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IPCC-BASED HOUSEHOLD CLIMATE VULNERABILITY INDEX IN SALOKARAJA VILLAGE, SOUTH SULAWESI

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Abstract

Climate change is intensifying floods and droughts across rural Indonesia, yet vulnerability assessments rarely drill down to the village scale. This study evaluates household-level climate vulnerability in Salokaraja Village, Soppeng Regency, using the IPCC framework of exposure, sensitivity, and adaptive capacity. Primary data were collected through a survey of 115 households, key-informant interviews, and focus-group discussions, while secondary data included long-term rainfall records (2000–2023), disaster reports, and a 30-m DEM. Indicators were normalised and weighted into a composite index, then analysed using t-tests, Spearman correlation, and multiple linear regression, complemented by Moran's I and IDW interpolation for spatial validation and mapping. Results show that 34% of households fall into the high-vulnerability category, with an average index score of 0.55. Flood-plain exposure and rice-monoculture dependence are the dominant risk drivers, while adaptive capacity—especially access to credit (27%) and climate-information literacy (46%)—exhibits a strong negative relationship with vulnerability (β = −0.44). Policy recommendations include rehabilitating tertiary irrigation and flood canals, integrating BMKG seasonal outlooks into extension services, expanding subsidised "Green KUR" for adaptive investments, and revitalising farmer groups as co-production platforms for climate *information. The findings underscore that strengthening human, financial, and institutional capital is as crucial as hazard control for building rural climate resilience.*

Keywords: Climate Change; Household Vulnerability; Adaptive Capacity; Vulnerability Index

A. Introduction

Global climate change has consistently increased the Earth's average temperature and intensified hydroclimatic extremes worldwide. Although this warming trend is well established, projections of future rainfall remain uncertain due to structural differences among climate models. Observation-based constraints, however, have helped narrow these uncertainties and improve confidence in 21st-century warming estimates.(Knutti et al., 2008). The IPCC AR6 report confirms without a doubt that human influences have warmed the atmosphere, oceans, and land, with an increase in extreme events across regions of the world (IPCC, 2021).

Indonesia ranks as the second most vulnerable country according to the World Risk Report 2024; in 2023 alone, 5,400 disasters were recorded, 99% of which were hydrometeorological, namely floods, landslides, and droughts that caused millions of people to be affected (BNPB, 2024). In South Sulawesi, climate pressure triggers uncertainty in agricultural production and increases socio-economic risks for agrarian communities (Busthanul et al., 2023; Naswar et al., 2023).

Salokaraja Village is a rural area in Soppeng Regency that is highly dependent on rice production, has limited access to education and health, and faces rising temperatures and erratic rainfall patterns. Remote geographical conditions, an undiversified agrarian economy, and limited infrastructure make households here vulnerable to floods and droughts (Piya et al., 2015; Mukherjee et al., 2019).

Most climate vulnerability research in Indonesia still focuses on the district-provincial scale or uses aggregate secondary data, so it fails to capture intra-village variations and socio-economic microeconomic dynamics. Local assessments that integrate physical-socio-economic indicators with participatory methods remain limited in Indonesia, particularly in eastern regions such as Sulawesi, where most studies still rely on district-level secondary data (Nguyen et al., 2017; Nazeer & Bork, 2020; Ibanga et al., 2023). Recent reviews also highlight that micro-scale, household-based assessments using the IPCC framework are comparatively scarce in rural Southeast Asia (Estoque et al., 2023) especially in the Sulawesi region (Nguyen et al., 2017; Nazeer & Bork, 2020; Falilul et al., 2021). This study fills the gap by: (i) building an IPCC-based multiparameter vulnerability index, (ii) combining household surveys and FGDs, and (iii) analyzing the contribution of relative exposure, sensitivity, and adaptive capacity at the village level.

Scientifically, this micro-participatory approach enriches vulnerability assessment methodologies in the tropics and can be replicated in other villages. In practical terms, the resulting hotspot indexes and maps provide an evidence basis for local governments to prioritize adaptation investments such as improving irrigation networks, diversifying livelihoods, and strengthening early warning systems, as well as synergizing disaster risk reduction agendas with climate adaptation (Djalante & Thomalla, 2012). Despite increasing interest in climate vulnerability research, most studies in Indonesia still operate at district–provincial scales or rely solely on secondary datasets, leaving a research gap in household-level, mixed-indicator, and participatory assessments—especially in Sulawesi, where such micro-scale analyses remain limited… The academic novelty of this study lies in integrating IPCC's exposure–sensitivity–adaptive capacity framework with household surveys, FGDs, and geospatial hotspot mapping to produce a fine-resolution vulnerability index at the village level.

This study aims to analyze the level of vulnerability of the Salokaraja community, identify the main biophysical and socio-economic determinants, and formulate contextual adaptation recommendations while presenting academic novelty and policy benefits for Indonesia's rural climate resilience.

B. Methodology

1. Research Design

This study uses a descriptive-qualitative design that combines quantitative surveys, in-depth interviews, and focus-group discussions (FGD). This mixed approach was chosen so that vulnerability analysis not only captures exposure rates and sensitivity, but also the social reasons behind the household's ability or lack of ability to adapt. The study location, Salokaraja Village (4°

19′ LS; 119° 54′ E), is a floodplain of the Bila River, which physically and economically represents a climate-sensitive agricultural village in South Sulawesi (Figure 1).

The population consisted of 1,284 households recorded in the 2023 village census. A sample of 115 households was selected using stratified random sampling with proportional allocation, with strata based on rice-field types (permanent irrigation vs. rainfed) to represent contrasting biophysical conditions. The minimum required sample size was calculated using the Slovin formula with an 8% margin of error, and an additional 10% was included to anticipate potential non-response, resulting in a final sample of 115 households.

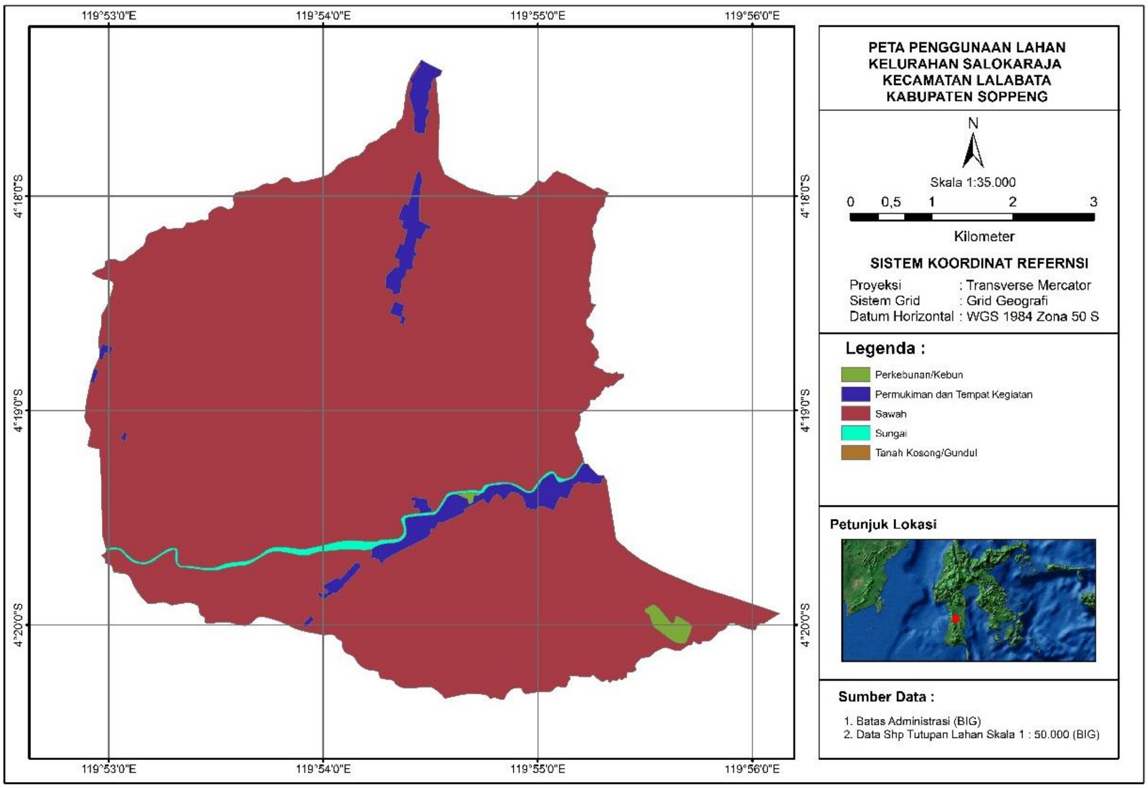

Figure 1. *Land use*
(Source: data analysis)

2. Instruments

The main instrument is a 42-item questionnaire that measures the three pillars of the IPCC framework: exposure (e.g., frequency of floods in the last decade), sensitivity (ratio of rainfed land, dependence on agricultural income), and adaptive capacity (access to credit, education, membership of farmer groups). Likert grains are arranged 1–5; climate change experts and methodologies verified logical validity, while internal reliability was tested via Cronbach-α ($\alpha = 0.87$).

In-depth interviews were conducted with 15 key informants (hamlet heads, agricultural extension workers, women leaders, BPBD staff) to explore adaptation narratives. Three cross-gender FGDs validated vulnerability indicators and mapped the location of routine inundation. Secondary data include 2000-2023 daily rainfall (BMKG), disaster records (BPBD), 30 m DEM imagery, and the most recent land cover map—all used to check the consistency of respondents' answers and enrich spatial analysis.

3. *Technique of Data Analysis*

Quantitative Data Analysis

1) Normalization of the indicator using min–max scaling:

$$.x' = \frac{x - \min(x)}{\max(x) - min\,(x)}$$

This limits each value to the range 0–1.

2) The weighting is set evenly between the dimensions to avoid expert bias.
3) Preparation of vulnerability index:

$$V = \frac{E + S + (1 - A)}{3}$$

With E = exposure, S = sensitivity, A = adaptive capacity—the higher the V, the more vulnerable.

4) The t-dependent test assesses the difference in V between hamlets, while the Spearman coefficient tests the relationship between A and V.

Qualitative and Spatial Analysis

Transcripts of the interview-FGD were thematically analyzed following Braun & Clarke's six stages to formulate local adaptation codes, themes, and sub-themes. The V score of each household was then geocoded and interpolated using Inverse Distance Weighting (IDW) to produce a high-resolution hotspot map; The village boundary polygon becomes a mask so that edge artifacts can be avoided. All operations are performed in ArcGIS 10.8, while the final visual is exported at 300 dpi for publication purposes.

Triangulation of methods (survey-interview-FGD), sources (primary-secondary), and member-checking examination in the final FGD session ensured the validity of the data. In addition, spatial autocorrelation (Moran's I) was calculated to validate hotspot patterns, while the Variance Inflation Factor (VIF < 4) test was applied to check the multicollinearity between indicators before regression.

C. Findings and Discussion

1. Findings

a. Perception of Climate Change and Its Impacts

Most respondents (86%) said the average annual temperature is now "hotter" than it was 10 years ago; 78% said the rain was "more erratic", while 64% felt an increase in the incidence of flash floods. This perception pattern is in line with qualitative findings. In three FGD sessions, farmers explained the delay of planting by ± 3 weeks due to the retreat of the beginning of the rainy season and the increase in leafhopper pest attacks during the generative period of rice. Interviews show that this change directly impacts production—the average rice yield fell by 14% in the 2022/2023 season. The main coping strategies include shifting the planting schedule (42% of households), planting mature varieties (31%), and rice-palawija planting patterns (17%). These perceptual findings are consistent with other tropical rural research patterns, where farmers indicate schedule adjustments and diversification to compensate for climate variability (Kupika et al., 2019).

Table 1. *Perceptions of Climate Change in Salokaraja Communities (n = 115)*

Perception indicators	Agree (%)	Disagree (%)	Average Likert score (1-5)
Warmer temperatures	86	5	4.3 ± 0.6
Rain is getting erratic	78	9	4.1 ± 0.7
Increase in flash floods	64	18	3.7 ± 0.9
Drought more often	53	22	3.4 ± 1.0

b. Exposure Analysis

Daily rainfall data (2000-2023) shows an upward trend in the number of days of extreme rain (> 50 mm/day) by 0.9 days/year. While the discharge of the Bila River rises by 3.2% per year during the peak rainy season, the peak flood (Q100) was recorded to increase from 420 m^3/s (2003) to 505 m^3/s (2023). Historical mapping of flood hotspots using a buffer of 250 m from the river channel identified Batu-E Hamlet and Lumpa Hamlet as the highest exposure zones with flood frequency ≥ 7 times/10 years. Meteorological drought, measured through the SPI-3 index, shows four dry-extreme events in 2013-2023, especially in the intense El Niño phase, in line with the pattern of eastern Indonesia (Basuki et al., 2022).

c. Sensitivity Analysis

The sensitivity dimension is based on eleven biophysical and socio-economic indicators. The average proportion of rainfed land reaches 48% of the total rice fields; dependence on agricultural income (≥ 70% of family income) was recorded at 62% of households. The ratio of semi-permanent homes—proxies of physical vulnerability was 41%, while the prevalence of ISPA disease rose 19% during the 2019 long dry season. The t-test showed a significant difference ($p < 0.05$) between lowland and hilly hamlets: the average sensitivity scores were 0.62 and 0.51, respectively. Spearman's analysis showed a strong positive correlation ($\rho = 0.71$) between the proportion of farm income and sensitivity scores, confirming the finding of parallels with the literature that a single dependence on rice fields increases vulnerability (Poudel et al., 2020).

Table 2. *Sensitivity Score per Indicator (n = 115; scale 0-1)*

Indicators	Average	SD	Weight	Contributions to S
Rainfall Land	0,69	0,21	0,15	0,104
Farm income	0,71	0,18	0,15	0,107
Semi-permanent house	0,41	0,26	0,10	0,041

d. Adaptive Capacity Evaluation

The average adaptation capacity was at a score of 0.46 ± 0.15; This value is lower than the village-agrarian study in the highlands of Sulawesi (0.55) (Busthanul et al., 2023). The dimension of human assets is reflected in high school ≥ education, which is only achieved by 23% of families; access to agricultural credit 27%, and membership of active farmer groups 36%. Regarding information, 54% of respondents "never" received official seasonal climate forecasts, signaling barriers to climate communication. On the social capital side, the community trust index (0.71) is relatively high, while institutional support (access to government programs) is still low (0.39). Thematic analysis of the interviews highlighted three main barriers to adaptation: limited capital, drought-tolerant variety mismatch, and lack of extension—in line with barriers to adaptation in Ethiopia and Nepal (Destaw & Fenta, 2021; Yang et al., 2021).

Table 3. *Details of Adaptation Capacity Score*

Dimension	Key indicators	Score (0-1)
Human assets	High ≥ Education	0,23
Physical assets	Ownership of water pumps	0,34
Financial capital	Access to agricultural credit	0,27
Information	Access climate forecasts	0,46
Institutional	Farmer group membership	0,36

e. Integrated Vulnerability Score and Hotspot Map

The total vulnerability index (V) is calculated via weighted average (E + S + [1 – A]) / 3. The V-value of households varies from 0.27 to 0.76 with an average of 0.55 ± 0.11; The range is categorized into low (≤ 0.40), medium (0.41-0.60), and high (> 0.60). As many as 34% of households are in the high category—concentrated in Batu-E Hamlet (55 households) and Lumpa Hamlet (32 households) (figure 2).

IDW's interpolation shows two dominant clusters: (i) floodplains along the Bila River and (ii) karst hill enclaves with limited water access. Participatory validation through FGDs confirmed the accuracy of the map (agreement rate > 80%). The Pearson correlation between the maximum flood depth and the high group vulnerability score reached $r = 0.68$ ($p < 0.01$), indicating the weight of the biophysical determinant. In contrast, multiple linear regression analysis showed adaptation capacity ($\beta = -0.44$; $p < 0.001$) as the most significant determinant in reducing vulnerability, supporting the importance of investment in human capital and local institutions.

These findings underscore the need for multi-layered adaptation strategies, improved irrigation infrastructure and levees in flood zones, diversification of livelihoods based on livestock and MSMEs, and community-based climate literacy programs—in line with the recommendations for DRR-CCA integration in Indonesia (Djalante & Thomalla, 2012)

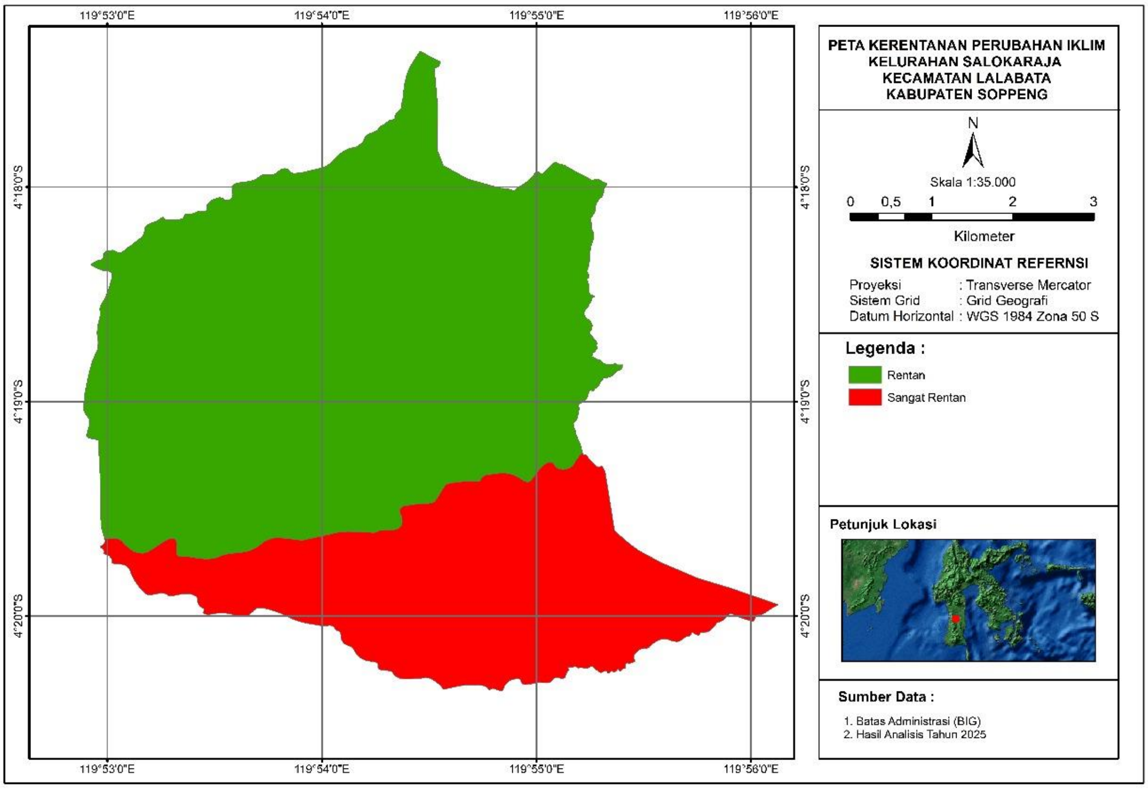

Figure 2. *Vulnerability map)*
(Source: data analysis)

2. Discussion

a. Factors Driving Vulnerability

Empirical findings show that the vulnerability of the Salokaraja community is multi-dimensional, driven by the interaction of hydrometeorological hazard exposure, socio-economic sensitivity, and limited adaptation capacity, precisely as defined in the *IPCC vulnerability framework* (IPCC, 2014). First, high exposure is triggered by a combination of the geomorphology of the Bila River floodplain and an increase in the intensity of extreme rainfall ± 0.9 days a year[1]. This pattern is similar to the results of a study in the Bengawan Solo floodplain (Pramono et al., 2020), where the frequency of extreme floods is the dominant determinant of vulnerability scores. Second, sensitivity is magnified by income dependence on monoculture rice (62% of households) and dominance of rainfed land (48%). A similar mechanism was reported in Terai-Nepal, where rice-dependent households face higher susceptibility to monsoon variability (Paudel & Shrestha, 2019).

Third, low adaptation capacity is reflected in access to agricultural credit (27%), high school ≥ education (23%), and climate literacy (46%). This condition reinforces Adger's (2006) argument that vulnerability is a function of danger and the "social determination" of human, financial, and institutional capital. A strong negative correlation between adaptation capacity (A) and vulnerability index ($\beta = -0.44$) is consistent with studies in the Mekong Delta (Nguyen et al., 2017), proving that investing in human and social assets reduces risk more effectively than simply reducing exposure.

Vulnerability in Salokaraja Village cannot be understood only in terms of physical danger; It was born from the complex interweaving between environmental characteristics, economic production patterns, and social-institutional capacity. Three clusters of biophysical, economic, and socio-institutional factors form a mutually reinforcing risk map, so one intervention alone is rarely adequate. This framework helps prioritize adaptation actions by exploring the root causes behind the high vulnerability index of villages.

At the biophysical level, the village's location in the floodplain of the Bila River causes inundation to be as high as > 0.5 m, which occurs repeatedly when extreme rains increase in frequency in line with regional climate trends. Intensive rice cultivation practices on flat land without vegetation buffer zones accelerate surface runoff, while riparian degradation decreases water absorption capacity. The combination of topography, hydrology, and land cover changes gives rise to high hazard exposure, even though the annual total rainfall does not change drastically.

The economic dimension further sharpens vulnerability. Rice monocultures run by 62% of households create a fragile single-income dependence on seasonal fluctuations and grain prices. When La Niña triggers a national production surplus, prices drop sharply, while El Niño knocks out crops without adequate price compensation. The lack of income diversification in the livestock sector and non-agricultural micro enterprises narrows the space for adaptation and prolongs the post-disaster recovery period.

Social-institutional limitations also add to the risks. Only 46% of residents have ever received seasonal forecast information, making planting decisions based on intuition rather than scientific data. Access to subsidized agricultural credit only covers a quarter of farmers, so investment in adaptive tools such as irrigation pumps and drought-resistant varieties has stalled. On the institutional side, farmer groups are less active as a learning vehicle, and cooperation with government technical institutions is still sporadic. Low climate literacy, limited financial capital, and weak institutional networks cause adaptation capacity to be below the safe threshold.

The three clusters above are closely related to the Pressure-and-Release Model (Wisner et al., 2012), which explains how the pressures of economic-political structures (e.g., market access, grain price policies, land distribution) channel "repressive forces" to the village level. Hydrometeorological hazards are only "triggers"; True vulnerability is rooted in historical processes that produce inequality in access to resources and information. Therefore, risk reduction efforts in Salokaraja require integrated interventions to restore riparian ecosystems, encourage economic diversification, and strengthen institutional capacity—so that pressure lines can be broken and community climate resilience is truly built.

The driving factors in Salokaraja can be grouped into three: biophysical, economic, and social-institutional. Biophysical factors include floodplain location, intensive rice field cover, riparian degradation, and magnifying exposure. Meanwhile, economic factors, namely monocropping rice crops, volatility in grain prices, and limited income diversification, increase sensitivity. Socio-institutional factors, namely low climate literacy, access to credit, and institutional support, weaken adaptive capacity. These three clusters of factors are also reflected in the *Pressure-and-Release Model* (Wisner et al., 2012), in which the pressures of economic-political structures contribute to the root of vulnerability at the local level.

b. Adaptation and Policy Implications

Local Adaptation Strategy

The adaptation strategy that Salokaraja residents are now carrying out was identified through focus group discussions dominated by three practices: adjusting the planting calendar**,** using genjah varieties**,** and rotation of rice-palawija**.** Farmers advance or delay the time of sowing seeds following personal predictions of the first rain, choose 90–100 days old varieties to "catch" the dry season, and plant maize or soybeans after the rice harvest to maintain income. This practice is relatively easy to implement and requires limited capital, so it is natural to be a spontaneous response when the weather changes erratically.

Even so, all three strategies are reactive and site-scale**,** with farmers adjusting after extreme weather occurs instead of anticipating it. The reliance on traditional calendars without the support of climate data makes planting decisions prone to mistiming, while genjah varieties help to remain quite long only during the wet season. Without structural measures, this kind of adaptation tends to follow a pattern of "maladaptation," delaying short-term losses but heightening long-term risks when the intensity of extreme events continues to rise.

Agribusiness diversification alternatives offer a more transformative path to adaptation. A study by Dewi & Pramono (2022) in Gunung Kidul shows that adding goat livestock and agroforestry systems increases farmers' adaptation capacity by up to 0.15 points on the IPCC index. Similar approaches have the potential to be adopted by Salokaraja, such as the integration of freshwater fish cultivation in rice fields, the planting of drought-resistant fruit trees on the edge of rice fields, or the development of post-harvest processing businesses. Income diversification spreads risks and extends households' "self-help range" when rice harvests fail.

Driving such transformation requires an integrated policy intervention package. First, improving tertiary irrigation networks and constructing flood control canals—such as *the Climate-Resilient Irrigation* model in Nusa Tenggara that increased rice productivity by 18% (ADB, 2021)—will reduce physical exposure. Second, integrating BMKG's Seasonal Climate Outlook into farmer extension, plus interpretation training in the style of *Climate Field School* Indramayu (Susanto et al., 2020), increases climate literacy so that the adjustment of the planting calendar becomes anticipatory, not reactive. Third, the low-interest "Green KUR" credit scheme for energy-efficient irrigation pumps or livestock investment can strengthen financial capital; Ferdous & Mallick's (2016) study in Bangladesh showed that adaptation microcredit effectively cut smallholders' vulnerability.

Finally, strengthening local institutions is the key to the survival of innovation. The revitalization of farmer groups as a forum *for co-production* of climate information (Djalante & Thomalla, 2012) can strengthen social capital, accelerate the diffusion of agroforestry practices, and negotiate collective grain prices to reduce market volatility. By combining physical interventions, information services, financial instruments, and social institutions, Salokaraja can transition from incidental adaptation schemes to proactive and sustainable climate resilience.

The recommended policy interventions are based on four complementary pillars. First, adaptive infrastructure needs to be improved through the rehabilitation of tertiary irrigation networks and the construction of flood control canals in hotspot hamlets; the experience of *the Climate-Resilient Irrigation* project in Nusa Tenggara proves that the improvement of adaptive irrigation systems can increase rice productivity by up to 18% (ADB, 2021). Second, improving literacy and climate services is carried out by integrating BMKG's *Seasonal Climate Outlook* into farmer extension programs equipped with forecast interpretation training like the successful *Climate Field School* model in Indramayu (Susanto et al., 2020) so that planting decisions become anticipatory, not reactive. Third, expanding access to adaptation finance through low-interest "Green KUR" credit schemes allows farmers to acquire energy-efficient irrigation pumps or develop livestock and agroforestry businesses; evidence in Bangladesh suggests adaptive microcredit is effective in reducing the vulnerability of smallholders (Ferdous & Mallick, 2016). Fourth, strengthening local institutions is realized by revitalizing farmer groups as a *co-production platform* for climate information and agribusiness innovation, so that social capital increases and the diffusion of adaptive practices occurs faster (Djalante & Thomalla, 2012). If implemented and integrated, these four pillars physical, informational, financial, and institutional are expected to reduce exposure, enrich adaptation capacity, and ultimately reduce the vulnerability of household climates in Salokaraja.

On a macro level, the findings of this study confirm the urgency of integrating *Disaster Risk Reduction* and *Climate Change Adaptation* (DRR-CCA) at the village level, in line with the RAN-API roadmap 2020–2024. By targeting hotspot hamlets as an investment priority, the district government can optimize the allocation of Village Funds for infrastructure and contextual adaptation training.

D. Conclusion

This study concludes that household climate vulnerability in Salokaraja Village is driven by the interaction between hydrometeorological exposure, agrarian economic dependence, and limited adaptive capacity. With 34% of households classified as highly vulnerable, the results emphasize that enhancing adaptive capacity particularly in financial access and climate literacy plays the most significant role in reducing vulnerability. These findings affirm the importance of integrated, multi-dimensional adaptation strategies and provide an empirical basis for strengthening rural climate resilience in Indonesia.

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