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# Livelihood Vulnerability and Adaptive Strategies Assessment of Farmers Living in Rajapur Municipality, Bardiya, Nepal

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## ABSTRACT

Floods in the Terai region of Nepal cause substantial property damage, increasing household indebtedness, disrupt sustainable livelihoods, and trigger migration. Despite the growing frequency and severity of floods, flood vulnerability remains under-researched. This study assesses local climatic trends, livelihood vulnerability, and adaptation strategies among farmers in Wards 1, 3, 4, and 7 of Rajapur Municipality. Specifically, it analyzes local climate trends to determine hazard exposure. It assesses the livelihood vulnerability of small, medium, and large farmers using the Livelihood Vulnerability Index (LVI) and LVI-IPCC frameworks. The study also evaluates the effectiveness of adaptation strategies adopted by these farmer groups in responding to climate-related hazards. It had combined 30 years of climate data with empirical evidence from 160 households, four focus group discussions, and five key informant interviews. Results indicated an average annual temperature increase of 0.0084 °C, with seasonally consistent warming trends, except during the post-monsoon period. Annual average rainfall increased by 8.318 mm annually, while seasonal patterns revealed declining winter and post-monsoon precipitation and rising pre-monsoon and monsoon rainfall. The data confirmed that the small farmers have the highest levels of vulnerability, followed by medium and large-scale farmers. Adaptation strategies identified as effective included early warning systems, flood shelters, raised tubewells, capacity-building programs, social networks, and river embankments. This finding contributed to a deeper understanding of flood-related livelihood vulnerabilities and adaptive responses in the region, providing evidence-based guidance for interventions and risk-reduction planning

## KEYWORDS

Climate change, flood hazard, vulnerability, adaptation, farmers' livelihoods.



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## 1. Introduction

Climate change is increasingly disrupting hydrological patterns. Across the globe, we are witnessing more frequent and intense floods and droughts, driven by both thermodynamic and other factors.[1] and dynamic[2] processes in the climate system. As the atmosphere warms, holding roughly 7% more water vapor per 1 °C rise (IPCC, 2021), extreme rainfall events have become more common, especially during monsoons and tropical storms (Alfieri et al., 2015; IPCC, 2021). At the same time, higher temperatures accelerate evapotranspiration, intensifying drought conditions, particularly in semi-arid and subtropical regions. These shifts are not only scientifically significant but also deeply consequential for everyday life, especially in rural, agriculture-dependent regions (Paudel et al., 2025; Bhatta et al., 2025).

In South Asia, the signals are clear. Between 1960 and 2010, the frequency of flood events globally increased by roughly 25%, with South Asia alone experiencing a 50% rise in extreme rainfall events (IPCC, 2021). Among the major global disasters, floods, droughts, cyclones, and earthquakes, floods stand out as the most frequent and economically damaging. Weather and climate-related hazards accounted for 50% of global disasters, 45% of disaster-related fatalities, and 74% of reported economic losses between 1970 and 2019 (WMO,2021). Crucially, the 6th Assessment Report by the IPCC (2021) identifies South Asia as a region of high human vulnerability, particularly among smallholder farmers, pastoralists, and other subsistence-based communities. Mortality from climate-related hazards has been up to 15 times higher in highly vulnerable regions than in regions with stronger institutional and infrastructural capacities (Jarraud & Steiner, 2012; Baniya et al., 2024).

Nepal exemplifies many of these dynamics. Its mountainous terrain, combined with rapid land-use change, melting glaciers, and intense monsoon rains, renders it highly susceptible to water-induced disaster. The Terai region, in particular, has faced increasingly frequent floods and droughts, along with associated disruptions to livelihoods. As the southern plains of Nepal, the Terai is both ecologically fragile and densely populated, making it especially vulnerable to flood hazards. In recent decades, the region has experienced more frequent and severe flood events that have significantly impacted agriculture, food security, and rural livelihoods (Huggel et al., 2020; Neupane et al., 2023). Nepal ranks as the tenth most exposed country globally in terms of physical vulnerability to riverine flooding, with potential economic losses equivalent to 1.4% of GDP (Tianyi et al., 2015).

Modeling suggests that, without effective adaptation, the number of people in Nepal affected annually by river flooding could more than double by 2030, with economic impacts expected to triple (WB & ADB, 2020). These risks are especially pronounced in low-income and subsistence farming communities that lack access to irrigation, crop insurance, and climate-resilient technologies. In many parts of the Terai, including Bardiya District, even basic adaptation options such as water storage or flood forecasting are often inaccessible. As a result, the poorest households are more likely to suffer repeated crop losses, increased debt, and long-term livelihood insecurity.

Rajapur Municipality in Bardiya District lies along the flood-prone Karnali River and is home to a large population of small and marginal farmers. Here, repeated flooding events have caused extensive damage to crops, homes, and infrastructures, undermining food security and pushing vulnerable households further into poverty. As such, climate-induced floods do not simply present a physical threat; they disrupt the entire livelihood fabric of affected communities. This study employs an integrated analytical logic.

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1 Thermodynamic processes consist of energy trapping by the GHG (Clausius-Clapeyron relationship), moisture amplification (that every 1 °C warming, air holds about 7% more moisture, intensifying extreme rainfall and drought cycles), and entropy production (irreversible phase changes – evaporation, condensation – in the hydrologic cycle dissipate energy, limiting the climate system's efficiency).

2 Dynamic processes consist of circulation shifts (warming alters temperature gradients, weakening jet streams, and shifting storm tracks leading to prolonged droughts or floods), convection changes (increase convection available potential energy (CAPE)" strengthens updrafts, elevating storm intensity despite stabilizing tropospheric layers), and hydrologic feedbacks (enhanced evaporation in subtropical regions reduces soil moisture, exacerbating droughts, while intensified monsoons raise flood risks).

First, the analysis of 30-year climate trends establishes the physical Exposure context—specifically, the increasing frequency of floods and extreme temperatures. Second, this exposure data is incorporated into the LVI's 'Natural Disasters and Climate Variability' component to assess how this physical reality interacts with the Sensitivity and Adaptive Capacity of households. Finally, the study compares small, medium, and large farmers to test the hypothesis that vulnerability decreases with landholding size and to identify specific adaptive limits for each group.

## 2. Methodology

### *2.1. Study area*

The research was conducted in Rajapur Municipality, Bardiya District, Lumbini Province, Nepal (Fig. 1). This area was selected for its geographic and socio-economic characteristics, which make it highly vulnerable to flood hazards. Rajapur lies between two flood-prone branches of the Karnali River, which originates in Tibet, traverses western regions of Nepal, and ultimately merges with the Ganges River in India. These river branches have historically caused recurrent flooding events, resulting in significant loss of life, property, and livelihoods. Among the ten administrative wards of Rajapur Municipality, four wards – 1, 3, 4, and 7 were purposively chosen for this study. These wards are situated directly along the branches of the Karnali River, where previous flood events have caused catastrophic damage, making them critical sites for assessing flood vulnerability and adaptive capacity. The selection is justified by the spatial concentration of flood impacts and the need to understand localized community responses.

Agriculture dominates land use in the study area, with approximately 57.89% of the total land area dedicated to farming. The average landholding size per household is 0.72 ha, indicating predominantly small-scale farming systems. The population is ethnically diverse, with over 80% belonging to the Tharu, an indigenous community of the Terai region, known for their traditional agricultural knowledge and close relationship with the floodplain environment. Other minority groups constitute around 10% of the population, contributing to the area's socio-cultural complexity. The fertile alluvial soils of the floodplains support long-standing agricultural practices integral to local communities' livelihoods. However, the same flood dynamics that replenish soil fertility also pose recurrent risks to crop production and food security. The interplay between natural resource endowment and hazard exposure underscores the importance of Rajapur Municipality as a representative and critical study area for examining flood vulnerability and adaptation strategies in Nepal's Terai region.

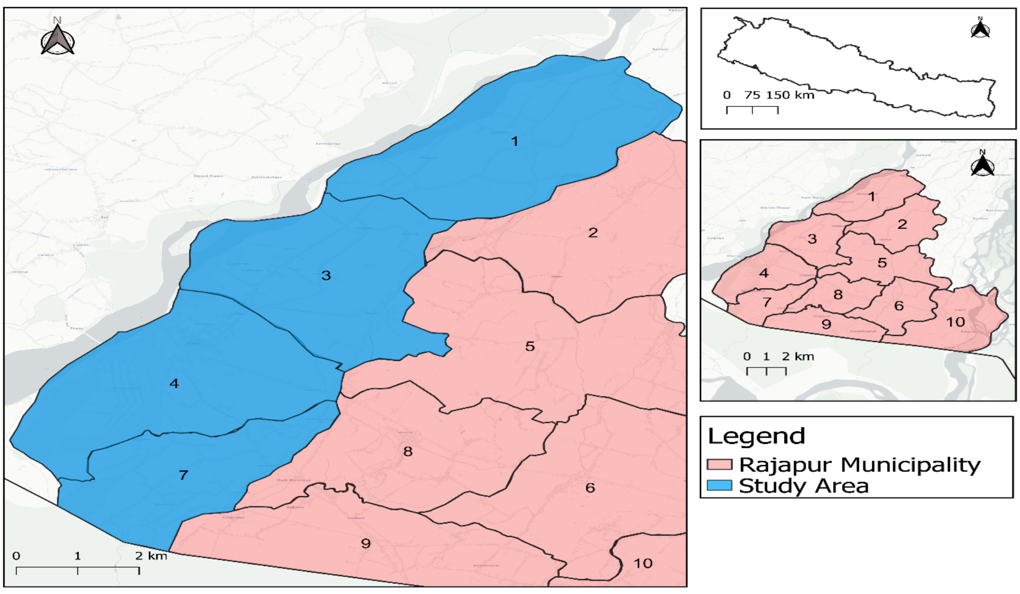


**Figure 1**. Map of Nepal with the demarcation of the Rajapur municipality.

## 2.2. Data collection and analysis

The research objectives were operationalized through a structured questionnaire designed to capture relevant information on flood vulnerability and adaptive strategies. Primary data were collected during field visits, involving direct interactions with local households and community members. Secondary data, including climate records and hydrological information, were obtained from the DHM and other reputable sources to complement and validate primary findings.

Primary data were collected through a combination of household surveys, key informant interviews (KII), focus group discussions (FGD), and direct field observations. The household surveys provided quantitative data on socio-economic status, farming practices, flood impacts, and adaptation measures. In the household survey, the sample size was calculated using Cochran's formula, which is widely recognized for determining statistically valid sample sizes in survey research. Given the relatively small population size in the selected wards, the standard Cochran's formula was adjusted using the finite population correction to ensure accurate representation. The detailed calculation and modification are presented below.

The sample size was calculated using Cochran's formula (Cochran, 1977)

$$n_o = Z^2 \; p \; q/e^2$$

Where,

Z = statistical value corresponding to the level of confidence required (1.96)

p = the (estimated) proportion of the population which has the attribute in question (0.95)

q = 1 – p (0.05)

e = the margin of error (5%)

Modification for the Cochran Formula for Sample Size Calculation in Smaller Populations

$$n = [n_0/(1+((n_0-1)/N)].$$

Where,

$n_0 =$ Cochran sample size

n = sample size

This yielded an initial sample size of approximately 170 households, which was adjusted to 160 using the finite population correction based on the total number of households in the study area.

A fixed allocation strategy was employed to ensure equal representation, with 40 households selected from each of the four wards (1, 3, 4, and 7). Households were selected using a systematic random sampling technique. A sampling frame (list of households) was obtained from the Rajapur Municipality. A sampling interval (k) was calculated for each ward, and households were selected at regular intervals starting from a random point. The sampled households were then categorized into large (n = 20), medium (n = 54), and small (n = 86) farmers based on their landholding size for comparative vulnerability analysis.

A multistage sampling technique was used to collect data from the study area. This approach is widely recommended in social and environmental studies for its efficiency in handling heterogeneous populations across different administrative units (Paudel et al., 2025; Cochran, 1977)

To capture diverse community perspectives and validate the survey findings, three Focus Group Discussions (FGDs) were conducted. The first FGD involved local farmers and focused on understanding grassroots experiences and traditional knowledge related to flood vulnerability and adaptation practices. The second FGD included ward members, community leaders (barghars), and flood-affected farmers, providing insights into institutional responses and community-level strategies for flood management. The third FGD was held with members of the Kamaiya Mahila Jagaran Samaj (KMJS), a women's organization that actively promotes social awareness and community resilience. These discussions enriched the study by offering a more nuanced understanding of flood impacts and adaptation efforts across different segments of the community.

The KII was conducted with a range of knowledgeable individuals, including a senior citizen with long-term local experience, an administrative officer from Rajapur Municipality, a sub-engineer from the Karnali River Management Committee, a flood expert, an NGO representative, and the municipality's disaster focal person. These interviews provided expert insights into flood dynamics, governance, and adaptation initiatives.

Secondary data supplemented primary data to enrich the analysis. Hydrological and meteorological records were obtained from the DHM, providing long-term climate and flood event data critical for understanding exposure and trends. Additional reports—both published and unpublished—were sourced from Rajapur Municipality, the Department of Agriculture, the District Emergency Operation Centre (DEOC), and various international and national NGOs. These documents provided contextual information on flood-inundation patterns, livelihood impacts, and previously implemented adaptation strategies.

## *2.3. Livelihood Vulnerability Index (LVI) and LVI IPCC Framework*

The Livelihood Vulnerability Index (LVI) is a composite indicator that quantifies the vulnerability of households or communities to climate change and related hazards by integrating multiple socio-economic and environmental factors. Originally developed by Hahn et al. (2009), the LVI incorporates seven major components: Socio-Demographic Profile (SDP), Livelihood Strategies (LS), Social Networks (SN), Health (H), Food (F), Water (W), and Natural Disasters and Climate Variability (NDCV). An additional component, Housing and Land Tenure, was incorporated to capture flood-specific sensitivity.

Standardization: Since the sub-components were measured on different scales (e.g., percentages, ratios, counts), they were standardized using a min-max normalization formula to create a unitless index ranging from 0 to 1: Each of these components comprises several subcomponents or indicators, which are standardized and weighted equally to ensure a balanced contribution to the overall index score, reflecting a comprehensive assessment of vulnerability at the community or household level (Urothody & Larsen, 2010).

To enhance the LVI's sensitivity to localized conditions, particularly in flood-prone riverbank settlements, an additional component, housing and Land Tenure, has been incorporated (Shah et al., 2013). This addition accounts for the heightened vulnerability of structures that face frequent flooding, thereby capturing critical socio-environmental dynamics often overlooked in traditional frameworks. The weighting of each major component is systematically based on the number of its sub-components, ensuring that the composite index reflects an equitable integration of diverse vulnerability dimensions (see below).

LVI calculation

$$LVI_h = \frac{W_{SDP}\,SDP_d + W_{LS}LS_d + W_{SN}SN_d + W_H H_d + W_W W_d + W_F F_d + W_{HLT}\,LT_d + W_{NDCV}NDCV_d}{W_{SDP} + W_{LS} + W_H + W_W + W_{SN} + W_F + W_{HLT} + W_{NDCV}}$$

Where,

- The LVI includes seven major components.
- Socio-Demographic Profile (SDP),
- Livelihood Strategies (LS),
- Social Networks (SN),
- Health (H),
- Food (F),
- Water (W), and
- Natural Disasters and Climate Variability (NDCV).
- Livelihood Vulnerability Index of the household ($LVI_h$)
- Weights of each major component ($W_{M_i}$)

The LVI-IPCC scale ranges from -1 (least vulnerable/resilient) to +1 (most vulnerable).

- Negative values indicate that Adaptive Capacity outweighs Exposure (net resilience).
- Positive values indicate that Exposure outweighs Adaptive Capacity (net vulnerability).

Due to the multiplicative nature of the formula, raw scores typically cluster near zero. Therefore, in this study, the magnitude of the score is interpreted as follows:

- to 0.05: Low to Moderate Vulnerability (Adaptive capacity nearly balances exposure),
- 0.05 to 0.15: High Vulnerability,
- 0.15: Very High Vulnerability.

The LVI is further refined through its integration with the IPCC vulnerability framework, which categorizes vulnerability into three contributing factors: *exposure*, *adaptive capacity*, and *sensitivity*. This approach, termed LVI-IPCC, differs from the traditional LVI by first aggregating major components into these three categories before combining them into a final vulnerability score using specified equations. This method allows for a nuanced understanding of vulnerability drivers, distinguishing between the degree of hazard exposure, the community's sensitivity to impacts, and its capacity to adapt or cope with stressors. The resulting LVI-IPCC score is scaled from -1 (least vulnerable) to 1 (most vulnerable), providing a standardized metric for comparing livelihood vulnerability across contexts.

LVI–IPCC calculation:

$$CF_h = \frac{\sum_{i=4}^{n} W_{Mi} M_{hi}}{\sum_{i=1}^{n} W_{Mi}}$$

Where,

- $CF_h$ = Contributing Factor
- $W_{Mi}$ = Weight of each major component ($Mi$ = Major component indexed by i)
- n = number of major components in each contributing factor

Once exposure, sensitivity, and adaptive capacity were calculated, the three contributing factors were combined using the following equation:

$$LVI - IPCC = (e - a) * s$$

Where,

- LVI-IPCC = LVI expressed using the IPCC vulnerability framework
- e = exposure
- a = adaptive capacity
- s = sensitivity

Note: The primary utility of the LVI-IPCC is comparing relative positions (e.g., small vs. large farmers) rather than absolute classification.

Scientifically, the LVI's strength lies in its composite index approach, which synthesizes diverse quantitative and qualitative indicators into a single, interpretable value that reflects the multi-dimensional nature of vulnerability. This approach facilitates targeted policy and intervention design by identifying specific vulnerability components that require attention. Empirical applications of the LVI have demonstrated its utility in differentiating vulnerability levels across, thereby supporting adaptive management and resilience-building strategies (Suryanto & Rahman, 2019; Majid, Nazi, Idris, & Taha, 2019).

## 3. Results and discussion

### *3.1. Trend of temperature and rainfall*

Historical climatic data (daily rainfall and maximum/minimum temperature) for 30 years (1992–2021) were obtained from the Department of Hydrology and Meteorology (DHM). The data were sourced from the Tikapur Meteorological station, which is the nearest representative station for Rajapur Municipality. Data gaps and missing values were handled using linear interpolation. The trend analysis was performed using linear regression analysis. The regression line represents the rate of change per year, and the coefficient of determination ($R^2$) was used to assess the strength of the relationship between time and climatic variables. The significance of the trend was evaluated using the p-value from the regression analysis. However, the trend in maximum temperature was not statistically significant ($R^2 = 0.0309$, $p = 0.35$).

The analysis of climatic data revealed distinct annual and seasonal temperature trends (Fig. 2). The annual maximum temperature peaked at 37.8 °C in May. Conversely, minimum temperatures show a declining trend, with the average minimum dropping to 7 °C in January. Seasonal breakdown indicates that maximum temperatures are rising consistently across all seasons, while minimum temperatures fall below average specifically during the winter and post-monsoon periods. The average annual maximum temperature remains above 30 °C, corroborating findings reported by DHM (DHM, 2017).

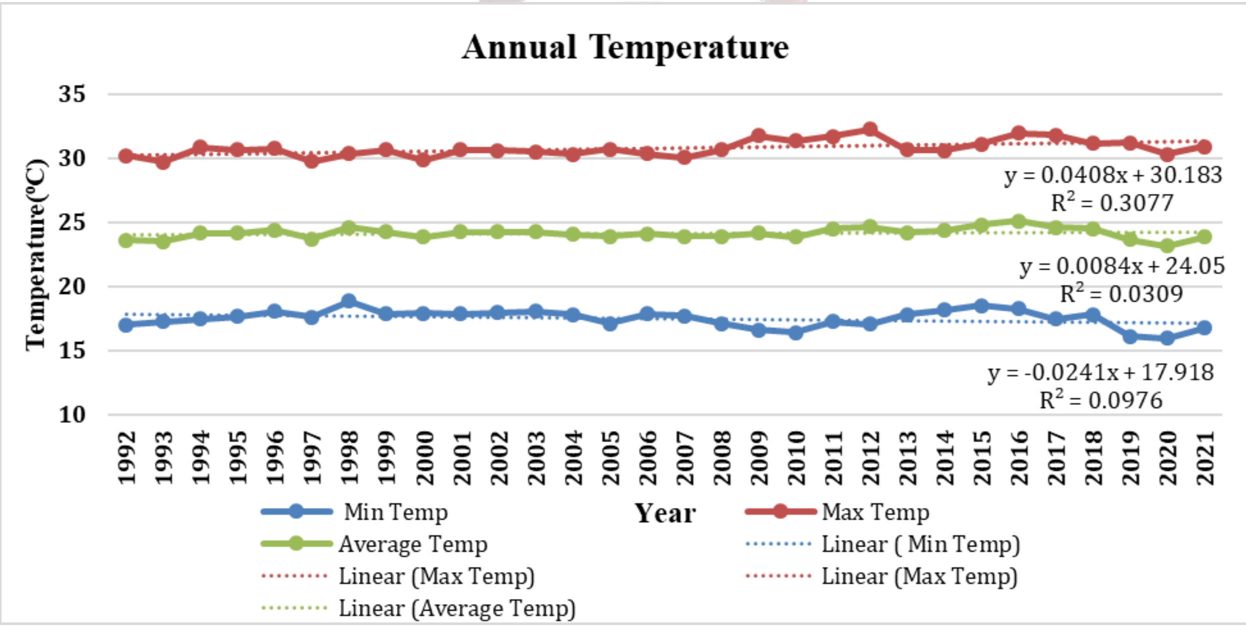


**Figure 2.** Trend of annual temperature (Source: DHM data).

Rainfall patterns demonstrate an overall annual increase of 8.318 mm. However, this increase is not uniform across seasons: precipitation during winter and post-monsoon seasons is decreasing, whereas pre-monsoon and monsoon rainfall shows an upward trend (Fig. 3). These observations are consistent with the projections and data outlined in the Local Disaster and Climate Resilience Plan (LDCRP) of Rajapur municipality (2078). Together, these findings highlight a warming climate characterized by more pronounced heat extremes and shifting precipitation regimes, which have critical implications for local disaster risk management and climate resilience strategies in Rajapur. The annual rainfall trend showed low statistical significance ($R^2 = 0.046$, $p = 0.25$), suggesting high inter-annual variability (Figure 4).

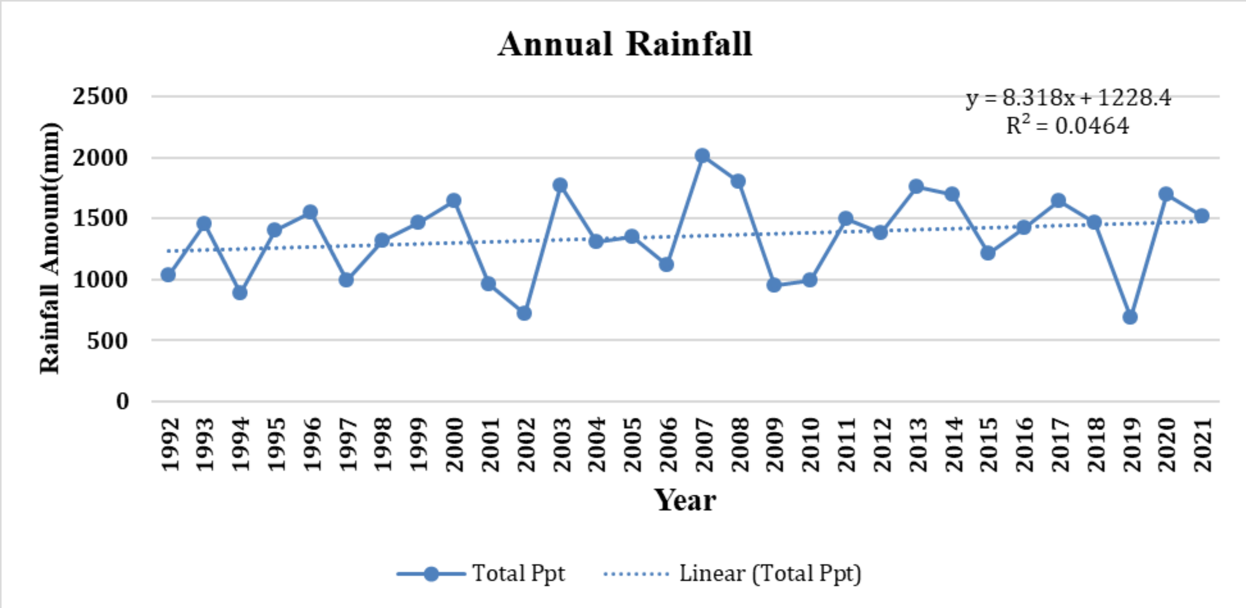


**Figure 3**. Trend of annual rainfall. (Source: DHM data)

### *3.2. Livelihood Vulnerability Index (LVI)*

This study quantitatively assessed the livelihood vulnerability of small, medium, and large farmers in Rajapur using the LVI and its IPCC-LVI (Table 1). ). The LVI-IPCC results confirmed a gradient of vulnerability among farmer categories (Table 5). Small farmers exhibited the highest LVI-IPCC score (0.043), followed by medium (0.034) and large farmers (0.028). While all absolute values fall within the lower range of the -1 to +1 scale, the positive scores across all groups indicate that Exposure consistently outweighs Adaptive Capacity in Rajapur. The higher score for small farmers (0.043) suggests they are furthest from achieving a balance of resilience compared to large farmers (0.028). This indicates that all groups experience moderate to high vulnerability, but small farmers are distinctly the most at risk. The difference in LVI scores between small and medium farmers is 0.094, and between medium and large farmers is 0.053. The large distance between small and medium farmers, compared to medium and large farmers, highlights a nonlinear vulnerability gradient, with small farmers disproportionately affected by climate and socio-economic stressors. This pattern is consistent with previous research in similar agro-economic contexts, in which smaller landholders are disproportionately affected by climate and socioeconomic stressors (Sujakhu et al., 2019).

The higher LVI for smaller farmers suggests greater exposure, higher sensitivity, and lower adaptive capacity, which is substantiated by studies in the Hindu Kush Himalayas and Bangladesh, where smaller landholders face compounded risks due to limited assets, insecure tenure, and fewer livelihood diversification options (Kabir, Rahman, & Sraboni, 2018; Cvetković & Martinović, 2020; Gerlitz, et al., 2017). The evidence underscores that the LVI is sensitive to differences in household characteristics and can reliably distinguish vulnerability gradients within a community. The relatively large distance between small and medium farmers' LVI scores suggests that interventions targeting the most vulnerable (smallholders) could yield significant reductions in overall community risk. The analysis of LVI components underscores that housing and land tenure are the most vulnerable domains for small farmers (0.698), reflecting their precarious living conditions along riverbanks and the predominance of temporary flood-prone structures. This finding aligns with that of Shah et al. (2013), who reported that insecure land tenure and substandard housing significantly increased disaster risk in riverine communities. Similarly, the high vulnerability scores for natural disaster and climate variability (0.474 for small farmers) corroborated the observed increase in flood frequency and intensity in Rajapur, as documented by the Ministry of Home Affairs (2018).

For medium farmers, water emerges as the most vulnerable component (0.456), highlighting challenges in water access and quality, particularly during extreme events. This is supported by

Hoq et all (2021), who found that mid-sized farmers in South Asia often face water insecurity due to variable rainfall and inadequate infrastructure. Large farmers, while overall less vulnerable, are most affected in the domain of livelihood strategy (0.526), indicating a reliance on agricultural income and limited diversification, which can increase sensitivity to climate shocks. This is inconsistent with Wilkinson & Peters (2015), who noted that even larger landholders may face heightened vulnerability if their income sources are not diversified.

**Table 1.** LVI values of Small, Medium, and Large Farmers of the Rajapur.

| Main Component | Sub-component | Small Farmer | | Average Sub-components | Max Value | Min Value |
|---|---|---|---|---|---|---|
| | | Actual Value | Standard Value | | | |
| **Socio-Demographic Profile** | Dependency Ratio | 0.745 | 0.248 | 0.325 | 3 | 0 |
| | Female-headed household (%) | 34.884 | 0.349 | | 100 | 0 |
| | Avg. age of female-headed household (1/yrs.) | 47.619 | 0.534 | | 70.0 | 22.00 |
| | Illiterate household heads (%) | 43.023 | 0.430 | | 100 | 0 |
| | Household with members needing dependent care (%) | 6.522 | 0.065 | | 100 | 0 |
| **Livelihood Strategy** | Households with family members working outside the community (%) | 73.217 | 0.732 | 0.385 | 100 | 0 |
| | Households' main income is dependent on agriculture, including livestock (%) | 34.000 | 0.340 | | 100 | 0 |
| | Avg. Agricultural livelihood diversity index (1/no. of livelihood) | 0.571 | 0.077 | | 5 | 0.2 |
| | Households without nonagricultural livelihood income contribution (%) | 39.130 | 0.391 | | 100 | 0 |
| **Social Network** | Avg. receive: give the ratio | 1.8478 | 0.300 | 0.455 | 5 | 0.5 |
| | Avg. borrow: lend ratio | 1.641 | 0.761 | | 2 | 0.5 |
| | Households seeking government assistance even after post-flood (%) | 30.532 | 0.305 | | 100 | 0 |
| **Food** | Households that rent and cultivate on other farms (%) | 38.043 | 0.380 | 0.539 | 100 | 0 |
| | Households dependent on family farm food (%) | 41.463 | 0.415 | | 100 | 0 |
| | Average number of months a household struggles to find food (1/no. of months) | 4.505 | 0.501 | | 7 | 2 |
| | Average Crop Diversity Index (1/no. of Crops) | 0.282 | 0.273 | | 0.5 | 0.2 |
| | Households that do not sell/ barter crops (%) | 89.535 | 0.895 | | 100 | 0 |
| | Households that do not have seeds from year to year (%) | 76.744 | 0.767 | | 100 | 0 |
| **Water** | Households' access to drinking (%) | 92.000 | 0.920 | 0.440 | 100 | 0 |
| | Avg days without clean drinking water (1/no. of days) | 5.804 | 0.201 | | 9 | 5 |
| | Households with water-related infections during monsoon days (%) | 20.000 | 0.200 | | 100 | 0 |
| **Housing and Land Tenure** | Houses with weak flood-resistant construction (%) | 80.435 | 0.804 | 0.698 | 100 | 0 |
| | Houses not elevated to avoid floods (%) | 85.870 | 0.859 | | 100 | 0 |
| | Households without ownership of the land they live in (%) | 34.783 | 0.348 | | 100 | 0 |
| | House near the river (%) | 78.261 | 0.783 | | 100 | 0 |
| **Health** | Average time to Health Facility (min) | 19.348 | 0.467 | 0.330 | 30 | 10 |
| | Household members suffering from chronic illness (%) | 13.043 | 0.130 | | 100 | 0 |
| | Households missed work/school due to illness (%) | 39.130 | 0.391 | | 100 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Natural Disaster and Climate Variability** | Average no. of flood events in the past 10 years (Counts) | 6.096 | 0.699 | 0.474 | 7 | 4 |
| | Average no. of drought events in the past 10 years (Counts) | 2.691 | 0.564 | | 4 | 1 |
| | Households with an injury or death by flood in last 10 years. (%) | 7.609 | 0.076 | | 100 | 0 |
| | Mean SD of the daily average. Max temp by month | 5.559 | 0.580 | | 40.568 | 17.355 |
| | Mean SD of the daily average. Min temp by month | 6.935 | 0.560 | | 27.323 | 5.039 |
| | Mean SD of the daily average. Max precipitation by month | 4.714 | 0.365 | | 12.862 | 0.029 |
| **LVI of Small Farmer** | | | | 0.456 | | |

### *3.3. Socio-economic and institutional factors*

The study also highlights the role of socio-demographic and institutional factors in shaping vulnerability. Small farmers have the highest socio-demographic index (0.325), with a greater proportion of female-headed households and higher out-migration rates due to limited local opportunities. Their low participation in local organizations and dependence on high-interest loans further constrain their adaptive capacity, echoing findings by Sujakhu et al. (2019) regarding the compounding effects of social marginalization and indebtedness. Food security is another critical issue: only 41.43% of small farmers' food needs are met by their own production, compared to 83% for medium and 100% for large farmers. The prevalence of sharecropping and low crop diversity among small farmers exacerbates their vulnerability to crop loss and market fluctuations, as observed in similar studies (Hoq et al., 2021; Qaisrani et al., 2018).

### *3.4. Health and disaster exposure*

Health-related vulnerability is pronounced among small farmers, with 39% reporting missed work due to illness and a higher incidence of waterborne diseases following floods. This pattern is consistent with Hahn et al. (2009), who emphasized the link between health shocks and reduced livelihood resilience in climate-affected regions. The proximity of small farmers' homes to the Karnali River, coupled with the prevalence of weakly constructed houses (80% among small farmers), exposes them to recurrent flood hazards (Fig. 4). The study's findings are reinforced by Emma et al. (2019), who documented similar patterns of settlement vulnerability in flood-prone areas due to poverty and insecure land tenure.

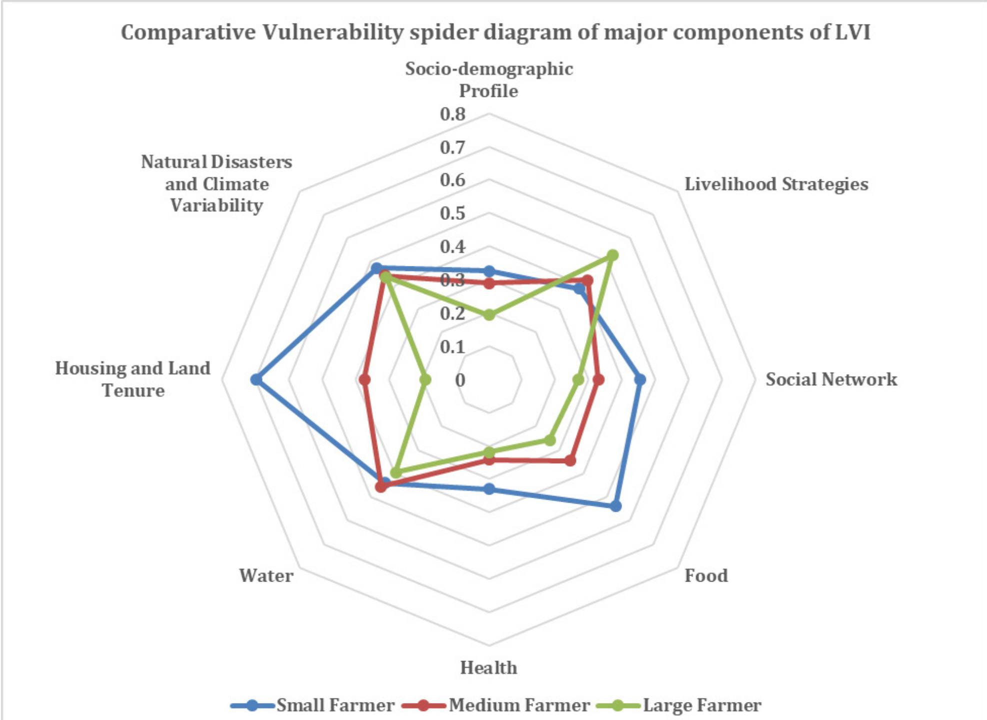


**Figure 4.** Vulnerability Spider Diagram of the Small, Medium, and Large Farmers.

### *3.5. LVI-IPCC Synthesis*

The LVI-IPCC scores, with small farmers at 0.043, medium farmers at 0.034, and large farmers at 0.028, reinforce the LVI findings while providing additional insights into the nature of vulnerability (Table 2). Given that the LVI-IPCC ranges from -1 (least vulnerable) to +1 (most vulnerable), all three scores indicate a relatively low level of absolute vulnerability. However, the values are all positive, suggesting that even the most resilient group (large farmers) is still somewhat vulnerable to climate change and related stressors. This aligns with the established understanding that climate change impacts are pervasive and can affect even those with greater resources.

The spider diagram (Figure 5) reveals distinct vulnerability profiles for each farmer category, highlighting the top three drivers of vulnerability for each group:

- Small Farmers: The most critical drivers were Housing and Land Tenure (0.698), Food insecurity (0.539), and Natural Disasters (0.474). This indicates that physical exposure and basic survival needs are the primary stressors.
- Medium Farmers: Vulnerability was driven by Water access (0.456), Natural Disasters (0.441), and Livelihood Strategies (0.385).
- Large Farmers: The primary constraint was Livelihood Strategies (0.526)—specifically dependency on agriculture—followed by Natural Disasters (0.435) and Water (0.395).

These relatively small numerical differences suggest that, while small farmers are the most vulnerable, the degree of differentiation in vulnerability is not drastic. These subtle differences can still be meaningful, especially when considering the compounding effects of multiple stressors. This aligns with the understanding that the LVI is used to study the impacts on farmers in Nepal. Even a small increase in vulnerability can have significant consequences for the livelihoods and well-being of already marginalized populations. The observed gradient reflects the interplay between exposure, sensitivity, and adaptive capacity, as conceptualized by the IPCC. Small farmers likely have higher exposure to climate hazards due to factors such as residing in more vulnerable locations (e.g., floodplains) and having less resilient housing. They may also exhibit greater sensitivity due to their greater reliance on rain-fed agriculture and limited access to irrigation. Finally, their adaptive capacity is likely constrained by factors such as limited financial resources, lack of access to information, and weak social networks.

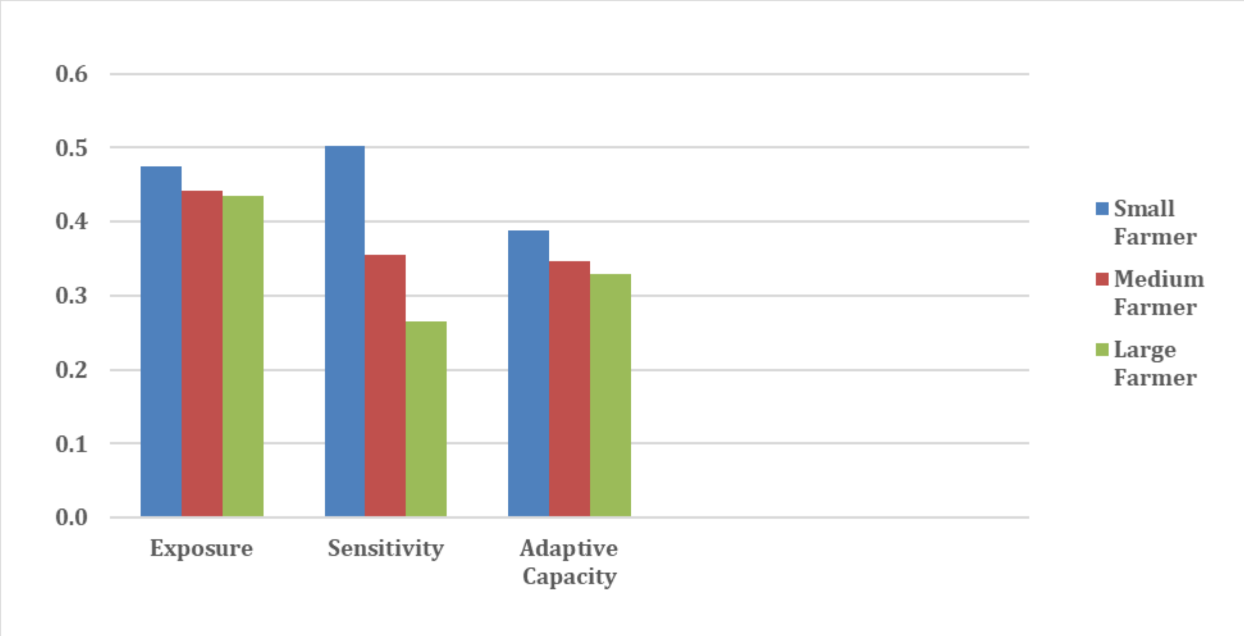


**Figure 5**. Vulnerability bar diagram based on IPCC-LVI

**Table 2**: LVI-IPCC of the small, medium, and large farmers.

| Contributing Factors | Major Components | Major Components Value | No. of Sub-Components | Contributing Factors Value | LVI-IPCC Value |
|---|---|---|---|---|---|
| LVI-IPCC value of the small farmer | | | | | |
| **Adaptive Capacity** | Socio-demographic Profile | 0.325 | 5 | 0.388 | 0.043 |
| | Livelihood Strategies | 0.385 | 4 | | |
| | Social Network | 0.455 | 4 | | |
| **Sensitivity** | Food | 0.539 | 5 | 0.502 | |
| | Health | 0.33 | 3 | | |
| | Water | 0.44 | 3 | | |
| | Housing and Land Tenure | 0.698 | 4 | | |
| **Exposure** | Natural Disasters and Climate Variability | 0.474 | 6 | 0.474 | |
| LVI-IPCC value of the medium farmer | | | | | |
| **Adaptive Capacity** | Socio-demographic Profile | 0.289 | 5 | 0.346 | 0.034 |
| | Livelihood Strategies | 0.421 | 4 | | |
| | Social Network | 0.329 | 4 | | |
| **Sensitivity** | Food | 0.346 | 5 | 0.355 | |
| | Health | 0.242 | 3 | | |
| | Water | 0.456 | 3 | | |
| | Housing and Land Tenure | 0.374 | 4 | | |
| **Exposure** | Natural Disasters and Climate Variability | 0.441 | 6 | 0.441 | |
| LVI-IPCC value of the large farmer | | | | | |
| **Adaptive Capacity** | Socio-demographic Profile | 0.193 | 5 | 0.33 | 0.028 |
| | Livelihood Strategies | 0.526 | 4 | | |
| | Social Network | 0.27 | 4 | | |
| **Sensitivity** | Food | 0.258 | 5 | 0.265 | |
| | Health | 0.219 | 3 | | |
| | Water | 0.395 | 3 | | |
| | Housing and Land Tenure | 0.189 | 4 | | |
| **Exposure** | Natural Disasters and Climate Variability | 0.435 | 6 | 0.435 | |

### *3.6. Types of adaptation strategies adopted by farmers*

This study reveals significant disparities in adaptation strategies among small, medium, and large farmers in Rajapur, driven largely by differences in socio-demographic profiles, livelihood diversification, institutional participation, and exposure to climate hazards.

*Socio-demographic and livelihood diversification*

The socio-demographic index for small farmers is notably higher (0.325) than for medium and large farmers, indicating greater vulnerability linked to household characteristics. A striking 34.88% of small farming households are female-headed, compared to 14.81% and 2.32% for medium and large farmers, respectively. This aligns with findings by Sujakhu et al. (2019), who reported that female-headed households often face greater adaptive challenges due to limited access to resources and decision-making power. Migration is a key adaptation strategy among small farmers, with 90.21% reporting at least one family member working outside the community to supplement income. This reliance on non-agricultural income sources—including wages, government and private jobs, business, and remittances—reflects limited landholdings, poverty, and recurrent crop losses due to frequent hazards. Similar patterns have been documented in South Asia, where migration serves as a critical mechanism for livelihood diversification for marginalized farmers (Hoq et al., 2021; Qaisrani et al., 2018). Livestock rearing, often a traditional buffer against shocks, was found to be negligible and declining due to disease outbreaks post-flooding and fodder scarcity, further constraining small farmers' adaptive options.

*Institutional participation and financial vulnerability*

Small farmers exhibit minimal involvement in local institutions and political processes, with only 0.17% participating in social organizations. This low social capital undermines their adaptive capacity, consistent with Hahn et al. (2009); Cvetković et al. (2021), who emphasize the role of social networks in enhancing resilience. Financial vulnerability is pronounced: small farmers have higher borrow-lend ratios and rely heavily on high-interest loans from moneylenders and cooperatives (91.25%), often for basic subsistence rather than productive investment. This indebtedness exacerbates their vulnerability, a pattern similarly reported by Sujakhu et al. (2019). The dependence on loans and remittances underscores the precarious economic position of smallholders.

*Training and capacity building needs*

Approximately 30.53% of small farmers reported no participation in training programs and expressed a need for additional support for income-generating skills, agricultural assistance, access to fertilizer, and risk-sharing mechanisms. Focus group discussions corroborated that adequate support could reduce out-migration by improving local livelihood opportunities.

*Food security and agricultural practices*

Food security varies markedly by farm size: large farmers meet 100% of their food needs from their farms, medium farmers 83%, and small farmers only 41.43%. The low agricultural yields among small farmers lead to widespread sharecropping (38%) and low crop diversity, increasing their vulnerability to crop failure and food insecurity. This echoes findings by Wilkinson & Peters (2015), Hoq et al. (2021), and Qaisrani et al. (2018), who document similar vulnerabilities in smallholder farming systems. Innovations such as the cultivation of spring season rice (chaite dhan), supported by PMAMP initiatives, represent promising adaptive responses to food scarcity.

*Health and environmental exposure*

Health vulnerability is higher among small farmers, with 39% missing work due to illness and 13% reporting waterborne infections during floods. Access to clean drinking water is generally available, though arsenic contamination affects some households, particularly among large farmers. Housing conditions further exacerbate vulnerability: 80% of small farmers live in weakly constructed houses near the Karnali River, compared to 62% and 21% for medium and large farmers, respectively. The proximity to flood-prone riverbanks and poor housing quality reflects poverty-driven settlement patterns, consistent with Emma et al. (2019), who highlight how marginalized communities often occupy hazardous locations due to economic constraints.

*Exposure to natural disasters and climate variability*

The natural disasters and climate variability index are highest for small farmers (0.456), indicating significant exposure and sensitivity. Historical flood data from the Department of Hydrology and Meteorology (DHM) and secondary sources document frequent floods in Rajapur over the past three decades, with increasing frequency and intensity (NPC, 2017; Practical Action, 2021; Dugar, 2016). The recurrent floods have severely disrupted livelihoods, particularly for smallholders living in vulnerable settlements.

*Scientific reasoning and comparison*

The findings illustrate that small farmers adopt a range of adaptation strategies primarily driven by necessity rather than choice, reflecting limited adaptive capacity. Migration and non-agricultural income diversification are consistent with adaptive responses documented in similar agro-ecological and socio-economic contexts (Hahn et al., 2009; Sujakhu et al., 2019). The low participation in institutions and high financial indebtedness further constrain their ability to cope with and adapt to climate stressors. Food insecurity and low crop diversity among small farmers align with regional studies highlighting the vulnerability of smallholders to climate variability and market fluctuations (Wilkinson & Peters, 2015; Hoq et al., 2021). The decline in livestock rearing due to flood-induced disease and fodder shortages underscores the compounding effects of environmental hazards on traditional livelihood buffers. Housing vulnerability and settlement patterns near flood-prone rivers are well-documented drivers of disaster risk in marginalized communities (Emma et al., 2019; Rai & Bhatta, 2025), reinforcing the need for integrated socio-environmental adaptation strategies.

This study confirms that adaptation strategies among farmers in Rajapur are strongly influenced by farm size, socio-economic status, and exposure to climate hazards. Small farmers face compounded vulnerabilities due to limited resources, low institutional engagement, and high exposure to floods, leading to reliance on migration, non-agricultural income, and high-interest borrowing. These findings are consistent with broader empirical evidence from South Asia and highlight the urgent need for targeted capacity building, financial inclusion, and infrastructure support to enhance adaptive capacity and reduce livelihood vulnerability.

## 3.7. Adaptation strategies

**Table 3**. Summary of Key Adaptation Strategies by Farmer Type.

| Key Strategy | Specific Indicator | Small Farmers (%) | Medium Farmers (%) | Large Farmers (%) |
|---|---|---|---|---|
| Early Warning | Early Warning System Adoption | 90% | About 100% | About 100% |
| | Siren and Miking | About 100% | About 100% | About 100% |
| Shelters | Shelter House Usage | About 70% | 50% | 15% |
| Tubewells | Elevated Hand Pumps | About 100% | About 100% | About 100% |
| Embankments | Concrete Embankment (Mentioned as effective) | 46.51% | 64.81% | 80% |
| | Complete Construction of Embankment | 100% | 100% | 100% |
| Training | DRR Training Received | 38% | 28% | 15% |
| | Income Generating Skills | 13% | 11% | 5% |

Based on the data presented in Table 3, the comparison of adaptation strategies among farmer groups reveals both similarities and differences. Basic infrastructure such as early warning systems, elevated tubewells, and embankments is widely accessible to all farmers, functioning as a shared safety mechanism. Early warning systems show near-universal adoption, with 100% of large and medium farmers and about 90% of small farmers reporting access, while siren and miking systems are available to all groups. Similarly, access to elevated hand pumps for drinking water and the presence of embankments are reported by 100% of small, medium, and large farmers, indicating equitable access to key protective infrastructure.

However, behavioral adaptations and capacity-building measures vary considerably among farmer categories. Shelter usage is highest among small farmers (70%), reflecting their higher vulnerability and limited access to secure private housing. In comparison, only 15% of large farmers reported using public shelters, suggesting reliance on their own elevated or permanent houses. Differences are also evident in perceptions of structural mitigation. Although embankments exist across the area, 80% of large farmers emphasized the importance of concrete embankments to protect their larger land assets. In contrast, only 46.51% of small farmers reported the same, possibly because their immediate priority is personal safety rather than land protection. Participation in disaster risk reduction training also differs across groups, with 38% of small farmers receiving DRR training and 13% gaining income-generating skills, compared to only 15% and 5% respectively among large farmers. Medium farmers generally fall between these two groups.

Overall, the results indicate that while structural infrastructure, such as early warning systems, tubewells, and embankments, benefits all farmers relatively equally, social and behavioral adaptation strategies are unevenly distributed. Small farmers rely more heavily on community-based support systems such as shelters and training programs. In contrast, large farmers tend to depend more on private assets and structural land protection measures.

This study identifies several key adaptation strategies employed by farmers in Rajapur to mitigate flood risks, including early warning systems, shelter houses, elevated hand pumps, embankment construction, and disaster risk reduction training. Despite these measures, small farmers remain the most vulnerable group due to their settlement patterns and limited adaptive capacity. Specifically, small farmers predominantly reside in temporary, non-elevated structures along the Karnali riverbanks, increasing their exposure and sensitivity to flooding. This spatial vulnerability, combined with socio-economic constraints, limits their ability to adapt effectively compared to medium- and large-scale farmers. The reliance of small farmers on sharecropping, labor migration for better earnings, and income from daily wage labor further underscores their precarious livelihood strategies. These coping mechanisms, while necessary, reflect adaptation limits and heightened vulnerability, as they often do not provide stable or sufficient income to buffer against the impacts of disasters. Medium farmers exhibit intermediate levels of these practices, while large farmers show the lowest engagement, indicating a clear vulnerability gradient aligned with farm size and resource access.

This pattern is consistent with broader evidence that poorer populations struggle disproportionately to cope with and recover from disasters due to limited resources and social capital. Hallegatte et al. (2020) highlight that in Nepal's 2011 flooding and landslides, only 6% of the very poor sought government assistance compared to nearly 90% of wealthier groups. Similarly, in Rajapur, despite government compensation packages declared for the October 2021 floods, many small farmers remain excluded from these schemes. This exclusion is often linked to their marginalization from decision-making processes and limited voice in governance, which reduces their access to timely and adequate post-disaster support. The findings reinforce the notion that increasing wealth alone does not guarantee resilience. Instead, the weaker socioeconomic resilience of poorer groups—characterized by limited financial resources, social isolation, and restricted institutional participation—is a critical factor driving their heightened vulnerability to disasters. This aligns with the conceptual framework of vulnerability, which emphasizes the interplay among exposure, sensitivity, and adaptive capacity, where socioeconomic factors critically shape adaptive limits. In summary, while structural adaptation measures and capacity-building initiatives are important, addressing the underlying socioeconomic vulnerabilities and governance exclusion of small farmers is essential to enhance their resilience to flooding in Rajapur.

## 4. Conclusion

The Standard LVI (scale 0–1) indicated a moderate-to-high level of vulnerability for small farmers (0.456). In contrast, the LVI-IPCC analysis (scale -1 to +1) yielded a score of 0.043 for small farmers. This positive value confirms that, despite their coping mechanisms, their exposure to floods still exceeds their adaptive capacity. The comparative analysis reveals that small farmers are the most vulnerable group, with a significant gap in adaptive capacity compared to large farmers. Their high vulnerability is mainly due to living in low-lying, flood-prone areas, having small and insecure landholdings, and limited access to resources and support systems. Frequent floods damage their crops and homes, leading to food shortages, financial stress, and a growing dependence on migration for survival. Many small farmers are forced to take loans at high interest rates, which adds to their financial burden and reduces their ability to recover or invest in better farming practices. These challenges highlight the need for strong government and policy support focused on small farmers. This includes better flood protection infrastructure, timely compensation after disasters, access to social safety nets, and training programs to improve their ability to adapt. Addressing the root causes of migration and supporting livelihood opportunities at the local level are also important. Overall, the study emphasizes that vulnerability is not only about natural hazards but also about limited resources and capacity to respond. A coordinated, inclusive approach is needed to reduce risks and build long-term resilience in flood-affected communities like Rajapur.

This study is subject to several limitations that offer avenues for future research. First, the reliance on household surveys introduces the possibility of self-reporting bias, where recall of past events (e.g., flood frequencies, income losses) may be subjective. While triangulated with Focus Group Discussions and Key Informant Interviews, the quantitative data remains reliant on respondents' perceptions. Second, the study is geographically confined to Rajapur Municipality. The unique topography of the Karnali River delta and the specific socio-economic fabric of the Tharu community may limit the generalizability of the findings to other Terai districts with different river systems or demographic compositions. Third, the selection of wards was purposive, targeting those most affected by the Karnali River. This sampling strategy captures high-exposure scenarios but may not represent the vulnerability of households in less exposed or urbanized wards within the same municipality. Finally, the classification of farmers into small, medium, and large categories was based on local landholding criteria. While this effectively highlights local disparities, applying these specific landholding thresholds to other national or regional contexts may require adjustment to account for varying agro-ecological definitions of farm size.

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