodes results in numerous farmers facing crop failure or a significant reduction in production levels. This unpredictability places financial burdens on farmers and underscores the broader issues associated with agricultural methods in a region where environmental conditions significantly impact crop profitability.

As the community grapples with these challenges, a critical need arises for strategic interventions that address the risks associated with unpredictable environmental factors. Enhancing predictive capabilities, implementing sustainable agricultural practices, and providing support mechanisms for farmers can contribute to building resilience around Tempe Lake's agricultural sector. Recognising and mitigating the impact of these risks is essential for fostering a more stable and secure livelihood for the farmers who depend on the intricate balance of nature for their agricultural pursuits.

Table 4 highlights significant variability in productivity and price, with productivity experiencing high fluctuations. The high coefficient of variation (CV) of 48.16% is primarily due to flooding, leading to substantial yield differences across observations. This variability is nearly two-thirds higher than price variation, with a CV of 29.20%, indicating that prices are relatively more stable. The pronounced instability in yield poses challenges for

farmers in maintaining consistent incomes, emphasizing the need for strategies to enhance productivity stability, mitigate flooding effects, and strengthen market resilience. Unlike many agricultural regions, the rice-growing season in Tempe Lake operates independently of South Sulawesi's rainy season and irrigation networks. This distinct planting cycle contributes to relatively stable rice prices but results in lower productivity than in regions where harvest timing exerts a more substantial influence on market prices.

Table 4. Productivity, price, and coefficient of variation on rice farm in Tempe Lake.

Description	Productivity	Price (IDR000/kg)
Average	4689 (kg/ha)	4520 (IDR/kg)
Standard of Deviation (kg/ha)	2258 (kg/ha)	1320 (IDR/kg)
Coeficient Variation	48.16%	29.20%

A comparative analysis with the Mekong Delta—a highly productive yet flood-prone rice-growing region—highlights both similarities and key differences in adaptation strategies. Farmers with access to formal credit, particularly through institutions like VBARD, experience lower yield variability [48]. In flood-prone and saline-affected regions, adopting stress-tolerant rice varieties has proven beneficial for food security and livelihoods, as seen in the Sundarbans [108]. Similarly, in Central Vietnam, saline water intrusion significantly affects rice productivity, with salt-tolerant varieties and improved irrigation proving essential for maintaining yields [109]. These comparisons emphasize the need for region-specific strategies that integrate financial access, infrastructure investment, and climate-resilient farming practices.

In Tempe Lake, limited credit access restricts landless and tenant farmers from investing in yield-enhancing technologies, increasing productivity risks. Unlike the Mekong Delta, where institutional support fosters climate-smart farming, Tempe Lake farmers operate with minimal intervention, making financial inclusion crucial for stability. Additionally, infrastructure differences shape adaptation; while the Mekong Delta benefits from large-scale irrigation, Tempe Lake's floating weir expansion to 10,000 hectares has disrupted traditional farming cycles. Mekong Delta farmers also face climate-induced challenges like extreme floods and soil degradation, requiring adaptation through climate-smart agriculture [110]. Education, credit, and land tenure influence adaptation, with smallholders facing more constraints [111]. While high-dyke farmers benefit from triple-crop systems, low-dyke farmers struggle financially [110]. Strengthening financial access, improving crop varieties, adjusting planting calendars, and promoting less water-intensive crops could enhance resilience in both regions [110,112].

Overall, the findings suggest that improving financial accessibility, investing in resilient agricultural practices, and implementing adaptive water management policies could enhance farmers' ability to cope with productivity risks in Tempe Lake. Lessons from the Mekong Delta highlight the importance of institutional support in stabilising agricultural output under unpredictable environmental conditions. A coordinated effort to provide financial resources, extension services, and infrastructure improvements could reduce vulnerability and promote long-term sustainability in Tempe Lake's farming communities.

In the communities around the lake, fishing serves as a primary or alternative income source and a recreational activity for numerous households. Nearly 91.2% of the community engages in rice farming, while all members participate in fishing activities. This diversification of livelihoods reflects the adaptive strategies of the community, where individuals often work as fishermen, traders, employees, or construction workers [113]. Rice farming, despite its high inherent risks, remains a dominant source of income, fostering the

formation of institutions regulating co-operative systems between farmers and irrigation pump enterprises.

Rice farming in the Tempe Lake area involves higher risks than other regions, yet it remains an essential source of income that significantly supports local livelihoods. This interdependence has given rise to institutions facilitating collaboration between rice farmers and irrigation pump enterprises, establishing a coordinated co-operation system. Agriculture, particularly in rice farming and fisheries, is the primary livelihood for the residents around Tempe Lake. However, the fisheries sector faces challenges during low water levels, as decreased water responses and distant fishing grounds reduce productivity. In contrast, rice farming tends to thrive when water levels recede as the conditions become more suitable for cultivation. Thus, rice farming and fishing around the lake complement each other, providing vital income and sustaining the community [114,115]. This livelihood strategy exemplifies the community's resilience and adaptation in addressing the challenges of Tempe Lake's dynamic environment. Despite the hazards of biannual floods, the lake's rich natural resources provide diverse and readily accessible employment opportunities, fostering residents' sense of security [116,117]. This adaptability underscores the community's ability to navigate and thrive in the fluctuating conditions of Tempe Lake.

In rice farms around Tempe Lake, the equilibrium between possible advantages and risks undertaken by each partner adheres to a distinct proportional framework. In instances of production failure, the primary responsibility falls on farmers, followed by pump operators, pump workers, and landowners, whose risk exposure diminishes accordingly. This risk hierarchy results in considerable financial losses, with farmers encountering roughly IDR 2–3 million per acre setbacks. Irrigation pump operators incur losses of approximately IDR 1 million per acre. The adverse effects include pump entrepreneurs, who face operational expenses, and pump workers, who have opportunity costs. The complex interplay of risks and repercussions underscores the intricacies of partnerships in rice farming in the Tempe Lake region, as each stakeholder must adeptly manage the equilibrium between prospective benefits and detriments.

Figure 3 provides a comprehensive view of the proportional distribution levels and risks among partners in the rice farming ventures around Lake Tempe. As farm productivity increases, the distribution levels received benefit by each partner also rise, with farmers receiving the largest share, followed by landowners and water pump owners. However, at ten quintals per hectare or lower productivity levels, landowners and pump owners do not yet receive any share of the output, highlighting a uniform distribution of production risk only under specific conditions. This visual representation clarifies the alignment of risk allocation with each partner's role and underscores how productivity influences the distribution of benefits. Farmers benefiting from the highest average revenue lead the hierarchy of profit-sharing, illustrating the intricate balance between productivity, risk, and the sharing of returns in these agricultural partnerships.

After deducting operational costs, farmers and landowners determine the benefit share in rice farming. These costs include expenses for land preparation, input purchases, and labour, directly impacting the net earnings of farmers. Meanwhile, irrigation service providers (ISPs) receive water fees as their share of the benefit, however, the operational costs they incur, such as fuel, maintenance, and labour for irrigation management, are not accounted for in the benefit calculation. This distinction highlights the financial burden on different stakeholders within the farming system, where farmers and landowners absorb production costs upfront while ISPs generate revenue through service fees. A more transparent and equitable cost-sharing mechanism could improve financial sustainability and support long-term agricultural resilience in flood-prone farming areas.

In flood-prone regions such as the Tempe Lake area, profit-sharing agreements can provide essential support to farmers by relieving them of obligations associated with crop failures due to flooding. This method substantially alleviates the financial strain on farmers, who would otherwise incur considerable losses, by dispersing it among landowners and irrigation pump operators. Numerous studies have suggested these relief solutions as protective measures to save farmers' livelihoods from the ongoing hazards of flooding [114,117]. Landowners and irrigation companies mitigate financial risks for farmers, safeguarding individual farmers and bolstering the resilience of the agricultural community [116].

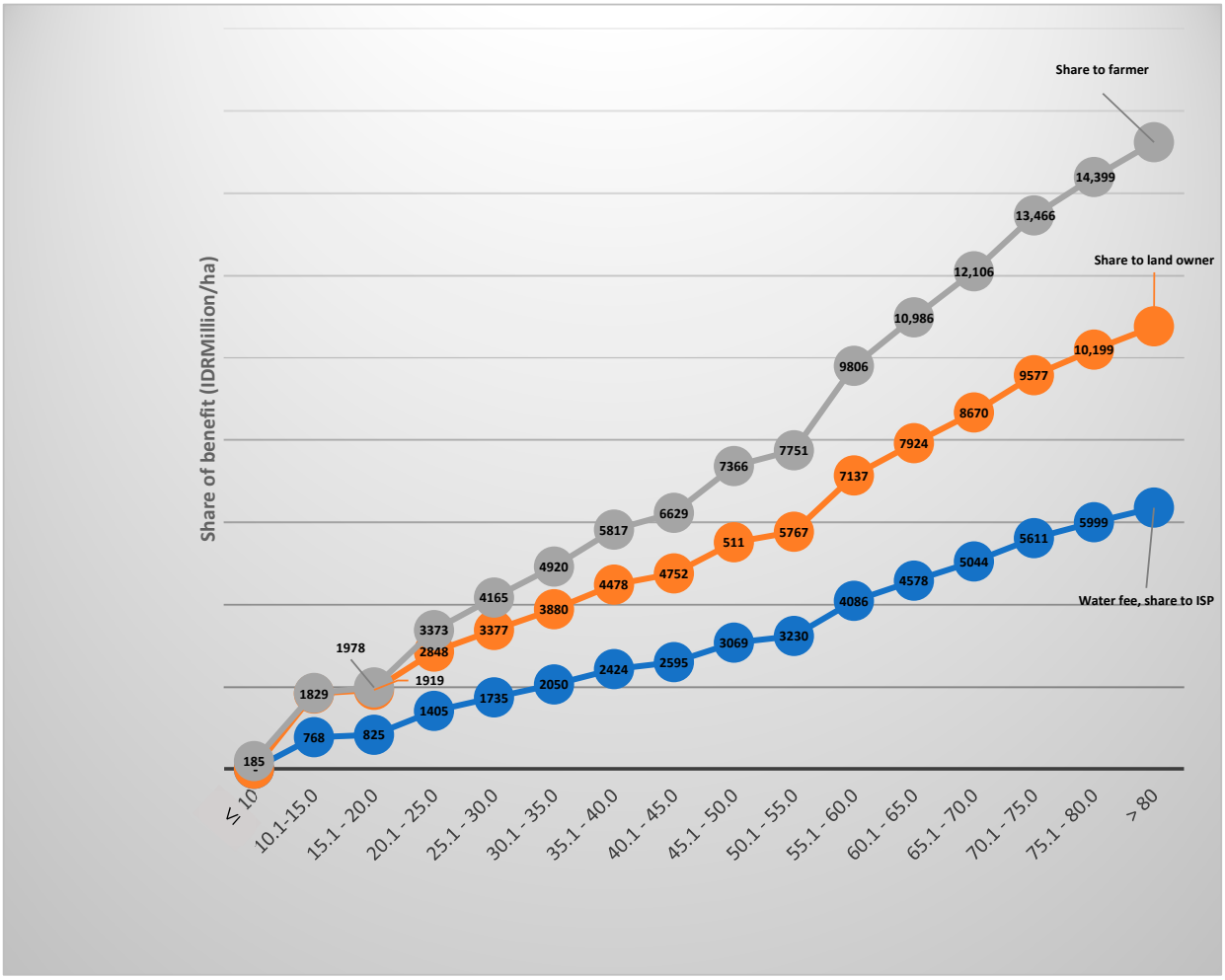

Figure 3. Share of benefit to each rice farm participant in Tempe Lake.

The varying degrees of production loss experienced by rice farmers reveal substantial challenges within the agricultural community, underscoring both resilience and vulnerability among farmers. While most farmers managed to maintain consistent rice output levels, with over half reporting no losses, a considerable number still faced reductions in production. These losses were modest for many, but some groups encountered significant declines in their rice yields. A small yet notable subset experienced substantial losses, reflecting more profound, underlying challenges within the community. This distribution of impacts highlights the urgent need for targeted support and effective risk mitigation strategies to help farmers manage the elevated risks they face. Ensuring stability and resilience for these farmers is crucial, as production difficulties directly affect their livelihoods and, ultimately, the broader agricultural sector.

Table 5 reveals that most farmers maintained stable rice production, with more than half reporting no loss. Nonetheless, a substantial portion faced some level of production decline. While many of these losses were manageable, certain groups of farmers experienced significant reductions in their yields. A smaller yet noteworthy subset endured severe losses, suggesting underlying challenges that may affect the community. This distribution underscores the resilience of many farmers but also points to potential vulnerabilities among those facing the most significant impacts, indicating areas where targeted support may be necessary to enhance stability and resilience within the farming community.

Table 5. Percentage of respondents based on the loss percentage of rice farm production.

Loss of Production (%)	Farmers	Percentage (%)
No loss	86	53.71
Loss of ≤25	29	18.29
Loss of 25.1–50	12	7.43
Loss of 50.1–75	18	11.43
Loss of ≥75	15	9.14
	160.00	100.00

Rice cultivation is significant beyond agriculture since it fulfils the essential needs of inhabitants, especially those in the villages and other settlements near Tempe Lake. Originally intended to satisfy home consumption needs, rice production has become integral to the community's agricultural endeavours and supports local livelihoods. Farmers systematically store harvested rice from each growing season to guarantee a dependable supply, which typically sustains their needs for approximately seven to nine months. An additional buffer stock of one to three months supplements it to alleviate potential shortages caused by crop failure. This systematic method emphasizes the critical importance of rice production in ensuring food stability and highlights its significance in promoting resilience and food security within the community. This storage strategy is essential in regions such as Tempe Lake, where erratic floods can hinder production, rendering rice cultivation a crucial factor in maintaining the community's welfare and stab [114,116].

3.5. Risk-Sharing Mechanisms for Resilient Rice Farming

Overcoming the challenge of flooding—closely tied to climate change—is a formidable task for farmers around Tempe Lake, making it difficult to pinpoint the ideal planting period. In this region, flooding is the primary factor behind production failures in rice farming, posing a substantial risk to agricultural stability. To address this pervasive threat, stakeholders involved in rice farming have established a partnership system that mitigates the likelihood of production failure. This strategic collaboration underscores a proactive effort to bolster the resilience of the local farming community, allowing them to navigate better the considerable challenges imposed by climate-induced flooding and maintain productive rice cultivation.

Within the framework of this partnership system in the rice industry, stakeholders play a vital role by supplying a wide range of production inputs and services. This includes contributions from pump operators, skilled farmers, suppliers of essential inputs like fertilizers and pesticides, and the Rice Milling Unit (RMU). Beyond its core function, the RMU occasionally extends additional support by providing agricultural machinery and facilities, such as tractors for tilling, harvesting equipment, drying facilities, grain storage warehouses, and even financial assistance for purchasing inputs. This collaborative effort highlights the comprehensive nature of the partnership, with each stakeholder contributing unique resources to enhance the overall efficiency and resilience of the rice farming system.

Despite its informal nature and lack of formal documentation of stakeholders' rights and obligations, the partnership system fundamentally relies on risk-sharing, particularly in the context of production failures due to flooding [118]. Without written agreements, this collaborative approach centres on mutual support, where each participant contributes to and shares the burdens of potential losses. By focusing on risk-sharing, the partnership system strengthens the resilience of the Tempe Lake rice farming community, enabling it to withstand better the challenges posed by climate-induced flooding. This co-operative model highlights the community's adaptability and collective response to environmental risks.

The financial implications of harvesting failures in rice farming illustrate the risks and potential earnings among various stakeholders. Farmers bear significant costs related to opportunity expenses, land preparations, and production inputs while benefiting from considerable net returns. Water pump enterprises and labourers face diesel, maintenance, and labour expenses, yet they also gain from returns on their services. Landowners incur costs related to land rent but also stand to earn notable returns. This distribution of financial responsibilities and potential earnings exemplifies the share-tenant system, in which farmers and landowners split the profits, underscoring the collaborative nature of this partnership and the complex economic dynamics that sustain it amid the challenges of farming in flood-prone areas.

Table 6 highlights a balanced risk-sharing framework developed among stakeholders to manage the high risks associated with rice farming in Tempe Lake. This arrangement distributes financial burdens and potential earnings to mitigate the impact of crop failures during harvest. Farmers bear the highest risk, facing average losses of IDR 2.50–3.2 million per hectare, primarily in production costs. Pump-based irrigation operators also encounter financial risks, with operational expenses averaging around IDR 1.0 million. Additionally, input suppliers often experience delayed payments, and water fees' revenue losses impact pumping workers and landowners. This complex network of financial interdependencies underscores the collaborative nature of rice farming in a flood-prone environment, where risk mitigation strategies play a crucial role in sustaining livelihoods [119,120].

Table 6. The value of loss and earning potency in harvesting failure (IRD million/ha).

Lost Items	Stakeholders	Value of Risk Potency	Net Return **
Opportunity cost	Farmer	2.00–3.00	10.93
Land preparation (tractor service)	Farmer	1.30–1.50	-
Input production (seed, fertilizer, pesticide)	Farmer *	0.70–1.20	-
Labour for plant cultivation	Farmer *	0.20–0.50	
Opportunity cost of irrigation pump (oil, diesel, maintenance)	Water irrigation pump enterprise	1.20	2.91
Opportunity cost of water pump labour (based on UMR)	Water pump labour	0.00–0.29	0.73
Opportunity cost of land rent	Landowner	2.00–2.50	6.43

* Equal share in share tenant system; ** average production 5 ton /ha. Note: tenant share systems are 60% farmers and 40% landowners after the deduction of all costs except land preparation (tractor fee) and plant cultivation (labour cost); the capacity of each labour per 2.0 ha per plant season.

An assessment of smallholder rice farming households in the Mekong Delta region of Vietnam highlights similar challenges in seasonal rice cultivation, where productivity varies due to land tenure differences. The findings suggest that strengthening communication networks among farmers, local governments, and organizations and providing subsidies and training programs can help farmers cope with climatic events and diversify their income sources [111,121]. However, tenant farmers face more significant productivity fluctuations due to uncertain land tenure, limited credit access, and dependence on informal irrigation

systems. These challenges are also evident in Tempe Lake, where tenant farmers struggle with restricted decision-making over land improvements and irrigation investments. Addressing these issues through secure land tenure and improved financial inclusion is crucial for stabilizing yields and enhancing the resilience of smallholder farmers in both regions.

To boost productivity in Tempe Lake, policymakers should focus on formalizing tenancy agreements, expanding tenant farmers' access to financial resources, and enhancing irrigation infrastructure. These strategies can potentially increase agricultural output and improve farmer livelihoods significantly. Expanding affordable credit and promoting co-operative farming can boost resilience in flood-prone areas, but long-term stability requires strategic climate-resilient investments. Lessons from the Mekong Delta highlight the need to integrate secure land tenure with flood-adaptive infrastructure to enhance economic stability and sustain rice farming. A holistic approach combining land rights, co-operative farming, and climate-resilient investments could help mitigate productivity risks and improve farmer livelihoods in the region.

3.6. Institutional Frameworks and Collaborative Risk Management

Farmers around Tempe Lake have extensively embraced new agricultural technology, particularly irrigation pumping devices, to meet the water demands for rice cultivation. This technology is critical in managing the recurring flooding in the region, which affects various elements of the partnership framework, including profit-sharing, risk-sharing, and the potential for crop failure. The unpredictable nature of floods hinders crop yields and necessitates diverse approaches to distributing risks and benefits across different geographical areas. In Tempe Lake, farmers often receive more than 60 per cent of the net output value, excluding labour costs such as tractor and maintenance expenses. By contrast, profit-sharing percentages for farmers in other regions typically range from 40 to 50 per cent. This variation underscores how localized flooding influences agricultural practices, leading to different impacts on the distribution of risks and rewards among farmers in distinct areas.

The level of risk inherent in agriculture intimately links to technological innovations designed to enhance production. Paradoxically, although these advances may enhance yields, they frequently result in diminished profit margins for farmers due to the accompanying expenses and increased risks. The interplay between risk variables and technical advancement in rice cultivation ultimately determines the value of the harvested crops, highlighting the necessary equilibrium in the implementation of new technologies. While technology improvements present opportunities for productivity enhancement, they also entail risks that may negate the economic advantages for farmers. This dynamic exemplifies the intricate relationship among risk, technology, and profit in agriculture, wherein enhanced production does not invariably result in improved financial security for farmers.

Table 7 shows an important finding that comes from the fact that many farmers around Tempe Lake use irrigation pumping technology. This technology is necessary to meet water needs and deal with frequent flooding. However, it also changes the partnership structure in a big way, especially regarding how profits are shared and who takes on the risk. Flooding remains unpredictable, disrupting crop yields and requiring tailored frameworks to distribute risks and benefits across various regions. Notably, farmers in Tempe Lake often secure over 60 per cent of the net production value, excluding labour-related expenses like tractor fees and maintenance costs. In contrast, farmers in other areas generally receive between 40 and 50 per cent, reflecting how localized flooding uniquely impacts agricultural practices and alters the economic landscape for farmers. This disparity underscores a crucial insight: technological advancements, while beneficial, create a complex web of financial

dynamics that varies by region, illustrating the nuanced interplay between productivity, risk, and profit in flood-prone agricultural settings.

Table 7. Revenue sharing system between landowners and tenant based on pumping-irrigation.

Cost and Revenue Components	Contribution Share	Value (IDRMillion /ha)
Land preparation	Farmer	1.3–1.5
Input production (seed, fertilizer, pesticide)	Equal share	0.70–1.20
Labour for maintenance and planting	Farmer	0.20–0.50
Harvesting cost (7.50% of gross production)	Equal share	2.20
Pumping water use fee 20% from net production. No water fee from fail culture	Equal share	0–5.96
Share tenant system after deduction all costs except land preparation and cultivation.	Farmer (60%)	0–17.9
	Landowner (40%)	0–12.5

In this co-operative framework, the collaboration between landowners and tenants includes an equitable sharing of production facilities, harvest, and pump-based irrigation costs, underscoring a balanced partnership. The landowner assumes half of these costs, highlighting a substantial technological contribution to the arrangement [120,122]. The profit-sharing mechanism further reflects this joint effort, with farmers receiving 60% and landowners receiving 40% of the production value after deducting production costs. Beyond the financial implications, this profit distribution reflects both parties' capital investment and shared risks. This shared commitment emphasizes their mutual stake in the success of rice farming around Tempe Lake and solidifies a balanced economic partnership. The structure of this relationship is a testament to how co-operative risk-sharing can enhance resilience and sustainability within agricultural ventures [123].

The revenue-sharing system in Tempe Lake reflects in Table 7 a well-balanced partnership between farmers and landowners, distributing financial contributions, risks, and capital value in a way that promotes sustainable rice farming in this flood-prone region. More than just an economic arrangement, this system fosters a co-operative spirit, where shared responsibilities and mutual understanding help farmers navigate environmental uncertainties [124,125].

Similar dynamic rice farmers in the Mekong Delta face similar challenges to those in Tempe Lake, including climate change, environmental pressures, and economic uncertainties. Unpredictable weather, market fluctuations, and long-term climate threats have made maintaining stable productivity increasingly tricky [126]. Social capital is vital in strengthening agricultural co-operatives in both regions, and trust is key to sustaining partnerships [127]. The resilience seen in Tempe Lake's revenue-sharing system mirrors that of the Mekong Delta, where co-operative farming structures help farmers adapt to external shocks.

While co-operative frameworks support resilience, additional adaptation strategies are needed to address climate-induced vulnerabilities. In the Mekong Delta, sustainable measures like allowing natural sediment deposition through periodic flooding offer a more equitable alternative to intensive triple-cropping, mainly benefiting wealthier farmers [128]. Similarly, integrating sustainable land and water management policies alongside revenue-sharing agreements in Tempe Lake could enhance long-term agricultural stability.

Farmers in both regions acknowledge climate-related risks, such as rising temperatures, drought, water pollution, and sediment shortages, as significant livelihood threats [111,129]. While short-term adaptations, like increasing inputs and modifying production methods, provide temporary relief, long-term solutions are needed. The success of revenue-sharing in Tempe Lake highlights the potential of co-operative agricultural systems, which, combined

with adaptive water management and climate-smart policies, could enhance resilience for rice farmers facing similar environmental challenges.

By drawing lessons from the Mekong Delta, policymakers and stakeholders in Tempe Lake can enhance the effectiveness of co-operative farming models by integrating sustainable adaptation strategies. Strengthening institutional support, improving access to financial resources, and promoting adaptive farming techniques will secure a stable future for rice farmers in flood-prone regions.

4. Conclusion and Policy Recommendation

4.1. Conlusion

The increasing vulnerability of rice farming around Tempe Lake is due to climate change-induced flooding, which heightens financial risks and exacerbates income disparities among farmers. While informal profit-sharing agreements between farmers, landowners, and irrigation pump operators help distribute risks, the lack of formalized institutional support exposes farmers to production failures, resulting in financial losses of IDR 2–3 million per hectare. With 36.98% of farmers earning above the regional minimum wage while 32.82% earn below 50% of it, the unequal access to resources and varying risk exposure further highlights the need for intervention. Strengthening risk-sharing mechanisms through formal legal frameworks and institutional policies can enhance resilience and long-term agricultural sustainability. Investments in flood-resistant rice varieties, improved irrigation infrastructure, and climate-resilient financial mechanisms, such as subsidized insurance, farmer training, and accessible credit, should be prioritized to mitigate climate risks.

4.2. Policy Recomendataion

To enhance the resilience of rice farmers in flood-prone areas like Tempe Lake, policy interventions should focus on improving flood management infrastructure, expanding access to climate-resilient rice varieties, and strengthening risk-sharing mechanisms. Formalizing profit-sharing agreements among farmers, landowners, and irrigation service providers can distribute financial risks more equitably. Subsidized crop insurance, accessible credit, and farmer training programs should be implemented to mitigate income instability. Investing in early warning systems, which have proven to be effective in reducing crop failures, and adaptive water management strategies can further enhance resilience. Collaboration between government, research institutions, and farmer co-operatives is essential to ensure sustainable, long-term agricultural productivity in flood-prone regions.

4.3. Limitation of the Study

The qualitative analysis method of this study presents a limitation. While interviews and observations provided in-depth insights into farmers' adaptive strategies and risk-sharing mechanisms, they are inherently subjective. They may not fully capture the diverse experiences of all community members. Moreover, the study restricted the sample size to a specific region, potentially underrepresenting the wider Tempe Lake population, which restricts the generalizability of the findings. Additionally, due to the reliance on self-reported data, there is a potential for response bias, where participants might have presented socially desirable responses. Addressing these limitations in future studies could involve a more extensive and diverse sample and quantitative methods to enhance reliability and broaden the study's scope.

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Institutional Review Board Statement: Ethical review and approval were not applicable for this study. This is because this study was conducted in Indonesia, where research ethics approval for non-clinical, social science, and community-based research is not legally required under local or national regulations.

Informed Consent Statement: This study strictly adhered to ethical standards, safeguarding participant anonymity, data confidentiality, and voluntary participation throughout the research process. All survey responses and interview transcripts were de-identified, with participants assigned unique identification codes to prevent personal identification. Audio recordings were transcribed and deleted; all data is securely stored and permanently deleted when no longer needed. Oral informed consent was obtained, considering participants with limited literacy levels were assured of their right to withdraw at any time without consequences. Although formal IRB approval was waived, the study followed the Helsinki Declaration and institutional ethical guidelines, with a statement on these safeguards included for full transparency.

Data Availability Statement: The raw data supporting the findings of this article are available from the authors upon reasonable request. As the dataset captures unique local conditions with limited generalizability beyond its original context, access is carefully managed on a case-by-case basis. This approach ensures that the data are utilized responsibly and align with the study's specific objectives. Researchers interested in accessing the data are encouraged to contact the authors to discuss its use and potential arrangements, ensuring that the data are applied appropriately and in ways that respect its context-specific nature.

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