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Assessing climate vulnerability and adaptive capacity of Ifugao agricultural households: An LVI–IPCC approach

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ABSTRACT

Climate change poses a serious threat to upland agricultural systems, where environmental hazards and socioeconomic constraints combine to determine livelihood vulnerability. This study assessed the livelihood vulnerability of agricultural households in Ifugao, Philippines, using the Livelihood Vulnerability Index (LVI) and the LVI–IPCC framework. A survey of 1,400 farmers across eight municipalities was conducted to assess vulnerability across three dimensions: exposure, sensitivity, and adaptive capacity. Results show that Ifugao is moderately vulnerable to climate change overall (LVI–IPCC = 0.00918), with exposure to climatic hazards being the most contributing factor. Typhoon occurrences, variable rainfall patterns, and landslides were identified as significant threats to agricultural production and rural livelihoods. While traditional agricultural systems continue to provide ecological resilience over time, farmers' adaptive capacity has been constrained by an aging farmer population, limited access to financial resources, and uneven coverage of agricultural training and climate information. The results underscore the need for contextualized climate adaptation mechanisms, strengthened local extension systems, improved access to capital for climate-resilient investments, rehabilitation of terrace irrigation infrastructure, and livelihood diversification in upland communities. The study integrates indigenous, climate-smart agricultural knowledge with institutional efforts to adapt to a changing climate and provides evidence-based recommendations for enhancing resilience in mountain agriculture.

1. Introduction

Climate change remains the major source of extreme risks to agricultural production, food security, and farming communities' resilience; thus, the problem is most acute in the developing countries that are highly dependent on climate-sensitive sectors (Polsky et al., 2007). In the Philippines, several studies have established the negative effects of extreme rainfall, temperature variability, and climate change on agricultural productivity (Crost et al., 2018; Defiesta and Rapera, 2014). Small-scale farmers are the most affected group since they hardly have enough resources to survive such climate-related shocks (Campomanes et al., 2024).

The province of Ifugao, which is known for its steep terrain and shortage of irrigation facilities, is still very much dependent on rainfall to maintain agricultural production. Changes in temperature, irregular rainfall patterns, and extended droughts have become major factors that threaten rice production, vegetable cultivation, and other farming systems. Eventually, the agricultural produce of the province has not significantly increased even with continuing government programs, as Ifugao has also been compounded by the frequent occurrence of natural disasters, landslides, and climate anomalies.

Agricultural production in Ifugao is highly dependent on rainfall. Rainfall is highest from June to August, reaching approximately 1,071.1 mm during these months. The province is also experiencing a temperature increase of 0.9 °C, based on data from the IRRI station in Banaue. In addition, rainfall patterns and amounts have become increasingly variable over time. Ifugao records the second-highest total rainfall in the Cordillera Administrative Region (CAR). Despite this relatively high rainfall, changes in rainfall patterns and

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variability have created challenges for farmers and affected agricultural production.

In addition, Ifugao province is among the 20 provinces in the country ranked as most vulnerable to temperature increase based on the 2080 climatology. As highlighted by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), it is one of the top 20 provinces in the country with a projected increase in temperature, top 3 in projected rainfall change, and among the top 3 provinces at risk of typhoons. Basically, Ifugao is one of the provinces in the country that is most at risk of variability in climate.

Several papers have pointed out the outcomes of changes in climate and livelihood vulnerabilities of diverse communities in different countries (Adjei-Nsiah et al., 2010; Hahn et al., 2009; Rogers and Xue, 2015; Tran et al., 2022); however, there is a dearth of studies and research on the vulnerability of Ifugao farmers' livelihood amid climate variability. It is therefore imperative to recognize the interplay of adaptive capacity, sensitivity, and exposure in the province of Ifugao to be able to develop proper interventions that would enhance resilience and livelihood sustainability.

This research work was an evaluation and analysis of the susceptibility of Ifugao farmer households to climate change using the LVI and LVI-IPCC methods. It examined eight key components: socioeconomic conditions, access to information, livelihood strategy, food sources, water sources, physical resources, financial resources, and their experiences with natural calamities that hit the province, from which a detailed vulnerability profile of the province was generated. Aside from identifying key vulnerability drivers that constrain sustainable livelihoods among Ifugao farmers, this paper also aimed to generate evidence-based perceptions that could serve as policy recommendations to local government planners, disaster and risk management officers, as well as the community to develop actionable adaptation strategies and sustainable agricultural development policies.

2. Materials and methods

Ifugao is a province in the Cordillera Administrative Region (CAR) made up of 11 municipalities situated in the mountain terrains with different agro-ecological zones. The Provincial Planning and Development Office identified eight municipalities producing the most agricultural produce, which the study focused on. The study used stratified random sampling to represent the different livelihood zones of Aguinaldo, Alfonso Lista, Banaue, Kiangan, Lagawe, Lamut, Mayoyao, and Tinoc.

To provide both quantitative and qualitative insights about the effects of climate change on agriculture-centered livelihoods in Ifugao, a mixed-method household vulnerability assessment was employed to gather data in this study. It made use of a structured household survey and was conducted among 1,400 farmers from eight municipalities. To meet the computational requirements of the LVI and the LVI-IPCC framework, a survey questionnaire was developed, while key informant interviews were also administered to municipal agriculturists, agricultural technicians, PAENRO personnel, irrigation managers, and seasoned farmers to gather local climate trends, institutional support mechanisms, and historical experiences amid environmental stressors. To gather community perspectives on coping mechanisms and shared vulnerabilities, focus group discussions (FGDs) were also used at selected barangays to validate the survey responses.

Additionally, secondary data on rainfall, temperature, disaster occurrence, and agricultural production were acquired from PAGASA, the Philippine Statistics Authority (PSA), and PAENRO to strengthen the analysis of the exposure components under the LVI-IPCC framework. Data on the 8 major components of the LVI framework: socioeconomic conditions, access to information, livelihood strategy, food sources, water sources, physical resources, financial resources, and their experiences with natural calamities that hit the province were standardized and weighted according to the specified calculations of earlier LVI research by Hahn et al. (2009) and Tran et al. (2022) to measure the vulnerability of the province of Ifugao.

2.1. Methodology

The Livelihood Vulnerability Index (LVI) originally used by Hahn et al. (2009) in his study is broadly applied as a composite, indicator-based framework; however, it is not expected to function as a rigid template. Present applications increasingly consider the LVI as a modifiable measurement architecture, where indicator domains may be re-specified to improve construct validity, provided that standardization procedures are preserved, aggregation logic is transparent, and component weights are consistently derived from indicator structure (Das et al., 2023). Additionally, recent empirical studies and syntheses demonstrate that LVI-based vulnerability assessment frequently involves context-driven adaptation of component domains and sub-indicator sets to reflect local livelihood systems and hazard regimes (Tran et al., 2022).

The Livelihood Vulnerability Index (LVI) has also been widely used as a tool for assessing climate vulnerability in agricultural communities where adaptive capacity, sensitivity, and exposure-based indicators are integrated. The LVI-IPCC framework has already proven useful for assessing farming household vulnerability in Southeast Asia, notably in Vietnam and Indonesia (Lan et al., 2025), which highlight key constraints to livelihoods and prioritize adaptation.

In mountainous and highland livelihood systems, biophysical constraints (slope instability, fragmented terraced plots, infrastructure limitations) may restrict productive capacity even where households have some financial inflows, while households with land-based assets may remain liquidity-constrained and unable to finance adaptive investments. This distinction is consistent with the broader climate-risk evidence base for mountain regions, which highlights how exposure pathways and adaptation limits are shaped by topography-linked infrastructure and access barriers (IPCC, 2023).

2.2. Expansion of the LVI framework

In the present study, the framework was expanded from seven to eight major components by dividing the conventional asset domain into physical resources and financial resources. This modification is methodologically appropriate for the upland context of Ifugao because physical production resources, such as irrigation access, land tenure security, farm size, and ownership of farm implements, are subject to different constraints from financial resources, such as liquidity, remittances, access to credit, livestock ownership, and subsidies. These two types of resources may therefore vary independently.

Disaggregating the asset domain improves the analytical resolution of adaptive capacity by allowing separate assessment of (a) infrastructure- and resource-based adaptive capacity and (b) liquidity- and finance-based adaptive capacity. This distinction can provide clearer results for policy design. Importantly, this modification does not change the mathematical structure of the LVI. The procedures for standardization (Eq. 1), component aggregation (Eq. 2), weighting (Eq. 3), and integration of the IPCC factors into the LVI–IPCC framework (Eq. 4) remain unchanged. The component weights continue to depend on the number of sub-components, preserving the composition of the composite index and maintaining conceptual consistency with the LVI–IPCC approach (Tran et al., 2022).

Because the indicators were measured using different scales, they were first standardized using Eq. 1:

$$Index\ S_d = S_d - S_{min}/S_{max} - S_{min} \tag{1}$$

where, S_d represents each component specifically designed for the province of Ifugao, while the minimum and maximum values for each component are denoted by S_{min} and S_{max}, respectively. The value of each LVI component was then calculated as follows:

$$\boldsymbol{M_d} = \frac{\sum_{i=1}^{n} \boldsymbol{IndexS_{di}}}{\boldsymbol{n}} \tag{2}$$

where, M_d represents one of the eight major components used to assess vulnerability in the province of Ifugao, $IndexS_{di}$ is the standardized value of sub-component (i), and (n) is the number of sub-components within the major component.

The overall LVI was then calculated using Eq. 3:

$$\boldsymbol{LVI_d} = \frac{\sum_{i=1}^{7} \boldsymbol{W_{Mi} M_{di}}}{\sum_{i=1}^{7} \boldsymbol{W_{Mi}}} \tag{3}$$

where, W_{Mi} denotes the weight assigned to each major component according to its characteristics. In this study, the weight of each component was determined by the number of sub-components it contains. For example, if Component A contains two sub-components while Component B contains one, Component B receives a proportionally greater weight than Component A.

2.3. Calculating the LVI-IPCC

To assess the vulnerability of households in Ifugao, the LVI–IPCC methodology was applied to identify and integrate the key vulnerability components. The original Livelihood Vulnerability Index (LVI) framework proposed by Hahn et al. (2009) consists of seven major components. In the present study, the conventional asset domain was divided into physical resources and financial resources to better capture the distinct infrastructure- and liquidity-related constraints faced by upland agricultural households in Ifugao, as presented in Table 1. This modification provides greater analytical detail while preserving the mathematical structure of the LVI–IPCC framework.

The LVI scores were expressed on a scale from 0 to 0.5, where 0 indicates the lowest level of vulnerability and 0.5 indicates the highest level of vulnerability, following the approach adopted by Tran et al. (2022) and Hahn et al. (2009).

In deriving the LVI-IPCC, Eqs. 1, 2, and 3 were used to arrive at the LVI-IPCC score of Ifugao. A different LVI-IPCC result from the LVI was obtained after the major components were combined. To integrate them according to the categories shown in Table 1, Eq. 4 was subsequently used, merging the primary components into the LVI in one step.

$$\boldsymbol{LVI - IPCC_i} = (\boldsymbol{e_i} - \boldsymbol{a_i}) * \boldsymbol{s_i} \tag{4}$$

A computed index of -1 would indicate the least vulnerability, and an index nearer to 1 would mean higher vulnerability based on the calculated exposure for the province of Ifugao (e_i), the adaptive capacity score (a_i); and the sensitivity score (s_i) (Hahn et al., 2009).

3. Results and discussions

The section describes the vulnerability index of Ifugao province along with its capacity to adapt to climate change. The index shows the interaction of the 3 factors of the LVI-IPCC: adaptive capacity, sensitivity, and exposure.

3.1. Adaptive capacity index of agricultural households

The overall adaptive capacity value (0.4006) of agricultural households in Ifugao, as shown in Table

2, depicts a moderate but structurally constrained capacity to respond to climate variability. The index indicates that households have certain assets that allow for some adaptive capacity, but an analysis of the sub-components suggests that many socioeconomic and institutional barriers remain and continue to constrain farmers' climate adaptive capacity.

Table 1: Factors of livelihood vulnerability index (LVI-IPCC) employed in the study

IPCC contributing factors	Key indicators	Sub-indicators
Adaptive capacity	Socioeconomic profile	Age of farmers, household size, gender of household head, farming experience, household income, educational attainment
	Physical resources	Farm size, land tenure security, irrigation access, ownership of farm implements
	Financial resources	Remittances, livestock units, access to credit, receipt of government agricultural subsidies
	Information sources	Participation in agricultural training, technical assistance received, membership in farmer organizations, number of climate information sources
	Livelihood strategy	Engagement in non-farm activities, dependence on agriculture, number of crops cultivated, adoption of traditional farming systems (Payoh, Muyung, Uma)
Sensitivity	Food sources	Household food production dependence, households below food threshold, food purchasing behavior, crop diversity, seed and crop storage
	Water sources	Water source reliability, distance to water source, water disputes, dependence on natural water systems
Exposure	Natural calamities and climate variability	Climate change awareness, frequency of natural disasters, early warning access, disaster-related injury/fatality incidence, temperature variability, rainfall variability

Among the adaptive capacity indicators, the socioeconomic profile of agricultural households in Ifugao has a relatively high sub-component value of 0.4479. This figure represents demographic and economic attributes of agricultural households that prevent them from embracing climate-resilient farming practices. The average age of farmers (42 years) and the relatively long farming experience (15.4 years) indicate that agricultural knowledge in the province is heavily based on traditional farming systems. Although this experience is an important source of local ecological knowledge, interviews with farmers highlighted that in many cases farm practices are very traditional and limited, suggesting little exposure to formal agricultural training or innovative technologies. As noted by studies on rural agricultural communities, aging farming populations often experience barriers to adopting climate-adaptive technologies due to factors such as limited digital literacy, risk aversion, and declining capacity for physical labor (Phuong et al., 2023).

The average household income shown in Table 2 (₱7,824 per month) is relatively low and reflects the economic constraints faced by farming households. Lack of financing limits farmers' ability to adopt hydro-resilient technologies, such as better irrigation mechanisms, tractors, and more climate-resistant crop varieties. Similar findings have been reported for climate vulnerability studies across Southeast Asia, where low capital endowments and lack of access to financial services dramatically reduce the capacity of smallholder farmers to implement long-term adaptation measures (Das et al., 2023). During interviews with local farmers in this study, many were hesitant to invest in advanced technologies despite recognizing the need for improvement; however, financial constraints and uncertainty regarding harvest outcomes often discourage landowners from investing in new agricultural inputs.

The physical resources Index shows moderate vulnerability related to agricultural infrastructure and land resources. While the average farm size is 1.63 hectares, indicating that households own land assets, Ifugao's highly fragmented lands and mountainous terrain still limit productive capacity. Rice terrace farming, the traditional agricultural system in the province, demands continuous maintenance of its terrace walls and irrigation channels. Landslides and soil erosion from extreme rainfall often result in costly repairs which households must undertake without significant institutional support. Studies of mountain agriculture consistently reveal that steep topography and fragile soils lead to structural constraints restricting the development of mechanization and infrastructure, decreasing adaptive capacity in upland farming systems (IPCC, 2023).

Similarly, access to irrigation illustrates uneven resource distribution among agricultural communities. Community irrigation systems (CIS) support 62.5% of farms, but the dependence on shallow wells and natural water sources suggests that many farmers still rely heavily on rain patterns. This dependency makes them more vulnerable to climate variability, especially during periods of prolonged drought or erratic rainfall seasons. New research about climate adaptation strategies in upland agriculture underscores that reliable rainfall has a critical influence on the resilience of mountain farming systems, given the direct relationship between variability of precipitation and crop productivity (Phuong et al., 2023).

The financial resources value of 0.4175 is an effective embodiment of liquidity constraints faced by farming households. Though a few households receive remittances or benefits in the form of livestock assets, a mere fraction receives government subsidies or financial support for agricultural production. Accordingly, the lack of formal credit institutions in many remote barangays limits farmers' access to financing mechanisms that would promote climate adaptation investments. Literature on climate-resilient agriculture highlights the centrality of financial inclusion in support of risk-reducing strategies among farmers such as crop diversification, effective irrigation, and climate-resilient seed varieties. Many farmers continue to rely on traditional practices which may no longer be enough with increasingly erratic climate conditions, without adequate access to Capital.

The access to information indicator (0.4007) highlights knowledge diffusion, which is an important constraint in agricultural adaptation. Farmer attendance at agricultural training sessions (0.79) indicates that farmers were not, in general, participating in formal extension programs. Even though most farmers reported receiving technical assistance, the extent of their membership in farmer organizations is very low (38%), and thus there are fewer opportunities for knowledge transfer and learning processes.

Interviews among farmers also indicate that the mountainous landscape and dispersed settlements of Ifugao often hinder the reach of agricultural extension services, leading to unequal availability of climate information for different communities. In the same manner, the study of Phuong et al. (2023) indicated that localized weather forecasts and climate advisories are increasingly perceived as important ways that shape farmers' capacity to anticipate climate risks and adapt agricultural practices.

The livelihood diversification Indicator (0.3415) offers a relatively low vulnerability score compared to the other variables, indicating that within the population, some households did diversify livelihoods outside of agriculture. 31.5% of farmers reported engaging in non-agricultural activities (i.e., small-scale trading, wage labor, or working seasonally). Diversification of livelihood activities is recognized as an important adaptive strategy to reduce reliance on climate-sensitive agricultural income (IPCC, 2023). However, these results also revealed that 68.5% of farmers are still dependent solely on agriculture, with very limited diversification opportunities in the mountainous economic ecology of Ifugao.

In a study by Altieri and Nicholls (2020), traditional land-use systems are known to promote diversified resource use and long-term environmental stewardship, which enhances ecological resilience. Accordingly, agroecological research reinforces the importance of localized knowledge in these processes. In Ifugao, traditional agricultural systems like Payoh (rice terraces), Muyung (woodlot agroforestry), and Uma (swidden farming) are also key in determining adaptive capacity. These local agricultural systems have equipped communities with the means to regulate soil fertility, water allocation, and biodiversity in the upland system. However, farmers revealed that the worsening intensity of typhoons, variability in rainfall patterns, and landslides increase the pressure on these systems during extreme weather events and eventually destroy terrace structures or irrigation channels.

Moderate vulnerability seen in Ifugao echoes the results of studies conducted in other agricultural communities in Southeast Asia, where climate exposure interacts with socioeconomic constraints to determine risk to livelihoods. Similar patterns of vulnerability were reported for rice farming households in Indonesia and ethnic minority communities in Vietnam, with the majority of the contribution from limited access to financial services, reliance on climate-sensitive crops, and disparities in agricultural information use (Lan et al., 2025).

In summary, the adaptive capacity indicators show that although Ifugao farmers have valuable traditional knowledge and land-based assets, their overall capacities to adapt to climate change are still limited by demographic trends, financial constraints, and inequality in access to information and infrastructure. These results support the argument that climate vulnerability in upland agricultural systems is both a function of environmental exposure and broader socioeconomic and institutional structural drivers of farmers' ability to respond to climate-related risks.

Thus, designing integrated interventions that respond to both ecological and socioeconomic facets will be imperative to strengthen adaptive capacity within the province. More specifically, expanding agricultural extension services and making financial resources accessible to farming households and supporting climate-resilient farm technologies could enable greater capacity of these farming households to adapt under moving climatic conditions while maintaining the traditional farmland that has characterized much of Ifugao.

Furthermore, as can be gleaned in Fig. 1, the composite structure of adaptive capacity among Ifugao agricultural households according to five livelihood components is presented: socioeconomic profile, physical resources, financial resources, accessibility to information, and livelihood diversity. The distribution of these indicators indicates that adaptive capacity at the provincial level is not driven by a single dominating factor, but depends on multiple demographic, institutional, and economic conditions that together shape farmers' ability to respond to climate variability.

The high socioeconomic component vulnerability value can be attributed to the structural demographic conditions existing in most upland agricultural communities in the Philippines. Farmers in Ifugao are still primarily family-based and labor-intensive; agricultural knowledge is passed down through generations rather than through formal educational systems. Though this continuity preserves indigenous ecological knowledge, it may inhibit the adoption of climate-resilient innovations. Recent research focused on adaptation of rural agriculture particularly notes that demographic transitions (especially the movement of younger people toward urban employment) are changing agricultural labor structures throughout Southeast Asia (Phuong et al., 2023). In these contexts, the aging population of farmers can have a large amount of practical knowledge but little ability to adopt new technologies or formally take part in capacity-building programs.

Table 2: Ifugao farmers' vulnerability in terms of adaptive capacity

Indicator	Sub-indicator	Unit	Value	Max value	Min value	Index value	Indicator component value
Socioeconomic profile	Age of farmers	Years	42	75	15	0.45	0.4479
	Average household members	Count	4.73	11	1	0.373	
	Percentage of households headed by females	Percent	28.5	100	0	0.285	
	Farming experience	Year	15.4	40	1	0.369	
	Average household income	Pesos	7824	30000	500	0.248	
	Percentage of adults in the household	Percent	61	100	0	0.61	
	Educational attainment of household head	Years	6.2	16	0	0.388	
	Percentage of adults with primary education	Percent	68	100	0	0.68	
Physical resources	Farm size	Hectares	1.63	5	0.1	0.688	0.3955
	Farm tenure	Percent	43	100	0	0.43	
	CIS irrigation	Percent	62.5	100	0	0.625	
	NIA irrigation	Percent	25	100	0	0.25	
	Shallow wells	Percent	10	100	0	0.1	
	Ownership of farm implements/machines	Count	2.8	10	0	0.28	
Financial resources	Remittances from family members	Percent	25	100	0	0.25	0.4175
	Number of animal units	Percent	66	100	0	0.66	
	Receives financial assistance or subsidy from the government	Percent	18	100	0	0.18	
	Has access to credit	Percent	58	100	0	0.58	
Access to information	Number of trainings attended on farming	Count	0.79	3	0	0.263	0.4007
	Percentage of technical assistance received	Percent	62	100	0	0.62	
	Percentage of participation in farm organization	Percent	38	100	0	0.38	
	Number of sources of climate information	Count	1.7	5	0	0.34	
Livelihood diversity	Percentage of farmers working in industries other than farming	Percent	31.5	100	0	0.315	0.3415
	Percentage of farmers dependent solely on farming	Percent	68.5	100	0	0.685	
	Mean agricultural livelihood diversity index (scale: 0.20–1)	1/# of livelihood	0.25	1	0.2	0.063	
	Number of crops planted	Count	3.1	8	1	0.3	
	Percentage of farmers using the Payoh farming system	Percent	38.6	100	0	0.386	
	Percentage of farmers using the Muyung (woodlot) farming system	Percent	22	100	0	0.22	
	Percentage of farmers using the Uma (swidden farm) farming system	Percent	42.14	100	0	0.421	
Overall adaptive capacity value							0.4006

The moderate vulnerability of physical resources further reflects the unique agro-ecological characteristics of Ifugao. While lowland agricultural areas may benefit from mechanization and irrigation systems that improve productivity, the less accessible mountainous terrain of the Cordillera must contend with limited infrastructure and mechanized farming. The rice terraces, the basis of Ifugao's agriculture, also demand daily handwork to maintain the terrace walls and irrigation channels. Landslide- or heavy rainfall-induced damage can thus be highly disruptive to production systems and represent additional labor and financial burdens for farming households. Indeed, research carried out in mountain agriculture reveals that physical infrastructure limitations are a primary determinant of vulnerability in upland areas across the world, as terrain restricts access to technology, markets, and irrigation systems (IPCC, 2023).

The financial resources indicator also demonstrates the structural economic constraints on adaptive capacity. While some agricultural households receive remittances or raise livestock, remote barangays still have limited access to formal agricultural financing. Without such access, farmers often struggle to adopt risk-reducing strategies such as crop diversification, irrigation investments, or climate-resilient seed varieties. Similar results have been documented in climate vulnerability studies on the Asian continent, where financial inclusion has limited farmers' potential to implement adaptation options (Das et al., 2023).

Access to information is another key factor that impacts adaptive capacity. While many farmers reported that they have received some degree of technical assistance from the government, participation in agricultural training programs remains low. The geographical dispersion of settlements in mountainous areas, like Ifugao, may also impede reaching the villages to deliver agricultural extension services, thereby causing uneven access to climate information and advisory services. The need for localized climate information systems and farmer education programs has been highlighted under increasing emphasis on the role of climate adaptation research in strengthening agricultural resilience.

Lastly, livelihood diversification is an important buffer against climate shocks. Households that diversify into non-agricultural activities tend to be more resilient to agricultural production losses triggered by extreme weather events. Yet, the results of the study imply that most of the Ifugao farmers still depend on agriculture because of limited economic diversification opportunities in mountainous rural areas. The dependence on climate-sensitive livelihoods highlights a necessity for holistic rural development approaches that promote agricultural resilience alongside alternative livelihoods.

Fig. 1 illustrates the factors influencing the adaptive capacity of Ifugao, which include traditional farming systems, demographic shifts, economic limitations, and support systems. Therefore, building adaptive capacity calls for systematic measures that improve the socioeconomic and informational resources existing at the farming household level.

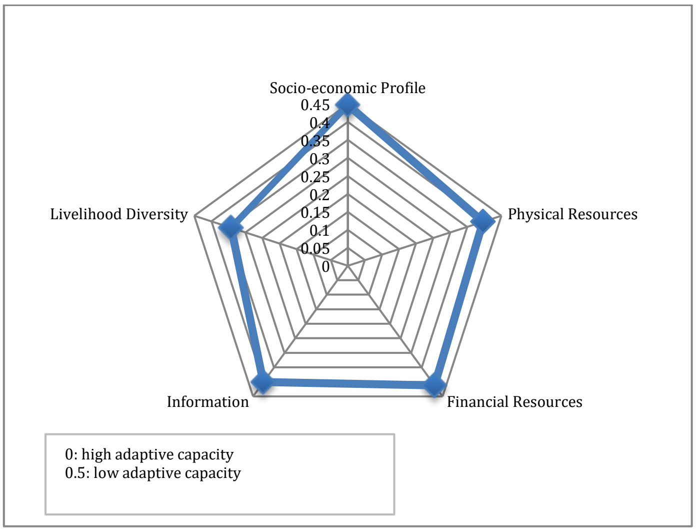

Fig. 1: Adaptive capacity of Ifugao farmers

3.2. Sensitivity index of agricultural households

Table 3, on the other hand, illustrates the sensitivity dimension of the LVI–IPCC framework, demonstrating the extent to which climate-related stressors affect the agricultural households due to their reliance on food and water resources. The findings suggest that relative to water access, the vulnerability associated with food security is more pronounced (0.4119 and 0.1568). This suggests that the instability of agricultural production is the main cause of livelihood sensitivity in the province.

Food sources with a high degree of vulnerability show reliance on self-produced food by households. Although self-sustaining agriculture is a fundamental part of the Ifugao's rural livelihood, numerous indicators depicted in Table 3 show that for at least some months in the year, the agricultural produce of a household is inadequate to meet food requirements. The high percentage of food indebtedness and adoption of cheaper food alternatives by households are indicators of the adverse effects posed by climate variability on the stability of agricultural production and the income-generating activities of households.

In mountainous regions, food insecurity is often attributed to both structural and environmental causes. Crop yields can be affected by climatic variability such as drought, erratic rainfall, and damage caused by typhoons.

Furthermore, rural communities face geographic isolation, which can restrict access to markets and escalate food costs. Recent vulnerability assessments in developing regions indicated that smallholder farmers suffer from seasonal food insecurity when climatic events interrupt the cycle of food production (Das et al., 2023).

In the case of Ifugao, historical traditional agricultural systems enabled food production to be stable, along with diversified cropping and integrated soil management. The rice terrace system, with the addition of crops and forests, helped households sustain equilibrium

agricultural ecosystems. However, the interviews with farmers in this study suggest that traditional systems are being disrupted by growing climate variability. Unpredictable rainfall was reported by farmers as well to make planting and crop management decisions, resulting in harvest delays and loss of yield.

Farmers have implemented various adaptive strategies to counter food insecurity challenges. Respondents frequently mentioned practices such as diversification of crops, rotation of crops, and the adoption of drought-resistant varieties. The practices complement the climate adaptation strategies already documented within the farming communities of Southeast Asia. It is common within the documented communities to adopt diversification along with adjustable planting calendars to buffer the impact of climate variability (Phuong et al., 2023).

Water resource indicators show lower vulnerability due to the continued functioning of irrigation systems and natural water sources for many farming communities in Ifugao. It would appear that water access is still relatively stable despite climate variability, as evidenced by the presence of community irrigation systems and relatively short distances to gather water sources. However, the dependence on natural water sources in some regions suggests critical vulnerability to long-term drought. In upland areas, water resource management may become critical to agricultural production as climate change exacerbates hydrological variability.

Overall, the sensitivity indicators indicate that although water access remains relatively stable, food security issues may become pronounced if climate variability continues to disrupt cycles of agricultural production. Thus, increasing agricultural productivity and providing livelihood security to households is an important aspect of reducing the sensitivity of farming communities in Ifugao.

Table 3: Ifugao farmers' vulnerability in terms of sensitivity

Indicators	Sub-indicators	Units	Values	Max value	Min value	Index value	Indicator component value
Food sources	Percentage dependence of HH on family farm for food	Percent	38	100	0	0.38	0.4119
	Percentage of family below the food threshold	Percent	32.3	100	0	0.323	
	Average months of households struggling to secure food (scale: 0–12)	Months	2.4	12	1	0.127	
	Percentage of households that buy food on credit in a month	Percent	72	100	0	0.72	
	Percentage of households that rely on less expensive foods bought in the market	Percent	88	100	0	0.88	
	Percentage of households that gather wild food, hunt, or harvest immature crops	Percent	33	100	0	0.33	
	Mean Crop Diversity Index (scale: >0–1)	1/#of crops	0.25	1	0.1	0.167	
	Percentage of households w/out stored crops	Percent	45	100	0	0.45	
	Percentage of households w/out stored seeds	Percent	33	100	0	0.33	
Water sources	Percentage of households experiencing water-related disputes	Percent	5	100	0	0.05	0.1568
	Percentage of households relying on natural water sources	Percent	18	100	0	0.18	
	Percentage of households w/out stable water supply	Percent	33	100	0	0.33	
	Mean duration to reach water source (minutes)	Min	8.7	60	5	0.067	
Overall sensitivity value							0.2843

3.3. Exposure index of agricultural households

Furthermore, the exposure component of the LVI-IPCC framework, as demonstrated in Table 4, captures how exposed agricultural households in Ifugao are to climate-related hazards and environmental variability. The findings reveal that climate hazards are among the top contributors to risk in the province, with an exposure index value of 0.4329.

This high exposure level is representative of the geographic and climatic conditions in the Cordillera region. Ifugao's mountainous terrain, however, makes it especially vulnerable to landslides, flooding, and damage to infrastructure during extreme weather events. Respondents reported a high frequency of natural disasters (typhoons, duration of intense rainfall events, length of dry spells), indicating that farming households often experience environmental shocks that can disrupt agricultural production.

This high level of knowledge regarding climate change among the respondents indicates that farmers are gradually becoming aware of these environmental changes. But raising awareness does not always lead to meaningful adaptation. An alarming forty percent of all households said they got no early warnings for approaching natural disasters, indicating wider issues in disaster preparedness and information dissemination systems. Therefore, enhancing early warning communication and local-level disaster preparedness mechanisms can help substantially mitigate exposure-related risks.

Temperature and rainfall measures provided even clearer pictures of the climatic forces affecting agricultural production. The temperature values determined in the study are already higher than those of climatic conditions recorded in the province according to long-term averages. Climate science research indicates that even small increases in average temperature can have pronounced effects on the productivity of crops, and alter pest dynamics and soil moisture levels in tropical agricultural systems (IPCC, 2023). Increased variability in precipitation could also lead to increased soil erosion and landslides in mountainous landscapes, especially in places where terrace structures are now failing because of aging infrastructure.

Research focusing on climate vulnerability in mountainous areas repeatedly emphasizes that when it comes to exposure to environmental hazards, geographic isolation and infrastructure deficiencies act as a multiplier (Phuong et al., 2023). With respect to Ifugao, remote barangays and poor road connectivity delay disaster response and recovery efforts that render farming households vulnerable in the long run to climate impacts. These findings underline the need for better strategies to manage climate risk in the province. Enhancing early warning systems and home strengthening programs for local businesses and households to cope with the repercussions of climate shocks could substantially mitigate such environmental risks already experienced by agricultural households.

3.4. Vulnerability index of agricultural households

The results of combining adaptive capacity, sensitivity, and exposure into one composite index for Ifugao using the LVI-IPCC framework are summarized in Table 5. The derived value of 0.00918 implies moderate overall vulnerability to climate change at the provincial level, with some structural livelihood constraints balanced by adaptive practices still in use by existing agricultural households.

Although Ifugao is not included in the bracket of extreme vulnerability according to the composite index, actual contributions by dimension indicate an unbalanced structure of resilience. In terms of the components, exposure (0.4329) was found to be the most dominant driver of vulnerability, while adaptive capacity (0.4006) and sensitivity (0.2843) followed suit. These patterns indicate that the main challenge for agricultural households is not limited livelihood assets, but rather increased frequency and intensity of environmental shocks affecting production systems.

Table 4: Ifugao farmers' vulnerability in terms of exposure

Indicators	Sub-indicators	Units	Values	Max value	Min value	Index value	Indicator component value
Natural disasters and climate change experience	Climate change awareness	percent	93	100	0	0.93	0.4329
	Mean number of natural calamities experienced in the past 5 years	count	4.2	12	0	0.35	
	Percentage of households that were not alerted about incoming natural disasters	percent	38	100	0	0.38	
	Percentage of households that suffered from injuries or fatalities due to natural calamities in the past 5 years	percent	5	100	0	0.05	
	Mean maximum temp by month (°C, 2020-2024 avg.)	Celsius	30.94	33.0	27.5	0.63	
	Mean minimum temp by month (°C, 2020-2024 avg.)	Celsius	20.26	23.5	16.5	0.54	
	Mean precipitation by month	mm	88.35	416.5	30.1	0.15	
	Overall exposure value						0.4329

The prominence of exposure speaks to the geographic realities of the province. Located in the mountainous Cordillera region, Ifugao is often hit by typhoons, extreme rainfall events, landslides, and changes in seasonal patterns. Mountain ecosystems are well-known highly climate-sensitive landscapes because, on these steep slopes, the hydrological extremes get amplified, and soils become much more unstable (IPCC, 2023). Even mild climatic perturbations can trigger cascading consequences in such settings by compromising agricultural infrastructure, including terrace collapse, irrigation shortages, and crop damage.

This moderate adaptive capacity score reflects the fact that although farming households possess resources that would help them adapt to changing climate situations, they are irregular and structurally constrained. The adoption of climate-compatible technologies has therefore remained elusive in these regions. Various indigenous farming systems such as payoh (terraces), muyung (woodlot), and uma (swidden-based) systems may act as ecological buffers towards land-use diversity and natural resources. Agroecological research highlights that such traditional agricultural landscapes often enhance resilience by maintaining biodiversity, soil fertility, and water regulation (Altieri and Nicholls, 2020). However, the results of this study suggest that these systems alone may not fully offset the increasing environmental pressures associated with climate change.

Though the sensitivity score is lower than exposure and adaptive capacity, there is still considerable sensitivity in the agricultural livelihood system. Food security vulnerability, dependence on climate-sensitive food crops, and volatility in agricultural production are driving factors of household sensitivity. Agricultural productivity in many upland farming communities remains closely associated with rainfall variability and soil conditions, rendering households especially vulnerable to climate disruptions. Studies conducted recently across Southeast Asia validate the claim that smallholder farmers in mountainous regions are comparatively more livelihood-sensitive, as they lack opportunities for agricultural diversification and alternative income sources (Das et al., 2023).

Collectively, the LVI–IPCC results suggest that climate vulnerability in Ifugao is driven by the interaction between features rather than exclusively one determinant: environmental exposure, socioeconomic constraints, and agricultural livelihood dependence. This relatively moderate composite index should not be seen as a marker of low risk; rather, it reflects a system that remains structurally vulnerable to further climate intensification. If targeted adaptation interventions are not taken, intensifying climate variability will increasingly tilt this balance toward greater vulnerability levels in the next decades.

These findings support a broader conclusion that enhancing adaptive capacity will only be successful as part of an integrated approach to reducing climate exposure and livelihood sensitivity. Integrated adaptation policies that simultaneously promote innovation, ecosystem management and institutional support will therefore be critical to increase long-term resilience in upland farming systems like that of the Ifugao.

Table 5: LVI-IPCC vulnerability index for the province of Ifugao

IPCC contributing factors	Contributing factor values	LVI-IPCC value
Adaptive capacity	0.4006	0.00918
Sensitivity	0.2843	
Exposure	0.4329	

3.5. Implications for climate adaptation in upland agricultural systems

The results underscore the importance of socioeconomically relevant impacts for climate adaptation and cross-sectoral policy choices in upland agricultural systems, where environmental hazards intersect with socioeconomic constraints to determine livelihood vulnerability. According to the LVI–IPCC outputs, vulnerability in Ifugao is influenced most by exposure to climate hazards, adaptive capacity (moderate), and sensitivity factors associated with food security and access to resources. Adaptation to these risks depends on an integrated socio-ecological approach that goes beyond conventional agricultural interventions in mountain landscapes.

Strengthening agricultural knowledge systems and extension services is key to boosting farmers' adaptive capacity. Results point to low participation in formal training and disparate access to climate information in farming households. Scaling up extension programs that deliver localized climate advisories, adaptive agriculture practices, and early warning information can enable farmers to better respond to climate variability. In geographically lightly populated upland areas like Ifugao, community-level extension networks play a critical role in the dissemination of climate information to remote farming communities (Phuong et al., 2023).

Another key adaptation pathway is improving financial access. Moderately high vulnerability scores of financial resources, combined with high risk factor scores for a number of involvement in non-farm activities, suggest that multiple households have liquidity constraints to invest in climate-resilient technologies or diversified farming systems, and that many households lack the means to invest financially. Increasing access to agricultural credit, climate risk insurance, and donor-research-backed government support can help farmers switch to drought-resistant crop varieties, invest in irrigation infrastructure, and improve soil conservation practices. Financial inclusion is increasingly recognized as a critical enabler that allows smallholder farmers to move beyond short-term coping mechanisms toward proactive adaptation to climate change (Das et al., 2023).

Lastly, supporting livelihood diversification could help rural households to not overly depend on climate-sensitive agriculture. Many families in Ifugao still depend heavily on agriculture, exacerbating vulnerability when agricultural productivity deviates. Expanding opportunities for non-farm employment, agro-processing enterprises, and community-based tourism may provide alternative sources of income that strengthen livelihood resilience in upland areas.

In general, climate adaptation in upland agricultural systems needs to be viewed as a multidimensional development challenge rather than an agricultural problem. The solutions have to address environmental threats, socioeconomic constraints, and gaps in institutional capacity at the same time. Alignment of indigenous knowledge and climate sciences with policies for inclusive rural development can enhance the resilience of upland communities and sustain the ecological.

4. Conclusion

This study evaluated the climate vulnerability of agricultural households in Ifugao using the Livelihood Vulnerability Index (LVI) and the LVI–IPCC framework. The results show that the province has moderate overall vulnerability (LVI–IPCC = 0.00918), with high exposure to climate hazards and moderate constraints in adaptive capacity being the primary contributors. Frequent typhoons, variability of rainfall, and landslides continue to disrupt the production of agricultural crops, especially in the rice terrace landscapes that support the rural economy of most provinces.

Despite the pressure of expanding agricultural frontiers, indigenous agroecological systems, such as the Payoh (rice terraces), Muyung (wood lot) and Uma (swidden farms), still provide significant ecological buffers that maintain stable soils and regulated water, while using diverse resources from the environment. But the study also points to structural constraints that hold back farmers' ability to adapt to increasing climate variability. The low adoption of a climate-resilient farming system is caused by older farmer populations, less participation in agricultural training, limited access to finance, and uneven distribution of climate information. Ifugao climate adaptation interventions should therefore, based on these findings, focus on strengthening local agriculture extension systems and expanding financial support for climate-resilient agricultural investments, rehabilitating terrace irrigation infrastructure, and promoting upland livelihood diversification. These targeted interventions can help improve farmers' adaptive capacity while enabling the continued maintenance of the ecological and cultural landscapes that are characteristic of Ifugao's traditional agricultural systems. Future research should further examine how indigenous ecological knowledge and modern climate adaptation strategies can be integrated to strengthen long-term resilience in mountainous agricultural regions.

List of abbreviations

CAR	Cordillera administrative region
CIS	Community irrigation system
FGD	Focus group discussion
HH	Household
IPCC	Intergovernmental panel on climate change
IRRI	International rice research institute
LVI	Livelihood vulnerability index
NIA	National irrigation administration
PAENRO	Provincial agriculture, environment and natural resources office
PAGASA	Philippine atmospheric, geophysical and astronomical services administration
PSA	Philippine statistics authority

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Compliance with ethical standards

Ethical considerations

This study involved agricultural household surveys, key informant interviews, and focus group discussions with adult farmers in Ifugao. Participation was voluntary, and informed consent was obtained before data collection. Participants were informed of the study purpose, their rights, and their right to withdraw at any time without consequence. No sensitive personal identifiers were collected, and all responses were anonymized to protect participants' privacy and confidentiality.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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