

Quantifying farmers' climate change adaptation strategies and the strategy determinants in Southwest China

Climate
change
adaptation
strategies

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Abstract

Purpose – This paper aims to document the adaptation strategies developed by local farmers to adjust to climate change and related hazards in Lijiang Prefecture in Southwest China, and quantify the determinants of the adaptation measures.

Design/methodology/approach – The study conducted a household survey with 433 respondents in Lijiang to document adaptation measures. The authors used a multivariate probit model to quantify five categories of adaptation measures against a set of household features, extension and information, resources, social network, financial assets and perception variables.

Findings – The most significant determinants consisted of information on early climate warnings and impending hazards, ownership to land and livestock, irrigation membership in community-based organisations, household savings, cash crop farming and perceptions of climate change and its related hazards. Adaptation strategies and policies highlighting these determinants could help to improve climate change adaptation in the region.

Originality/value – This study quantified the determinants of adaptive strategies and mapped important determinants for the region that will provide farmers with the appropriate resources and information to implement the best practices for adapting to climatic changes. The method and findings could be useful and easily replicable for future agriculture policies.

Keywords Adaptation, Sustainable livelihood, Income diversification, Adaptation barrier, Climate change perceptions, Lijiang

Paper type Case study

1. Introduction

Farmers are close observers of the land and the food system, making them an experts in land management and to apply the necessary techniques for adaptation

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(Sherren and Darnhofer, 2018). Appropriate adaptation measures are difficult to implement. Hypothetically, the accuracy of farmers' perceptions of climate change improves their selection of adaptation strategies. Studies in the Himalayas and adjoining regions (Hein *et al.*, 2019; Paudel *et al.*, 2020; Sujakhu *et al.*, 2016) revealed some degree of accuracy in the farmer's perception of climatic change. Recent studies (Paudel *et al.*, 2020; Sujakhu *et al.*, 2016) demonstrated the importance of valuing the knowledge of farmers in formulating adaptation strategies. Understanding farmers' perceptions of climate change and their ongoing adaptation practices is imperative because agriculture is a highly important sector very susceptible to climate change (Adger, 2003; Gentle and Maraseni, 2012). Policymakers – particularly in the agricultural sector – must be aware of successful adaptation practices implemented at the local level to increase the adaptation capacity of a region to maintain and improve livelihoods (Nhemachena and Hassan, 2007). Livelihood issues are intricately linked to local development, as development is largely affected by vulnerabilities affecting livelihoods. The livelihoods of the agriculture-dependent community are vulnerable because of agriculture's high susceptibility to the climatic changes. Within the farming community, the most vulnerable people are those who are heavily dependent on rain-fed agriculture as they are often limited by their rural locations due to their livelihoods and lack adaptive capacities, such as irrigation systems (IPCC, 2014; Mertz *et al.*, 2009). Nevertheless, indigenous farmers have been using different strategies to cope with climate change and its impacts; however, the adaptive strategies used by farmers are location-specific and largely determined by socio-economic factors (Piya *et al.*, 2013; Sujakhu *et al.*, 2018). For example, some farmers implement traditional strategies such as collecting wild edibles, shifting cropping time, replacing existing crops/varieties with new crops/varieties and crop rotation (Hein *et al.*, 2019; Paudel *et al.*, 2020). Economically capable farmers adopt new technologies and practices (Gentle and Maraseni, 2012; Nhemachena and Hassan, 2007). Other strategies include taking out loans, spending savings to afford and implement available agriculture technologies, and even diversify their income sources by switching to non-agricultural work such as tourism and other businesses present in their communities. In fact, tourism development has become a major driver of socio-economic development and poverty alleviation in China (Su, 2010).

Documenting ongoing adaptation practices in the agricultural sector is important, especially in the context of changing livelihood options that are susceptible to climate change, such as traditional farming practices. Unfortunately, merely documenting these adaptive measures is not a sufficient response; to that end, researchers must attempt to understand the factors used by farmers to determine the necessary measures to adopt to better formulate policy recommendations that are responsive to climate change for vulnerable communities (Piya *et al.*, 2013). Previous studies have reported that farmers' adaptation strategies are influenced not only by climate factors and geographical features but also by social, institutional, household economic, governance and community perception factors (Zheng *et al.*, 2013).

In the context of a rapidly changing community such as the Lijiang prefecture in Southwest China that shifted from an agro-economy to a tourism-based economy, it is important to document current adaptation practices in response to a changing climate. Agriculture and tourism are major income sources of the Lijiang people, and both sources depend on water availability (Su *et al.*, 2016). Effects of climate change, including a decline in snow, receding glaciers and an increase in the frequency of climate-related hazards like droughts and floods, have already been reported in Lijiang (Ning *et al.*, 2006; Zheng *et al.*, 2013). Yuan *et al.* (2006) reported that 43% of domestic tourists would not be interested in visiting Lijiang if the aesthetic beauty of Yulong Mountain and the region's water resources

are depleted. Meanwhile, the decline in farming practices and the shift toward tourism has led to the loss of indigenous farming skills and knowledge in subsequent generations (Bernard *et al.*, 2014; Su *et al.*, 2016). Such an impact could cause future generations to become more vulnerable due to the dependency on income from the single industry of tourism, which is also dependent on water, a resource made increasingly vulnerable by the changes in Lijiang's climate (Su *et al.*, 2016). The overexploitation of water resources in the city caused by tourism and the frequent occurrence of climate-induced drought may threaten the economic gains made over the past three decades. Moreover, the loss of indigenous farming skills and cultivable land will increase the fragility of agricultural livelihoods.

There is an absence of in-depth research on the factors that influence adoption measures of farming communities whose livelihood income is greatly influenced by tourism (Jianjun *et al.*, 2015). As such, the research described in this article examines the adaptation practices undertaken in Lijiang to adjust to climate change and quantifies the determinants of the adaptation measures at the household level. Household-level research on the quantification of adaptation in the face of climate change is limited, and it is urgent to document adaptation practices in such a community. This research contributes to the existing literature by using a quantitative approach to better understand farmers' adaptation practices at the junction of the Himalayas and Hengduan mountains and, importantly, how the nation can become better prepared to make adaptation choices.

2. Research methods

2.1 Study area

This study was conducted in Gucheng and Yulong Counties in Lijiang, one of the ecologically fragile mountain areas in Yunnan Province, Southwest China (Figure 1 and Table 1) from February to July 2013. Lijiang ranges from 99°23'E to 100°32'E, and from 26°34'N to 27°46'N. It lies in the transition zone extending from the low altitudes of Yunnan plateau to the high altitude of Qinghai-Tibet Plateau, crisscrossed by rivers and mountains. It is characterised by high mountains and deep gorges, resulting in the rugged topography (Peng *et al.*, 2008). The city of Lijiang is located in a sub-tropical zone and is influenced by the South Asian/Indian monsoon. The mean annual temperature is 12.6°C, and the mean annual rainfall is 967.8 mm, 94% of which falls from May to October and originates from the south-eastern summer monsoon's moisture-rich air masses. Winter is relatively dry and is controlled by the winter monsoon that originates on the continent (Baoying and Yuanqing, 2007). Meteorological data from 1980 to 2019 revealed a rise in temperature by 0.36°C/decade (Appendix, Figure S1). Rainfall during the same period showed an erratic pattern, while annual total rainfall is decreasing as compared to earlier decades (Appendix, Figure S2). Drought events are getting longer, and more frequent compared to earlier decades with severe drought conditions (Appendix, Figure S3).

Lijiang's "Old Town" (Dayan), a UN World Heritage site, is booming with tourism development. Lijiang Ancient Town (LAT) reflecting Naxi culture along with the running water from glaciers on Yulong Xueshan (the Jade Dragon Snow Mountain) and Heilongtan (the Black Dragon Pool) are the major tourist attraction (Ning *et al.*, 2006). Combined with the fast-growing tourism industry, which has increased Lijiang's water usage, the recent drought (induced by climate change) has created a water crisis in Lijiang that has significantly reduced the amount of water available for agricultural production in the study area. Climate change will likely result in glacial melt and subsequently in long-term water shortages that will alter the alluring landscape of the city and its surrounding villages (Baoying and Yuanqing, 2007).

Most of the farmlands in the study area are irrigated with the glacier meltwater. A substantial portion of the lowland villages' agricultural water supply has been transferred to

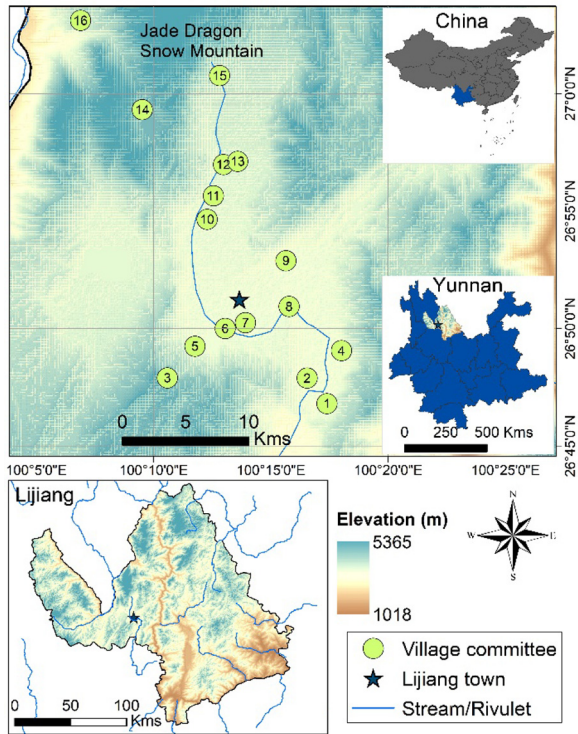


Figure 1. Map showing 16 village committee of two counties in Lijiang, where household survey was conducted

County	Township	Village	Population	No. of HH	Surveyed HHs	Annual net income/ person (US\$, 2011)
Yulong	Baisha	Yuhu	1465	383	26	918.36
	Baisha	Wenhai	873	260	28	270.11
	Baisha	Mudu	1651	410	26	374.36
	Baisha	Baisha	1672	411	29	384.98
	Huangshan	Nanxi	1514	373	23	1029.89
	Huangshan	Baihua	3249	662	26	1184.52
	Huangshan	Changshui	2123	540	27	435.96
Gucheng	Huangshan	Wenhua	2025	501	26	358.88
	Dayan	Wenzhi	3940	858	28	758.73
	Jinshan	Dongyuan	2492	633	28	376.93
	Jinshan	Liangmei	2352	579	28	289.98
	Jinshan	Guifeng	2077	514	28	262.06
	Jinshan	Yangxi	3920	912	28	327.01
	Suhe	Huangshan	3271	701	28	986.34
	Suhe	Longquan	2895	705	27	1669.20
	Xianghe	Xiangyun	2042	529	26	1060.24

Table 1. Socio-demographic characteristics of the study villages

Source: Lijiang statistics 2011

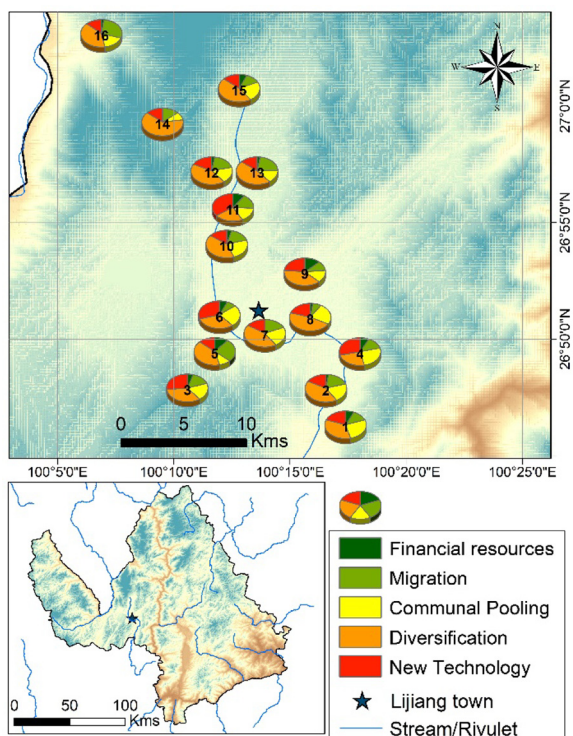


Figure 2. Different adaptation measures practised by the local community at different locations in the study area

LAT for tourism, reducing the villages' agriculture water supply and viable farming land. These impacts have shifted the affected households' dependency from agricultural production to off-farm activities and livestock sales as major income sources. These adaptations are possible in the region because of convenient access to the city centre.

In several villages, water resources are scarce and can hardly be used only sparingly to irrigate the farmlands. For example, the water resource in Nanxi village is very scarce and insufficient for domestic water use, especially during the dry season, resulting in the village's farmlands being completely rain-fed. Most the agricultural water supplies in the other villages have been similarly impacted by the water transferring policy in the name of tourism development.

2.2 Data collection and analysis

A household survey was conducted with 433 local household heads from 16 villages in two different Lijiang Prefecture counties (Table 1) from July to August 2013. The survey was conducted among farming households, and the snowball sampling method was applied to select the participants. A nearly equal number of households was included in the survey from each village. The survey featured a pretested, semi-structured questionnaire that explored the current adaptation practices used, and it examined the determinants of the adopted measures and the barriers that impede certain adaptation practices.

2.2.1 *Empirical model and variable selection.* Generally, the respondents had adopted more than one adaptation strategy to cope with climate change and its related hazards. Therefore, a multivariate probit (MVP) econometric technique was used to identify the role that determinants of adaptive capacity play in shaping smallholders' perceived self-efficacy and adaptation intent. This technique overcomes the limitations of univariate and the multinomial discrete choice techniques. Following the approach used by [Nhemachena and Hassan \(2007\)](#) and [Piya et al. \(2013\)](#), the MVP econometric approach used in this study is characterised by a set of n binary dependent variables y_i (with observation subscripts suppressed), such that:

$$y_i = 1 \text{ if } x' \beta_i + \varepsilon_i > 0, \\ = 0 \text{ if } x' \beta_i + \varepsilon_i \leq 0, i = 1, 2, \dots, n, \tag{1}$$

where x is a vector of explanatory variables; $\beta_1, \beta_2, \dots, \beta_n$ are conformable parameter vectors, and random error terms $\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n$ are distributed as multivariate normal distributions with zero means, unitary variance and $n \times n$ contemporaneous correlation matrix $R = [\rho_{ij}]$, with density $\phi(\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n; R)$. The likelihood contribution for observation is the n -variate standard normal probability:

$$Pr(y_1, \dots, y_n | x) = \int_{-\infty}^{(2y_1-1)x' \beta_1} \int_{-\infty}^{(2y_2-1)x' \beta_2} \dots \\ \times \int_{-\infty}^{(2y_n-1)x' \beta_n} \phi(\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n; Z' R Z) d\varepsilon_n \dots d\varepsilon_2 d\varepsilon_1, \tag{2}$$

where Z is $\text{diag}[2y_1 - 1, \dots, 2y_n - 1]$ that acquires a diagonal element of the data matrix. The maximum likelihood estimation maximises the sample likelihood function, which is a product of probabilities [explained by the relation in [equation \(2\)](#)] across sample observations. Multidimensional integration is necessary for the calculation of the maximum likelihood function using multivariate normal distributions, and a number of simulation methods have been developed to approximate such a function, with the Geweke–Hajivassiliou–Keane (GHK) simulator being used widely ([Belderbos et al., 2004](#)). This study uses the simulated maximum likelihood (SML) using the GHK simulator in STATA, developed by [Cappellari and Jenkins \(2003\)](#), to estimate the MVP model. The number of draws (R) in this study was set to 100 (default $R = 5$) to ensure consistent estimates. To perform the diagnostic tests, individual ordinary least squares (OLS) estimates were conducted for each individual choice variable against the same set of explanatory variables. The variation inflation factor (VIF) test was calculated to determine if there were any multicollinearity problems. The VIF values for all independent variables were lower than 10 (with ranges from 1.06 to 1.21), suggesting that there were no multicollinearity problems. The marginal effects of the explanatory variables regarding the propensity to adopt each of the different adaptation measures were calculated as:

$$\partial P_i / \partial x_i = \phi(x' \beta) \beta_i, i = 1, 2, \dots, n \tag{3}$$

where P_i is the probability (or likelihood) of the event i (or increased use of each adaptation measure), $\phi(\cdot)$ is the standard univariate normal cumulative density distribution function, and x and β are vectors of regressors and model parameters, respectively (Hassan, 1996). Given that a presence of heteroskedasticity in the data – where the variance differs across the values of explanatory variables, violating the hypothesis – would make the OLS estimator unreliable with regard to bias, the Breusch–Pagan test and White test were performed to detect the possibilities of heteroskedasticity in the model.

The probability value of the chi-square statistic is less than 0.005 for the Breusch–Pagan test in four out of the total five choices, while the probability value of the chi-square statistic is greater than 0.005 for the White's test for all the choices. These results indicate a presence of heteroskedasticity in the model. This may be due to measurement error, model misspecification or subpopulation differences. Accordingly, following the approach by Nhemachena and Hassan (2007) and Piya *et al.* (2013), this study conducted model estimation using robust standard errors to correct heteroscedasticity of any kind. The use of robust standard errors gives relatively accurate p values though it does not change the significance of the model and coefficients.

2.2.2 Model variables.

2.2.2.1 Dependent variables. Following the methods used by Agrawal (2010) and Gentle *et al.* (2018), the interview responses were categorised into five types of adaptation practices. The categories included diversification of income sources and agriculture practices; migration; adoption of new technologies; communal pooling; and access to financial resources. These five dummy variables served as the dependent variables in the model. These variables were mapped to show which and to what extent the activities were practised in the studied villages. Detailed explanations of these adaptation practices are summarised in Table 2.

2.2.2.2 Explanatory variables. Nineteen explanatory variables were selected based on an empirical literature review, location-specification and data availability. Table 3 presents brief descriptions of these variables and their hypothesised effects on farmers' adaptation practices.

3. Results

3.1 Adaptation practices

The farmers have adopted a range of strategies to adapt to the recent changes, including livelihood diversification, adoption of new technology, spatial adaptation (migration), communal pooling and access to financial resources (Table 2). However, many of these adaptation practices were implemented differently by different farmers; hence, the variations across studied villages (Figure 2). It was evident that the studied villages used different practices; however, livelihood diversification was the most adopted one. In terms of use, adoption of new technology, migration, and communal pooling followed diversification practice, in that order. Access to financial resources was not adopted in all villages, and, when it was, it was comparatively speaking always the least used practice among the surveyed population (Figure 2). Most practices were autonomous (rather than planned) and short term in nature. Adaptation practices reported here use available skills and resources with the aim of maintaining the basic functioning of an existing livelihood system. Findings suggested that livelihood in mountainous region determined by availability of natural resources such as water, forest and land. Climate is an important driver of change in these resources, but other drivers of change include demographic shifts such as population growth, rural-urban migration and requirements for better and healthy life. Therefore, any adaptation strategies to cope with climate change must also prove adaptive within a larger

Table 2.
Adaptation practices
adopted by farmers

Classes of adaptation practices	Corresponding adaptation practices	Percentage of households adopting the practices
1. Diversification of income sources and agriculture practices	1.1. Livelihood and income diversification	200 (46.1%)
	1.2. Agriculture diversification	167 (38.56%)
	1.3. Changed farming and grazing practices	46 (10.62%)
2. Adoption of new technologies	2.1 Used alternate and new crop varieties and a new type of livestock	144 (33.25%)
	2.2. Used drought resilient crops	6 (1.38%)
3. Migration	3.1. Migration for work	97 (22.40%)
4. Communal pooling	4.1. Household and community invested in irrigation infrastructure, rainwater harvesting and disaster preparedness	101 (23.32%)
	4.2. Received compensation and relied on relief assistance	13 (3.00%)
5. Access to financial resources	5.1. Borrow money from bank and money lender	37 (8.54%)

context of ongoing economic, political, technological and environmental dynamics, many of which are not driven by climate.

3.1.1 Diversification of income sources and agriculture practices. The interviewees who reported that they diversified their income sources and agricultural practices ($n = 243$, 56.12% of total interviewees) did so in the following manner: by transitioning from subsistence agriculture towards other employment opportunities, diversifying their agricultural practices and leaving the farmland barren. Agricultural diversification includes cultivating cash crops, using multiple cropping systems, using an intercropping system and developing a crop-livestock integrated system. In the study area, the cash crops include summer and winter potatoes, maize, summer vegetables, soybeans, barley, legumes and walnuts. These crops are grown mainly to meet the demands of the tourism market. Similarly, livestock is a major financial asset for farmers. As reported by a respondent from Yuhu village:

[. . .]our main occupation was farming but it is not profitable due to many uncertainties. It is not possible to survive only through agriculture. We left our land barren and are now shifting to the tourism business for survival.

Likewise, 77 interviewees who were diversifying their income sources were involved in tourism businesses. Currently, they rely heavily on income earned by providing tourism services to sustain their livelihoods. In fact, they revealed that tourism services comprised 18.5 to 76% (47% on average) of their total income. The total number of households relying heavily on agriculture for their income decreased from 90 to 100% in 2008 (Su *et al.*, 2016) to 23.4% in 2013. The survey respondents reported that they used the tourism industry to diversify their income both directly (e.g. offering horse rides) and indirectly (e.g. selling products in local markets due to the increase in demand). Similarly, 46 respondents (10.62%) reported that they changed their farming practices (e.g. sowed/harvested either earlier or later in the season) based on changes in the timing of rainfall. Eighty-four respondents (19.39%) reported leaving their land barren.

Explanatory variables	Indicators	Unit	Mean	SD	Impact
<i>Climate and hazards</i>					
Rainfall	Perceived decreasing rainfall	Dummy; 1 = yes, 0 = otherwise	0.96	0.17	+
Temperature	Perceived increasing temperature	Dummy; 1 = yes, 0 = otherwise	0.98	0.12	+
Snowfall	Perceived decreasing snowfall	Dummy; 1 = yes, 0 = otherwise	0.47	0.49	+
Climate hazards	Does household face the climate related hazard like drought, flood, landslides, crop pest, strong winds, thunderstorms, etc.	Dummy; 1 = yes, 0 = otherwise	0.65	0.47	+
<i>Household features</i>					
Gender	Is the sex of household head male	Dummy; 1 = yes, 0 = otherwise	0.879	0.325	±
Age	Age of household head age	Number	49.392	11.588	±
Education	Highest education status of household	Number of schooling years	7.789	2.978	+
EAM	Number of economically active members in the household	Numbers	3.173	1.215	+
<i>Extension and information</i>					
Technologies	Number of technological items used ^a	Number	5.422	1.382	+
Warning system	Is there any system of communication to inform the communities of climate change or warn of coming disaster	Dummy; 1 = yes, 0 = otherwise	0.24	0.43	+
<i>Household resources</i>					
Land	Total land holding size by household	Local unit Mu	0.936	0.653	+
Tenure	Land tenure	Local unit Mu	0.189	0.330	-
Irrigated land	Irrigated land holding size	Local unit Mu	0.278	0.267	+
<i>Social networking</i>					
Membership in CBO	Whether household has membership in any community based and social organisation or not	Dummy; 1 = yes, 0 = otherwise	0.226	0.418	+

(continued)

Table 3.
Explanatory variables selected for the model

Table 3.

Explanatory variables	Indicators	Unit	Mean	SD	Impact
Assistance	Does household receive assistance from relatives, friends, community, insurance company, financial institution, local government, local NGO, international organisation, community organisation, women's group/co-operatives, foreign government and others) during and after hazard period	Dummy; 1 = yes, 0 = otherwise	0.822	0.38	+
Influence	Is it easy for your household to influence the decision-making process at the local level	Dummy; 1 = yes, 0 = otherwise	0.24	0.42	+
<i>Financial assets</i>					
LSU	Ownership of LSU ^b	Number	0.64	2.66	+
Saving	A total annual saving of household	RMB	3291.27	3267.48	+
Cash crop	Does household grow cash crop or not	Dummy; 1 = yes, 0 = otherwise	0.47	0.50	+

Notes: ^a = Calculated as sum of households' scores (No = 0, yes = 1) based on the ten variables: television, radios, mobile phone, telephone, motor vehicle, non-motorised vehicles (carts, bicycles, etc.), renovator, Shelter, electricity and solar used for cooking, electricity and solar used for warming. Index ranges between 0 and 10 ^b = Livestock unit is an aggregate of different types of livestock kept in the household in standard unit calculated using the following equivalents: bullock/cow/horse = 0.65, buffalo = 0.70, yak = 0.4, goat/sheep = 0.10, sheep = 0.10 and poultry = 0.01 LSU (Chilonda and Otte, 2006) Positive or negative signs in the impact column means it is hypothesised that the explanatory variable has positive or negative influence to adopt adaptation strategies

3.1.2 Adoption of new technologies. The survey results showed that 127 respondents (29.33%) adopted new technologies to cope with climate change. They reported using new crops that were, for example, hybrid and drought-resistant. The respondents explained that the use of a new variety of potato marked a shift towards an intensive cultivation of potatoes and was facilitated by easy market access and high-yielding hybrid crops. In addition, the paved road, which had already increased market accessibility from rural areas to the village and led to enhanced agricultural production, now offered a new economic opportunity in the form of tourism. Overall, favourable market conditions – driven by high product demand in Yunnan province – contributed to the success of Lijiang's economy.

3.1.3 Migration. The survey results showed that 96 respondents (22.17%) used migration as an adaptation strategy. Respondents indicated that young people are attracted to nearby towns or large cities because of the comfort, conveniences and facilities they provide. Declining agricultural production due to drought was reported by respondents as one of the major drivers of migration.

3.1.4 Communal pooling. The survey results indicated that 108 respondents (24.94%) reported adopting a communal pooling option to adjust to climate change. This option consisted of receiving emergency and hazard-based support and compensation as well as engaging in collective action and investment to develop an irrigation infrastructure and a rainwater harvesting system to negate the water scarcity caused by water diversion and to create a community-level disaster preparedness programme. The local government and other local institutions provided support during the emergency periods. Twenty-nine respondents (6.69%) reported that they acted collectively to develop a disaster preparation programme. Also, 101 respondents (23.32%) noted that they engaged in collective action by contributing to the development of a community irrigation infrastructure to protect and manage the water resources available for irrigation. Finally, 35 respondents (8.08%) stated that they had contributed financially to collective actions in relation to rainwater harvesting and disaster preparedness. Rainwater harvesting is an indigenous technique that has been modified to increase the agricultural water supply. This technique includes the collection, conveyance, storage, delivery and utilisation of rainwater runoff for use in cropping systems. The present study's survey results, however, indicate that only 15 farmers (3.46%) in the study area actually harvested rainwater.

3.1.5 Access to financial resources. In response to the survey, 38 interviewees (8.77%) reported that they received a loan from at least one bank or social group during an emergency/hazard period. Also, 26 respondents (6.01%) took out a consumption loan as a major coping strategy to handle their finances during times of crop failure or other emergencies.

3.1.6 Barriers to adaptation. We received multiple responses to questions related to adaptation. The survey results indicate that 114 respondents (26.33% of total respondents) indicated lack of information regarding climate change, financial resources to cope with climate change or the impacts of climate change, and options for adapting to mitigate losses. Ninety responses (20.78%) revealed they did nothing in response to climate change because the changes were too erratic. They were aware of climatic change but did not expect a disaster to happen, and did not expect that any potential loss would be serious if a disaster did occur.

3.2 Determinants of adaptation strategies

The results of the analysis show that the direction of influence for the most of the explanatory variables was as expected with a few exceptions (Table 4). The likelihood ratio

statistics (Wald χ^2) were highly significant ($p < 0.0000$), which indicates that variables add something to the model. The likelihood ratio test for the null hypothesis of the absence of correlation between the individual equations was strongly rejected ($p < 0.0000$), thus validating the use of the MVP model to simultaneously estimate all equations (unlike estimating the equations individually).

As shown in [Table 4](#), the diversification of income sources and agriculture practices are significantly more likely to be adopted by households who correctly perceive that climate change is real (i.e. they experienced the decrease in rainfall/snowfall and the increase in average temperatures) and by households with more money in savings. Contrary to our hypothesis, these measures are less likely to be adopted by households with membership in community-based and social organisations (CBOs) and more economically active family members.

New technologies are significantly more likely to be adopted by households:

- with an experienced head;
- with access to extension (ownership of a higher number of technologies) and information (receive information about climate change and early warnings about impending hazards);
- with membership in CBOs; and
- that grow cash crops and own more livestock units (LSUs).

However, the results indicated that households with an influence on the local-level decision-making process were less likely to adopt new technologies.

Respondents revealed the importance of CBO membership for receiving updates on farming progress and new technologies, such as drought-resilient crops and livestock. Similarly, households with CBO memberships received relevant training and information on climate change and how it could impact their livelihoods. According to the model results, households that were aware of extension services and households that viewed the broadcasted agricultural-related programmes (either on television or on the radio) were more likely to diversify their crops and livestock. Access to technology and information on new developments enabled farmers were able to switch to new crops, diversify their crop options, use irrigation systems more and implement water conservation techniques.

The results indicated that households with more irrigated and tenured land were likely to migrate. In the study area, most of the households with farmland that had been impacted by the water transfer policy and faced drought events abandoned their farms and migrated to the city. The results also demonstrate that households were significantly more likely to adopt a communal pooling strategy if they had more irrigated land, had received assistance during an emergency period, perceived that climate-related hazards were occurring, realised a decrease in snowfall and had more money in savings.

The climate-induced drought and the diversion of an enormous amount of water to LAT negatively affected the study area's farming system and the villagers' livelihoods. Consequently, households were more likely to invest in irrigation system development and to prepare at the community level when they had more irrigated land, perceived a decrease in snowfall, or were impacted by the drought. In addition, households that received assistance from relatives, friends, the community, insurance companies, financial institutions, the local government and/or local NGOs during and/or after the hazard period were more likely to report a contribution to disaster preparedness programmes.

Explanatory variables	Diversification of income sources and agriculture practices		Adoption of new technologies		Migration		Communal pooling		Access to financial resources	
	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
<i>Climate and hazards</i>										
Rainfall	1.026	0.026**	4.869	0.976	0.039	0.934	-0.333	0.492	3.894	0.987
Temperature	1.065	0.092*	4.512	0.982	4.445	0.985	4.598	0.986	4.122	0.990
Snowfall	0.362	0.006***	0.002	0.991	0.280	0.056*	0.466	0.002***	0.042	0.831
Climate hazards	0.172	0.215	0.035	0.822	-0.010	0.946	0.448	0.006***	0.509	0.037**
<i>Household features</i>										
Gender	-0.030	0.887	0.393	0.111	0.094	0.688	-0.060	0.802	0.542	0.256
Age	-0.007	0.212	0.011	0.092*	0.000	0.997	-0.012	0.065*	-0.009	0.336
Education	-0.025	0.266	-0.012	0.633	-0.008	0.759	0.020	0.437	0.023	0.502
EAM	-0.125	0.022**	-0.085	0.159	0.087	0.154	-0.038	0.536	0.151	0.073*
<i>Extension and information</i>										
Technologies	0.047	0.337	0.097	0.071*	-0.072	0.193	0.090	0.094*	-0.065	0.371
Warning system	0.148	0.338	0.732	0.000***	0.220	0.192	-0.576	0.003***	0.122	0.606
<i>Household resources</i>										
Land	-0.081	0.519	-0.220	0.161	-0.402	0.021**	-0.184	0.260	0.197	0.278
Tenured land	-0.154	0.520	0.512	0.068*	0.510	0.077*	0.217	0.434	-0.149	0.683
Irrigated land	0.049	0.854	0.005	0.987	0.611	0.057	0.850	0.005	-0.852	0.043**
<i>Social networking</i>										
Membership	-0.261	0.096*	0.585	0.000***	0.193	0.260	-0.144	0.413	0.631	0.003***
Assistance	0.089	0.596	0.232	0.223	-0.178	0.326	0.457	0.026**	0.430	0.148
Influence	-0.116	0.440	-0.386	0.024**	-0.332	0.064*	0.221	0.189	-0.453	0.064*
<i>Financial assets</i>										
HH savings	0.000	0.057*	0.000	0.613	0.000	0.716	0.000	0.107	0.000	0.500
Cash crop	0.074	0.570	0.410	0.005***	-0.178	0.226	0.167	0.256	-0.236	0.244
Livestock unit	-0.007	0.784	0.056	0.013**	-0.056	0.370	-0.061	0.295	0.030	0.278
_cons	-10.47	0.98	-1.55	0.06*	-11.53	0.97	-5.73	0.98	-5.00	0.98

(continued)

Table 4.
Parameter estimates
of the multivariate
probit model
explanatory

Table 4.

Explanatory variables	Diversification of income sources and agriculture practices		Adoption of new technologies		Migration		Communal pooling		Access to financial resources	
	Coeff.	P value	Coeff.	P value	Coeff.	P value	Coeff.	P value	Coeff.	P value
Coefficient correlation										
rho21	-0.439	0.000***								
rho31	0.178	0.173								
rho41	0.048	0.718								
rho51	-0.203	0.172								
rho32	0.251	0.004***								
rho42	0.023	0.801								
rho52	0.294	0.001***								
rho43	0.240	0.010**								
rho53	-0.049	0.618								
rho54	-0.079	0.434								
Draws	100									
Number of observations	433									
Wald χ^2 (100)	198.88									
P value	0.0000***									
Log pseudo likelihood	-1006.60									

Notes: Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0; $\chi^2(10) = 42.5857$ Prob > $\chi^2 = 0.0000$ ***; ***, **, * Significant at 10; 5 and 1% respectively

Households that experienced climate-related hazards, were members of CBOs, and included economically active family members, were more likely to adopt the access to financial resources adaptation strategy. However, the access to financial resources practice was less likely to be adopted by households that owned irrigated land and by households that had access to the local decision-making processes.

4. Discussion

This study's results demonstrate that farmers are well aware of climate change, as the majority of the farmers interviewed perceived climate change in the study area. Several studies in Africa (Mustapha *et al.*, 2012; Muzamhindo *et al.*, 2015) and Asia (Sujakhu *et al.*, 2018) have yielded similar results. The predominant changes perceived by farmers include, a decrease in rainfall and snowfall, long dry periods, a higher frequency of severe droughts, increasing temperatures and associated warmer and drier conditions. Such changes were verified by the long-term meteorological data analysis for annual temperature, and drought condition (Appendix). The annual rainfall data did not show a fixed pattern, indicating that it was the erratic in nature. However, data revealed a recent decrease in total summer precipitation, especially after 2003.

Farmers are close observers of the land and the food system that makes them an experts in land management (Sherren and Darnhofer, 2018). Historically, farmers' perspectives have been relegated to "informal" knowledge (Sherren and Darnhofer, 2018; Šumane *et al.*, 2018). Farmers are tested with economic and climatic problems in every agricultural decision they make (Darnhofer, 2014). This exposure does not suggest that all farmers are necessarily viably adapting to climatic, social or economic changes and shocks. Although this is variable, highlighting the farmers and their adaptation measures is important as they are the best interpreters of their needs and capacities within a given farm system. Any intervention to aid adaptation will benefitted directly from understanding farmers viewpoint and specific forms of knowledge. In that context, the present study documents the adaptation strategies of farmers in response to climate and economic changes. Farmers use such strategies to maintain food supplies and secure their livelihoods. The present research indicates that these strategies are influenced by several socio-economic factors, including specific household features, access to extension services and natural and financial resources, membership in CBOs and awareness of climate change and related hazards.

The major adaptation strategies reported in this study include diversifying income sources and agricultural practices, adopting new technologies, engaging in communal pooling, migrating and access to financial resources. It appears that households that grow cash crops and own livestock have strong financial assets that can be used to improve their resource base and to ultimately invest in adopting new crop/livestock varieties and new related technologies (Hassan and Nhemachena, 2008). Selecting appropriate crops suitable for changing agro-ecological conditions for agricultural diversification, climatic resistant varieties and other climate resilient technologies and strong financial assets can serve to a climate-smart agriculture. Therefore, selection of appropriate local adaptation practices is important to develop adaptation strategies. This requires evaluating farmers' knowledge and combining it with scientific knowledge to develop sustainable and resilient agriculture (Šumane *et al.*, 2018).

Many adaptation practices, including migration, leaving farmlands barren, receiving compensation and relying on relief assistance were short term and reactive and, consequently, made the farmers more vulnerable. Though these practices might temporarily reduce the current vulnerability to climate change, the accumulated responses may lead to undesirable and adverse outcomes for communities. Similar to

our findings, [Zheng et al. \(2013\)](#) also reported seasonal migration as an adaptation strategy to lack of water due to extreme climate in Xihu village of Lijiang. Migration seems to be highly correlated with climate variability in some regions, such as the Sahel in Africa, and is thus interpreted as an adaptation strategy ([Cissé et al., 2010](#)). This migration trend might impact future agricultural productivity in farming communities due to loss of labour, indigenous farming skills and crop varieties, knowledge and food supplies ([Fazey et al., 2009](#)).

The model's results indicate that households with more irrigated and tenured land are using the migration strategy. A major reason farmers abandoned their land was due to water shortage, which occurred because of the frequency of severe drought events and because water was diverted away from the Sanshu River, a major agricultural water source in Baisha Township. The farmland irrigated from the Sanshu River has been severely impacted by this water transfer, as the farmers who had already adapted to irrigation could not return to rain-fed farming. This water transfer also affected other villages in our study area (namely, Baisha, Xinshan, Mudu, Yuhu and Wenhua). Therefore, some households abandoned their farms and migrated elsewhere despite owning more irrigated and tenured land.

Although tourism has brought wealth and economic opportunities in Lijiang, these developments raise concerns regarding the sustainability of such growth. Numerous farmers in the area left their farming land barren because of severe droughts and water scarcity. Nevertheless, certain adaptation measures like diversifying/altering agricultural practices and using improved drought-resilient crops are helping the region's agriculture. In this instance, the indigenous people's traditional knowledge and experiences are significant. As indicated by survey, the elderly and more experienced farmers are more likely to adopt new technologies in comparison to inexperienced farmers because an experienced household head is more likely to have better information on climate change and to have learned how to cope with the corresponding changes ([Nhemachena and Hassan, 2007](#)).

Our findings also indicated that increasing farmers' awareness of climate-related issues and training them on new technologies could also improve their adaptive capacities. [Piya et al. \(2013\)](#) similarly reported that such training enhances awareness concerning climate change and influences a person's likelihood of adopting adaptation strategies. Farmers with better technologies usually have access to markets through which proper and timely information can be obtained. Farmers require different types of climate information during each stage of the farming process to properly adapt to climate change and its related hazards. Through the use of various media outlets and technological devices, CBOs provide an early warning system and climate-related information on weather forecasting, crop pest attacks, input management, cultivation practices and pest and disease management. [Maddison \(2007\)](#) and [Nhemachena and Hassan \(2007\)](#) similarly discussed the importance of farmers being aware of climate change before they can making decisions on using adaptation strategies.

With more financial resources, farmers are better able to use the available information to alter their management practices in response to the changing climate and other conditions. For instance, with access to financial resources, farmers can purchase new crop varieties and irrigation technologies that are necessary for adjusting to climate changes. Also, a household with greater savings reflects that the household has a higher income and is more capable of adapting ([Sujakhu et al., 2018](#)), whereas a lack of savings increases a household's vulnerability. Households with more savings

are more likely to make productive investments, such as diversifying their livelihood and income sources, using their savings during emergencies.

Households with greater access to these factors are significantly more likely to use the various adaptation measures. Designing policies that aim to improve these factors for farming systems can potentially improve farmers' abilities to adapt to climate changes. For example, improving climatic and agronomic information could significantly increase farm-level adaptation. Any future developments in adaptation plans, strategies and support mechanisms should incorporate the existing adaptation practices as well as the farming households' needs. Future responses might be ineffective if they do not consider individual situations. Government policies need to support research and development that advances and distributes the appropriate technologies to help farmers and agricultural systems adapt to climate changes.

Based on our findings, we make the following recommendations to strengthen the policy intervention for farming communities:

- Provide easier access to loans to increase the market's demand for cash crops and to enable farmers to raise the necessary livestock. In addition, CBOs should provide farmers with appropriate vocational training on climate change (and its related hazards) and on impact reduction measures to strengthen farmers' adaptive capacities.
- Concerned governments should provide a better forecast on climate and impending hazards to help the farmers to adjust their cropping patterns.
- Farmers should be encouraged to invest in new technologies, such as using drought-resistant crops and water-efficient irrigation facilities.

Future research is needed to provide a more detailed analysis of the barriers to adaptation practices so that local policy measures can address those identified barriers and, subsequently, enhance farmers' adaptive capacities.

5. Conclusion

The study identified major location-specific determinants of farmers' adaptation practices. The number of technologies used by households, access to information on climate change and impending hazards, ownership of more land, ownership of irrigated land, CBO membership, receiving assistance, maintaining household savings, growing cash crops, ownership of more LSUs and perceiving/observing climate change and its related hazards are important determinants of adaptation measures. Thus, using various technologies (e.g. radio and television) and CBOs to distribute information on climate change and its related hazards to the impacted community members can be an effective way to promote adaptation strategies. Our findings also indicated that top-down policies are not suitable at the local level; for example, the water diversion policy (developed to sustain the tourism industry) caused many villagers to abandon their farms. It is important to maintain adequate farming activity levels given the importance of food security. Moreover, in the context of an increasing population, the relationship between tourism development and farming should be mutually beneficial (Liu *et al.*, 2008). In summary, farmers' adaptation strategies were driven by immediate tangible benefits. Generation of support from the governing body is fundamental to implementing policies at the local level. However, such policies must include combined knowledge integrating farmer's knowledge and support with that of science to make better adaptation choices and additional knowledge systems to strengthen the adaptation capacity of communities as they are at the frontline of climate change.

References

- Adger, W.N. (2003), "Social Capital, collective action, and adaptation to climate change", *Economic Geography*, Vol. 79 No. 4, pp. 387-404.
- Agrawal, A. (2010), "Local institutions and adaptation to climate change", in Mearns, R. and Norton, A. (Eds), *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*, World Bank, Washington, DC, pp. 173-197.
- Baoying, N. and Yuanqing, H. (2007), "Tourism development and water pollution: case study in Lijiang ancient town", *China Population Resources and Environment*, Vol. 17 No. 5, pp. 123-127.
- Belderbos, R., Carree, M., Diederens, B., Lokshin, B. and Veugelers, R. (2004), "Heterogeneity in R&D cooperation strategies", *International Journal of Industrial Organization*, Vol. 22 No. 8/9, pp. 1237-1263.
- Bernard, F., Noordwijk, M., van Luedeling, E., Villamor, G.B., Sileshi, G.W. and Namirembe, S. (2014), "Social actors and unsustainability of agriculture", *Current Opinion in Environmental Sustainability*, Vol. 6, pp. 155-161.
- Cappellari, L. and Jenkins, S.P. (2003), "Multivariate probit regression using simulated maximum likelihood", *The Stata Journal: Promoting Communications on Statistics and Stata*, Vol. 3 No. 3, pp. 278-294.
- Chilonda, P. and Otte, J. (2006), "Indicators to monitor trends in livestock production at national, regional and international levels", *Livestock Research for Rural Development*, Vol. 18 No. 8, pp. 1-12.
- Cissé, P., Malicki, Z., Barbier, B. and Maïga, A. (2010), "Les migrations, une stratégie d'adaptation à la variabilité climatique en zone sahélienne", *Revue de Géographie Du Laboratoire Leid*, Vol. 8 No. 2005, pp. 184-196.
- Darnhofer, I. (2014), "Resilience and why it matters for farm management", *European Review of Agricultural Economics*, Vol. 41 No. 3, pp. 461-484.
- Fazey, I., Gamarra, J.G., Fischer, J., Reed, M.S., Stringer, L.C. and Christie, M. (2009), "Adaptation strategies for reducing vulnerability to future environmental change", *Frontiers in Ecology and the Environment*, Vol. 8 No. 8, pp. 414-422.
- Gentle, P. and Maraseni, T.N. (2012), "Climate change, poverty and livelihoods: adaptation practices by rural Mountain communities in Nepal", *Environmental Science and Policy*, Vol. 21, pp. 24-34.
- Gentle, P., Thwaites, R., Race, D., Alexander, K. and Maraseni, T. (2018), "Household and community responses to impacts of climate change in the rural hills of Nepal", *Climatic Change*, Vol. 147 Nos 1/2, pp. 267-282.
- Hassan, R.M. (1996), "Planting strategies of maize farmers in Kenya: a simultaneous equations analysis in the presence of discrete dependent variables", *Agricultural Economics*, Vol. 15 No. 2, pp. 137-149.
- Hassan, R. and Nhemachena, C. (2008), "Determinants of African farmers' strategies for adapting to climate change: multinomial choice analysis", *AFJARE*, Vol. 2 No. 1, pp. 83-104.
- Hein, Y., Vijitsrikamol, K., Attavanich, W. and Janekarnkij, P. (2019), "Do farmers perceive the trends of local climate variability accurately? An analysis of farmers' perceptions and meteorological data in Myanmar", *Climate*, Vol. 7 No. 5, pp. 1-18.
- IPCC (2014), Climate Change 2014 Synthesis Report. contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by RK, P., MR, A., VR, B., J, B., W, C., R, C., JA, C., *et al.*, IPCC, Geneva.
- Jianjun, J., Yiwei, G., Xiaomin, W. and Nam, P.K. (2015), "Farmers' risk preferences and their climate change adaptation strategies in the Yongqiao district, China", *Land Use Policy*, Vol. 47, pp. 365-372.
- Liu, G., Liu, Z., Hu, H. and Dai, L. (2008), "The impact of tourism on agriculture in Lugu lake reion", *International Journal of Sustainable Development and World Ecology*, Vol. 15 No. 1, pp. 3-9.

- Maddison, D. (2007), "The perception of and adaptation to climate change in Africa", Policy Research Working Paper 4308, Washington, DC, [10.1596/1813-9450-4308](https://doi.org/10.1596/1813-9450-4308).
- Mertz, O., Halsnaes, K., Olesen, J.E. and Rasmussen, K. (2009), "Adaptation to climate change in developing countries", *Environmental Management*, Vol. 43 No. 5, pp. 743-752.
- Mustapha, S.B., Sanda, A.H. and Shehu, H. (2012), "Farmers' perception of climate change in central agricultural zone of Borno state, Nigeria", *Journal of Environment and Earth Science*, Vol. 2 No. 11, pp. 21-27.
- Muzamhindo, N., Mtabheni, S., Jiri, O., Mwakiwa, E. and Hanyani-Mlambo, B. (2015), "Factors influencing smallholder farmers' adaptation to climate change and variability in Chiredzi district of Zimbabwe", *Journal of Economics and Sustainable Development*, Vol. 6 No. 9, pp. 1-9.
- Nhemachena, C. and Hassan, R. (2007), "Micro-Level analysis of farmers' adaptation to climate change in Southern Africa", IFPRI Discussion Paper No. 00714, International Food Policy Research Institute (IFPRI), Washington, DC DC.
- Ning, B., He, Y., He, X., Pang, H., Yuan, L., Zhao, J. and Lu, A. (2006), "Potential impacts of glacier retreating of the Mt.Yulong on the socioeconomic development in Lijiang city", *Journal of Glaciology and Geocryology*, Vol. 28 No. 6, pp. 885-892.
- Paudel, B., Zhang, Y., Yan, J., Rai, R., Li, L., Wu, X., Chapagain, P.S. and Khanal, N.R. (2020), "Farmers' understanding of climate change in Nepal Himalayas: important determinants and implications for developing adaptation strategies", *Climatic Change*, Vol. 158 Nos 3/4, pp. 485-502.
- Peng, J., Wu, J., Yin, H., Li, Z., Chang, Q. and Mu, T. (2008), "Rural land use change during 1986–2002 in Lijiang, China, based on remote sensing and GIS data", *Sensors*, Vol. 8 No. 12, pp. 8201-8223.
- Piya, L., Maharjan, K.L. and Joshi, N.P. (2013), "Determinants of adaptation practices to climate change by Chepang households in the rural Mid-Hills of Nepal", *Regional Environmental Change*, Vol. 13 No. 2, pp. 437-447.
- Sherren, K. and Darnhofer, I. (2018), "Precondition for integration: in support of stand-alone social science in rangeland and silvopastoral research", *Rangeland Ecology and Management*, Vol. 71 No. 5, pp. 545-548.
- Su, B. (2010), "Rural tourism in China", *Tourism Management*, Vol. 32 No. 6, pp. 1438-1441.
- Su, Y., Hammond, J., Villamor, G.B., Grumbine, R.E., Xu, J., Hyde, K., Pagella, T., Sujakhu, N.M. and Ma, X. (2016), "Tourism leads to wealth but increased vulnerability: a double-edged sword in Lijiang", *Water International*, Vol. 41 No. 5, doi: [10.1080/02508060.2016.1179523](https://doi.org/10.1080/02508060.2016.1179523).
- Sujakhu, N.M., Ranjitkar, S., Niraula, R.R., Pokharel, B.K., Schmidt-Vogt, D. and Xu, J. (2016), "Farmers' perceptions of and adaptations to changing climate in the Melamchi valley of Nepal", *Mountain Research and Development*, Vol. 36 No. 1, pp. 15-30.
- Sujakhu, N.M., Ranjitkar, S., Niraula, R.R., Salim, M.A., Nizami, A., Schmidt-Vogt, D. and Xu, J. (2018), "Determinants of livelihood vulnerability in farming communities in two sites in the Asian highlands", *Water International*, Vol. 43 No. 2, doi: [10.1080/02508060.2017.1416445](https://doi.org/10.1080/02508060.2017.1416445).
- Šumane, S., Kunda, I., Knickel, K., Strauss, A., Tisenkopfs, T., Rios, I., Des, I., Rivera, M., Chebach, T. and Ashkenazy, A. (2018), "Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture", *Journal of Rural Studies*, Vol. 59, pp. 232-241.
- Yuan, L., Lu, A., Ning, B. and He, Y. (2006), "Impacts of Yulong Mountain glacier on tourism in Lijiang", *Journal of Mountain Science*, Vol. 3 No. 1.
- Zheng, Y., Byg, A., Thorsen, B.J. and Strange, N. (2013), "A temporal dimension of household vulnerability in three rural communities in Lijiang, China", *Human Ecology*, Vol. 42 No. 2, pp. 283-295.

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Appendix. Temperature

Analysis of meteorological data after 1980 till 2013 revealed increasing in annual average temperature. Temperature anomaly (Figure S1) clearly show temperature increase steadily after 2000. Annual average temperature rise is significant and increase rate is 0.036°C per year (equation below).

$$TEMP = -47.77 + 0.031 * Year (R^2 = 0.32; p < 0.0001).$$

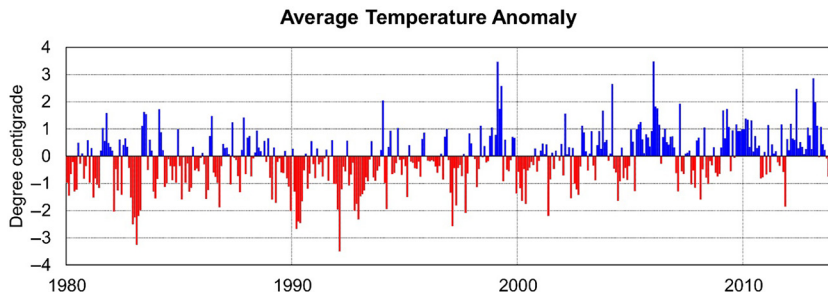


Figure S1.
Anomaly of average temperature: average temperature of each month from 1980 to 2013

Precipitation

Precipitation was erratic, without a definite trend (Figure S2).

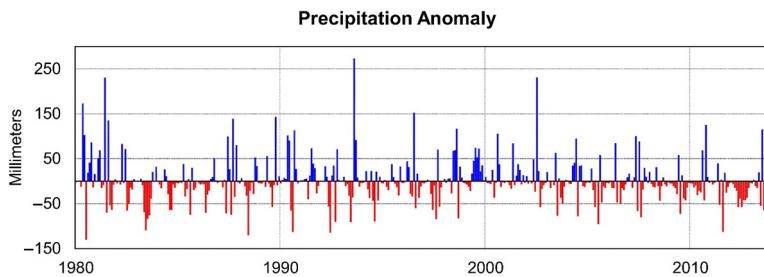


Figure S2.
Anomaly of precipitation: average precipitation of each month from 1980 to 2013

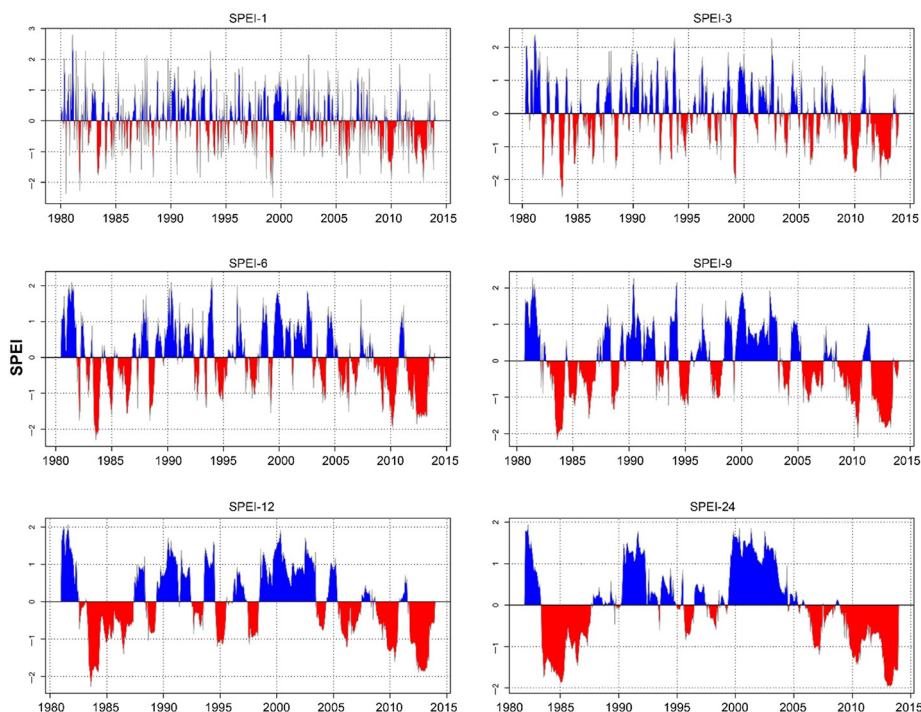


Figure S3.
The temporal
progression of SPEI
at 1-, 3-, 6-, 12- and 24-
month lags

Drought

The standardised precipitation extended index (SPEI) series with different time scales all indicated a drying trend during the period 1980–2013 in Lijiang. A drought event is defined when the SPEI value is less than or equal to -1 in a certain period. The temporal evolution of SPEI at 1-, 3-, 6-, 12-, and 24-month lags were displayed in Figure S3. The calculated SPEI values in Lijiang revealed contrast drought condition before and after year 2005. Between 1990 and the year of 2005, the study area was mainly characterised by the normal and wet moisture conditions. However, the drought events increased frequently after 2005 and severe drought condition ($\text{SPEI} > -1.5$) occurred during 2010 and later. Frequently drought and wet condition altered afterward as revealed in SPEI at 1-, 3-, 6-, 9- and 12-month lags.

It could be found the most severe drought was recorded in the year of 2010 with several monthly regional-averaged SPEI approximating to -1.5 .

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