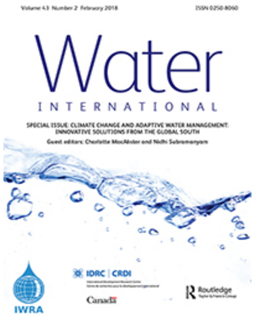

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Determinants of livelihood vulnerability in farming communities in two sites in the Asian Highlands

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ABSTRACT
To identify the indicators of adaptive capacity that determine vulnerability of households, an intensive investigation was conducted in farming communities at two locations in the Asian highlands. Livelihood vulnerability was assessed, classified to four categories and regressed against current adaptive capacity using logistic regression. Household head's education, irrigated land, non-agricultural income, and technologies used were associated with adaptive capacity. The strengthening of human, natural and financial capital is identified as the best means of managing risk in farming communities in this mountainous region.

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Climate change; households; vulnerability; adaptive capacity; Pakistan; Nepal

Introduction

Farmers' livelihoods are directly dependent on climate-sensitive sectors such as agriculture, especially in developing countries. Climate change is a creeping disaster that impacts agriculture in the form of increased crop pests and disease outbreaks, higher frequency and severity of landslides, droughts and floods, reduced yields, crop failure and higher livestock mortality (Harvey et al., 2014; Morton, 2007). Even moderate increases in temperature can have adverse impacts on staple crops (Rosenzweig et al., 2014). Alterations in seasonality of runoff due to fast melting of glaciers and increase or decrease in winter precipitation can have significant effects on crop and livestock production (IPCC, 2007a). Scarcity of water increases aridity and drought problems in some areas, while excess water induces erosion, floods and landslides in others. Such changes and hazards hit hard on smallholder farmers who significantly depend on subsistence agriculture (Zhai & Zhuang, 2009). The Fifth Assessment Report suggests that addressing impacts of climate change and climate risk management requires sound adaptation strategies as well as proper mitigation steps (IPCC, 2014a).

South Asia is home to over one-fifth of the world's population and is known to be the most disaster-prone region in the world (Sivakumar & Stefanski, 2011). The

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Supplemental data for this article can be accessed here.

projected impacts of climate change in South Asia will vary across sectors, locations and populations. Rapid population growth and natural resource degradation along with poverty and food insecurity make the study area, which includes Pakistan and Nepal, one of the regions most vulnerable to the impacts of climate change (Porter et al., 2014; Sivakumar & Stefanski, 2011). The impacts will be heaviest on smallholder farmers because the majority of them depend on rainfed agriculture in this region (Thapa, Scott, Wester, & Varady, 2016; Grumbine, Nizami, Tharu, Salim, & Xu, 2015; Piya, Maharjan, & Joshi, 2016; Sivakumar & Stefanski, 2011; Sujakhu et al., 2016).

The vulnerability of farming communities and households to climate variability and change needs an examination to identify actions that can ameliorate adverse impacts. The concept of vulnerability is vague, and its definition varies across disciplines (Gallopín, 2006). In practice, vulnerability has become an important concept used to formulate the design, evaluation and directing of programmes. Multiple disciplines such as anthropology, sociology, disaster management, climate science and sustainable livelihoods provide the foundation for approaches to study vulnerability (Adger, 2006; Gallopín, 2006; IPCC, 2014a). In this article, we attempt to understand individual households' vulnerability using the Livelihood Vulnerability Index developed by Hahn, Riederer, and Foster (2009) and followed by Islam, Sallu, Hubacek, and Paavola (2013).

Vulnerability is an individual or group's reduced capacity to cope with, resist, and recover from the impacts of a natural or human-made hazard (Birkmann, 2006). Investigations of vulnerability at the national scale have been made through different methods. However, national or regional-level studies have overlooked the micro-level because of their constraint in accounting for the fact that people vary in their exposure to the impacts of climate change (Coulibaly et al., 2015; IPCC, 2014b). Physical, financial, social and natural capital determine the vulnerability and the adaptive capacity of people (Hahn et al., 2009). This study focuses on understanding the major determinants of vulnerability and adaptive capacity of two Himalayan communities.

Various methods have been developed to measure and understand the determinants of household vulnerability (Zhang, 2016). Nkondze, Masuku, and Manyatsi (2013) used a multinomial regression model in investigating the factors affecting households' vulnerability to climate change in Mpolongeni, Swaziland. Edoumiekumo, Tombofa, and Moses (2013) used a logistic regression model to demonstrate the major determinants of poverty in Bayelsa State, Nigeria. Zhang (2016) used an ordinal logistic regression model to evaluate the vulnerability of households in Wenchuan, China. Tsue, Nweze, and Okoye (2014) used principal component analysis to develop a vulnerability index for an individual household and then used an ordered logistic regression model to identify the key determinants of vulnerability in Nigeria.

We have seen few studies that study the impact of specific hazards on farmers' livelihoods in the Asian Highlands (Thapa et al., 2016; Asad, Wali, Hassan, Salim, & Ara, 2015; Chaudhary & Bawa, 2011; Hussain & Hussain, 2013; Manandhar, Vogt, Perret, & Kazama, 2011; Nizami, Fakhruddin, & Policarpio, 2009; Piya et al., 2016; Sujakhu et al., 2016). Most climate change projections using empirical models have contributed to our understanding of process and influences of climate change at global and regional scales, but they are incapable of specifying impacts of climate change at the local level (IPCC, 2007b; Xu & Grumbine, 2014a). Observed and projected climate changes are having and will have spatially and socially notable impacts experienced at local levels (Kais & Islam, 2016). How communities use available resources in effective ways to cope with climate change is key to helping people with adaptation planning. In addition, mapping the connections between climate change, communities' coping strategies and various kinds of capital could provide information necessary for policy makers to help communities avoid or withstand losses from climate hazards. Therefore, this study aims to conduct an in-depth analysis of local-level vulnerabilities and adaptive capacities of smallholder farmers in two different study areas.

Methodology

Study sites

The study included two farming communities in the Asian Highlands: the Garam Chasma Valley of Chitral District, Pakistan; and the Melamchi River Valley of Sindhupalchok, Nepal (Figure 1). The Asian Highlands cover the mountainous landscape of the Hindu-Kush Himalayas, a part of the Tibetan and Yunnan highlands, which is the source of nine major rivers systems of Asia (Xu & Grumbine, 2014a, 2014b). This region has been warming at a rate that is greater than the global average and is projected to increase by 1.5–3 °C by 2040–2060, with greater changes by the end of the century (Salinger et al., 2014).

Garam Chashma is one of the seven sub-tehsils of the Chitral tehsil (sub-district) and district. It is a highly picturesque valley and rich in natural resources, including forests, natural springs and streams, minerals and glacial reserves. The majority of the community here belongs to the Ismaili sect of Islam. Major castes and families residing here are Shahzada (Royals), Darwish, Dashmane, Zondray, Sheikhan and Syeds. It has a dry temperate climate dominated by a winter-bound weather pattern, with rain and snow occurring in December–March. The annual mean precipitation in this region was about 452 and 462 mm as recorded in 1971–2000 and 2001–2010, respectively (Hussain, Hussain, & Hanif, 2013). The main source of farmers' livelihoods is subsistence agriculture and natural resources. Landholdings are small, and the main crops cultivated are wheat, maize, pulses, potato and rice, with about 60% of the area being mono-cropped. Besides these crops, fruits such as apple, apricot, pomegranate, walnut, pine nut, grapes and pears are highly valued. The low temperatures of the higher altitudes do not allow two crops during the cropping season. In Chitral, the local community faces a variety of water-induced hazards throughout the year, such as heavy snowfall in winter and flash floods, soil erosion, and landslides in summer and autumn (Asad et al., 2015). One of the most significant changes observed over the years is the occurrence of showers during the summer and early autumn, which in the past used to be part of the dry season (Hussain et al., 2013).

The Melamchi River Valley, located in the upstream reaches of the Indrawati River basin in the Sindhupalchok District of Nepal, has a subtropical to cool temperate climate. The average annual precipitation in the Melamchi River basin is about 2800 mm. Melamchi River water is mainly used for irrigation and to operate water mills. Commercial uses include paper mills and pisciculture. The people residing in the valley belong to different social groups (Hyolmo, Tamang, Brahmin, Chhetri, Dalit, Newar, Gurung, Majhi and other), the names of which correspond to the names of groups in the caste system of Nepal. Agriculture and livestock

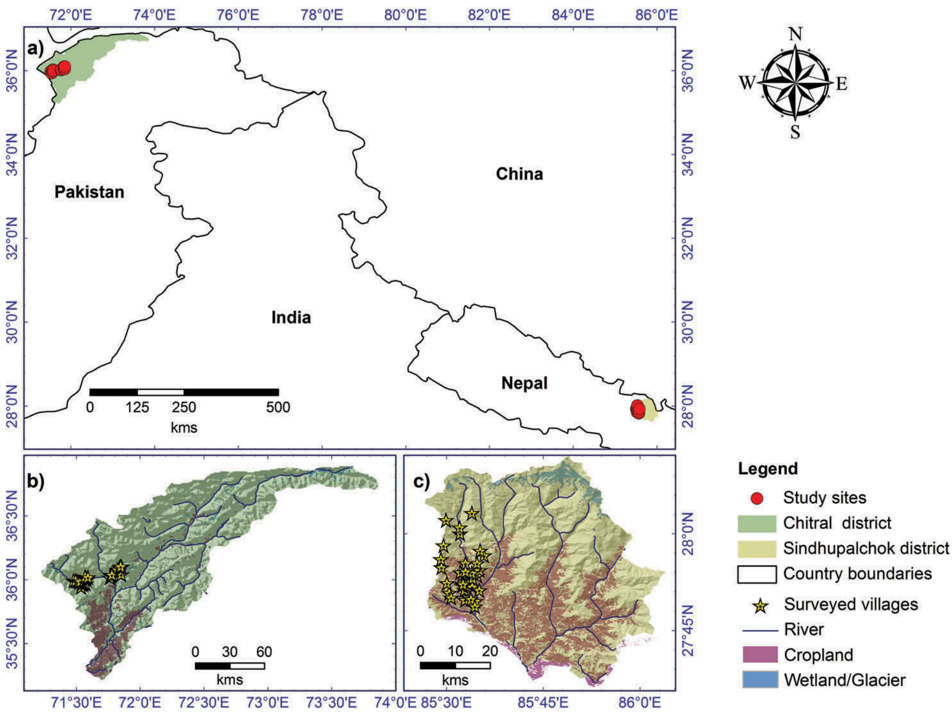

Figure 1. Study area: (a) study locations in the Asian Highlands; (b) Chitral District and surveyed settlements in the Garam Chasma Valley; (c) Sindhupalchok District and surveyed settlements in the Melamchi River Valley.

keeping is major livelihood activity in the valley, and almost 95% of households rely on it. The main crops include rice, maize, wheat and millet, while cows and goats are the main livestock. Sindhupalchok is highly vulnerable because of frequent landslides, and moderately vulnerable regarding rainfall and temperature sensitivity (MoE, 2010).

Vulnerability indicators

The main factors that define the vulnerability of households and communities to the impacts of climate variability and change include exposure, sensitivity, and adaptive capacity (IPCC, 2007a). In this study, exposure refers to the nature and degree to which agriculture-based livelihood systems are susceptible to significant climate variation (modified from IPCC, 2001)). Exposure indicators selected for the two study sites characterize the frequency of water-induced hazards and variation in past temperature and precipitation (Table 1). We use the standard deviation of temperature and precipitation (source: WorldClim, www.worldclim.org) and aridity (source: Consortium for Spatial Information, www.cgiar-csi.org) as variation in temperature, precipitation and dryness of the area. The value of each of these three parameters was extracted for each studied village based on the coordinates collected during the household survey. Historical hazard data could not be extracted for each household or village as they were reported for the whole area and damage was distributed across the studied villages. Therefore, the same value is used as the exposure sub-index in the vulnerability calculation.

Sensitivity is the degree to which an agriculture-based livelihood system is affected by or responsive to climate stimuli. In this study, sensitivity includes loss of property (land, livestock, or crop) to climate-related hazards over the last 10 years. Similarly, income from agriculture and animal husbandry, the severity of climate-related hazards to agriculture and food security, distance of the house from the hazard zone, conflict over the use of water resources in the community, crop production trends in the past 20 years, and land type owned by the household represent its sensitivity. Annex 1 in the online supplemental data contains detailed information on the indicators of sensitivity used in this article.

We identify adaptive capacity as the ability or capacity of farmers to adjust to climate change, to cope with the consequences, and to take advantage of opportunities (modified from IPCC, 2001). Following Jakobsen (2011) and Nelson et al. (2010), we used the sustainable rural livelihoods framework to analyze the adaptive capacity of the communities in the study areas. Adaptive capacity of a household is taken to be an emergent property of the five types of livelihood assets: physical, human, natural, financial and social. Detailed information on the indicators of adaptive capacity used in this article is given in Annex 1 in the online supplemental data.

Data collection and analysis

This study uses primary data collected using semi-structured interviews conducted in households in the Melamchi Valley in February–July 2013 and September–November 2013 in the Garam Chashma Valley. Households were selected randomly, and the sample size was computed according to a formula with a 5% margin of error (95% confidence level) and 50% esponse distribution. We used pre-tested semi-structured questionnaires in 739 households (374 in the Garam Chashma Valley and 365 in the Melamchi Valley). The questionnaire prepared for semi-structured interviews consisted of three broad sections:

Table 1. Community exposure to climate and water induced hazards.

Climate variability and water-induced hazards	Garam Chashma		Melamchi		Source of data
	Mean	STDEV	Mean	STDEV	
No. of glacial lake outburst floods, flash floods and floods (1990–2010)	5	NA	2	NA	District Disaster Management Authority, Focus Humanitarian Assistance and Community, Pakistan and National Society for Earthquake Technology, Nepal
No. of landslides and river erosion (1990–2010)	2	NA	6	NA	
No. of avalanches (1990–2010)	2	NA	-	NA	
No. of mud flows (1990–2010)	4	NA	-	NA	
No. of snowfalls (1990–2010)	1	NA	-	NA	
No. of hailstorms (1990–2010)	-	NA	1	NA	
No. of thunderstorms (1990–2010)	-	NA	1	NA	
Standard deviation of annual temperature (1970–2000), °C	1.81	0.60	1.11	0.40	www.worldclim.org
Standard deviation of annual rainfall (1970–2000), mm	30.29	15.85	68.69	48.84	www.worldclim.org
Aridity index representing dryness of the area (1970–2000)	1.26	0.18	0.99	0.40	www.csi.cgiar.org

exposure, sensitivity, and adaptive capacity. Focus group discussions were conducted to triangulate the data and to supplement the semi-structured interviews conducted at the household level. Focus groups consisted of community members, including leaders of the village where the household interviews were conducted.

Composite livelihood vulnerability index

A composite vulnerability index was used to assess relative exposure, sensitivity and adaptive capacity. This method computes a vulnerability index by aggregating data for a set of indicators. It helps identify indicators or determinants for targeting interventions and programmes (Czúcz, Torda, Molnár, Horváth, & Botta-Dukát, 2009; Eakin & Bojórquez-Tapia, 2008). Each indicator was normalized (rescaled from 0 to 1):

$$index_{Si} = \frac{S_i - S_{min}}{S_{max} - S_{min}} \tag{1}$$

Where $index_{Si}$ is a normalized value of an indicator for a household (HH); S_i is the actual value of the same indicator, and S_{min} and S_{max} are the minimum and maximum values, respectively, of the same indicator.

The normalized values were averaged to yield the three sub-indices for exposure, sensitivity and adaptive capacity. Use of the same exposure sub-index score to calculate intra-community livelihood vulnerability indices help us gain understandings of the factors of livelihood vulnerability among similarly exposed households (Eakin & Bojórquez-Tapia, 2008). Sub-indices for household-level sensitivity and adaptive capacity were also normalized. Sub-indices were combined to create a composite vulnerability index by using an additive (averaging) approach:

$$V = \frac{E + S + (1 - AC)}{3} \tag{2}$$

where *V*, *E*, *S* and *AC* represent the vulnerability, exposure, sensitivity and adaptive capacity of the household, respectively.

Analysis

We divided the livelihood vulnerability index results into four quartiles (very high, high, moderate and low); each represents one-fourth of the population sampled for each indicator and index. A one-way ANOVA was conducted to test the difference between the vulnerability classes defined by each of the selected indicators.

While exposure is beyond the reach of policy, adaptive capacity can be enhanced by policy measures (Maiti, Jha, Garai, Nag, & Chakravarty, 2014) to reduce sensitivity (Piya et al., 2016), and hence vulnerability. Therefore, it is necessary and useful to know which sub-indicators of adaptive capacity are most important to describe the vulnerability. To identify which adaptive capacity sub-indicators determine vulnerability, we used an ordered logistic regression, as described by Tsue et al. (2014). It is a regression model for ordinal dependent variables, which are 'very high', 'high', 'moderate' and 'least', and used when the purpose of the investigation is to see how the response can predict the responses to other questions. Here, the dependent variable is categorized, and therefore, the model was specified as:

$$\Pr(Y \leq j) = \ln\left(\frac{\sum pr\left(Y \leq \frac{j}{X}\right)}{1 - \sum pr\left(Y \leq \frac{j}{X}\right)}\right) = \alpha_j + \beta_1 X_1 + \ldots + \beta_{17} X_{17} \tag{3}$$

j = 1,2,3,4

where Y is vulnerability to climate change (on a scale of 4: very highly vulnerable = 4, highly vulnerable = 3, moderately vulnerable = 2; least vulnerable = 1); α is a threshold; β_1–β_{17} are estimated parameters; and X_i are the subcomponents of adaptive capacity (human, physical, natural, financial and social assets).

Before ordered logistic regression, a Pearson's correlation test was used to examine multicollinearity between sub-indicators of adaptive capacity. Both study sites showed less significant and low correlation between the sub-indicators (Annex 2 in the online supplemental data). Vulnerability classes were regressed as response variables, and sub-indicators of adaptive capacity as explanatory variables. STATA (Version 12.0) was used for analysis.

Results and discussion

Exposure

The overall mean exposure is 0.25 ± 0.02 in Garam Chashma and 0.27 ± 0.04 in Melamchi. ANOVA results indicate that exposure plays a significant role ($p < 0.001$) in determining vulnerability classes in both Garam Chasma and Melamchi. Sub-indicators of exposure included water-induced hazards and climatic variability, which cannot be changed using policy measures. Water-induced hazards have frequently occurred in the study sites: flash floods, avalanches, glacial lake outburst floods, and mudflow were the major hazards in the Garam Chashma Valley, whereas landslides, floods, thunderstorms and hailstorms were identified as the major hazards in the Melamchi Valley (Table 1).

People vary in their exposure (Coulibaly et al., 2015; IPCC, 2014b), but the lack of data for each household makes it very difficult to incorporate exposure data at the household level. We extracted data for deviation of temperature, rainfall and dryness as exposure for each household or clusters of households in proximity. Aridity index, representing dryness of the area, was statistically significant ($p < 0.001$) for both study sites (Tables 2 and 3), and standard deviation of annual temperature and annual rainfall was statistically significant ($p < 0.001$) for the Melamchi Valley (Table 3).

Flash floods have caused greater damage to land, crops and property in the last 10 years than other risks in Garam Chashma. Rainfall in Garam Chashma is usually limited to the winter months; erratic and unpredictable rains are frequent and cause flash floods. However, Nadeem, Elahi, Hadi, and Uddin (2009) have reported unprecedented intense and short-duration showers in summer, triggering flash floods and then landslides. In July 2015, flash floods caused enormous destruction in Chitral, affecting 60% of the population and several thousand hectares of land and property (UN OCHA, 2015).

Household surveys indicated drought, crop pests, and diseases as the major hazards in Melamchi, with varying intensities, magnitudes and impacts on crop production.

Local communities reported that pre-monsoon rains are necessary to determine the sowing season. Most of the farmland in the Melamchi is rainfed, and declining precipitation in recent years and increasing drought can impact livelihoods through the impact on agriculture (Sujakhu et al., 2016).

Hussain et al. (2013) reported that rising temperatures in winter and spring have significant implications for winter crop growth and yields. While there is an increase in winter precipitation in Garam Chashma (Hussain et al., 2013), this is of no use because at high altitude crops are cultivated only in the summer (Nadeem et al., 2009). Summer droughts cause water scarcity, which is a particularly acute problem in an area that does not have an irrigation network. Sujakhu et al. (2016) reported an increase in drought periods from two months in 2005 to 10 months in 2009, and nine months in 2010 and 2012. Paddy farmers severely feel the impact of drought. Water scarcity and water hazards associated with climate change intensify the exposure of the community, and hence, its vulnerability. Unpredictable water-related hazards due to climate variability can intensify the existing water crisis (Miranda, Hordijk, & Molina, 2011).

Sensitivity

The overall sensitivity is 0.38 ± 0.09 in Garam Chashma and 0.42 ± 0.1 in Melamchi. The ANOVA test revealed that sensitivity varies significantly between the household vulnerability classes in each community ($p < 0.001$) (Tables 2 and 3). Among the eight sub-indicators of sensitivity, six are significant ($p < 0.001$) in Melamchi, whereas all sub-indicators are statistically significant in distinguishing the vulnerability classes in Garam Chashma.

In both locations, the higher sensitivity of livelihoods of the vulnerable households is due to high dependence on climate-sensitive agriculture for income. In both study areas, households with high vulnerability are located in an area exposed to water-related hazards. Vulnerable households spend more time fetching water and reported more conflicts over the use of water resources than less vulnerable households due to water scarcity, depletion and poor access. They also have little voice in the decision-making process (Miranda et al., 2011).

Household respondents and focus group discussions stated that conflicts over water use, especially in the upland, could be averted through efficient management. For example, rainwater harvesting in the rainy season and providing the water during the dry season could reduce conflict. Still, decision-making processes which directly affect water use should not be neglected (Miranda et al., 2011). Therefore, effective water governance is essential, along with water management.

Respondents and focus groups also reported decreasing crop production due to erratic rainfall in the last 20 years. Moreover, the land owned by highly vulnerable households is susceptible to landslides and other water-induced hazards. The steep slopes in the upland are less productive than areas in the lowland. Most are not irrigated and face greater risks of landslides and loss of topsoil due to runoff during rains (Siddiqui, Bharati, Pant, Gurung, & Rakhal, 2012).

Table 2. Vulnerability classification of households in Garam Chashma (exposure index reflects community scale, while sensitivity and adaptive capacity represent household scale).

Indicators and sub-indicators	Least vulnerable	Moderately vulnerable	Highly vulnerable	Very highly vulnerable	Mean	STDEV
No. of households	94	94	92	94		
Standard deviation of annual temperature	0.66	0.71	0.66	0.68	0.67	0.22
Standard deviation of annual rainfall	0.39	0.32	0.35	0.30	0.34	0.25
Aridity index representing dryness of the area***	0.49	0.62	0.64	0.69	0.61	0.22
Sub-index of exposure***	0.24	0.26	0.26	0.26	0.25	0.02
Indicators of Sensitivity						
Total lost properties and crops in term of cost***	1572.06	2034.04	2175.97	3372.43	2289.23	3068.24
Share of income from agriculture***	17.77	28.19	30.11	42.71	29.69	29.80
Overall hazards severity on agriculture and food security***	3.04	3.81	4.00	4.36	3.80	1.37
House distance from hazard area ***	2.98	3.28	3.40	3.62	3.33	0.84
Water collection time in dry season**	2.09	1.72	3.13	4.22	2.79	5.19
Conflicts over the use of water in community***	0.34	0.33	0.34	0.99	0.50	0.89
Crop trend in last 20 years**	0.10	−0.05	−0.29	−0.55	−0.20	1.29
Land type owned by household***	1.59	1.75	1.99	2.25	1.90	0.77
Sub-index of sensitivity* **	0.30	0.36	0.39	0.48	0.38	0.10
Indicators of adaptive capacity						
Highest education status of household head***	4.89	3.23	1.72	1.83	2.93	4.37
Percentage of economically active members in household*	76.06	72.00	68.26	66.47	70.71	22.04
Membership in community-based organizations	1.00	0.98	0.96	0.98	0.98	0.14
Household-head sex*	0.96	0.99	0.93	0.88	0.94	0.24
*Sub-index of human assets****	0.77	0.77	0.67	0.66	0.71	0.12
Wall type of house owned by household***	2.90	2.74	2.55	2.54	2.69	0.64
Roof type of house owned by household***	2.22	2.05	2.03	2.00	2.08	0.36
No. of technologies used by household***	3.65	3.34	2.76	2.66	3.10	1.61
*Sub-index of physical assets****	0.52	0.47	0.42	0.41	0.45	0.12
Share of irrigated land	88.54	81.29	86.33	76.94	83.26	33.19
Total land ownership (hectares)	0.82	0.86	0.51	0.70	0.72	1.08
Have bullock	0.94	0.94	0.89	0.91	0.92	0.27
Sub-index of natural assets	0.64	0.62	0.60	0.59	0.61	0.17
Total livestock units	2.08	2.08	1.59	2.08	1.95	1.73
Total annual saving	286.40	274.80	269.54	261.20	272.92	73.11
Share of income from non-agriculture***	79.04	70.74	69.89	57.61	69.32	30.46
Total no. of cash crops grown by household	1.12	0.96	0.90	0.93	0.98	0.84
*Sub-index of financial assets****	0.40	0.37	0.35	0.33	0.36	0.09
No. of assistance received during and after hazard period	1.32	1.50	1.07	1.20	1.27	1.15
Influence of household in local government decision making***	3.45	2.90	2.51	2.66	2.88	1.27
Access to loan	0.32	0.26	0.28	0.23	0.27	0.45
*Sub-index of social assets***	0.39	0.34	0.29	0.29	0.33	0.23
Sub-index of adaptive capacity* **	0.54	0.51	0.47	0.46	0.49	0.07
$V = (E + S + (1 - AC))/3$***	0.33	0.37	0.39	0.43	0.38	0.04

Table 3. Vulnerability classification of households in Melamchi (exposure index reflects community scale, while sensitivity and adaptive capacity represent household scale).

Indicators and sub-indicators	Least vulnerable	Moderately vulnerable	Highly vulnerable	Very highly vulnerable	Mean	ST DEV
No. of households	92	91	90	92		
Standard deviation of annual temperature***	0.24	0.22	0.18	0.17	0.20	0.10
Standard deviation of annual rainfall***	0.42	0.50	0.60	0.61	0.53	0.21
Aridity index representing dryness of the area***	0.59	0.65	0.72	0.72	0.67	0.16
Sub-index of Exposure***	0.25	0.27	0.28	0.29	0.27	0.04
Indicators of sensitivity						
Total lost properties and crops in term of cost	538.14	454.39	489.57	1036.27	630.84	1795.61
Share of income from agriculture***	71.79	87.89	87.31	87.31	85.65	25.56
Overall hazards severity on agriculture and food security	2.40	2.28	2.46	2.42	2.39	1.27
House distance from hazard area ***	2.37	2.95	2.83	3.20	2.83	1.00
Water collection time in dry season***	6.24	8.18	12.71	18.09	11.09	17.43
Conflicts over the use of water in community***	0.73	1.14	1.31	1.45	1.15	1.08
Crop trend in last 20 years***	1.90	1.03	−0.46	−1.40	0.27	3.32
Land type owned by household***	1.59	1.83	2.14	2.51	2.01	0.71
Sub-index of sensitivity***	0.32	0.39	0.44	0.52	0.42	0.10
Indicators of adaptive capacity						
Highest education status of household head***	3.80	1.69	1.57	1.20	2.07	3.58
Percentage of economically active members in household	74.41	69.09	69.95	66.21	69.98	22.89
Membership in community-based organizations***	0.76	0.66	0.59	0.30	0.58	0.49
Household-head sex**	0.97	0.93	0.89	0.89	0.90	0.30
*Sub-index of human assets****	0.68	0.59	0.56	0.46	0.57	0.19
Wall type of house owned by household	2.15	2.10	2.06	2.04	2.09	0.45
Roof type of house owned by household	2.26	2.15	2.16	2.09	2.17	0.51
No. of technologies used by household***	3.42	2.80	2.30	2.12	2.66	1.37
*Sub-index of physical assets****	0.40	0.36	0.34	0.32	0.36	0.12
Share of irrigated land***	81.72	75.06	66.24	46.36	67.33	42.32
Total land ownership (hectares)**	0.63	0.63	0.53	0.25	0.51	0.77
Have bullock***	0.53	0.40	0.23	0.21	0.34	0.48
*Sub-index of natural assets****	0.46	0.40	0.31	0.23	0.35	0.22
Total livestock units***	1.74	1.45	1.18	1.17	1.39	1.09
Total annual saving***	335.65	182.50	147.05	104.36	192.67	236.29
Share of income from non-agriculture***	25.76	11.71	10.87	4.32	13.18	24.17
Total no. of cash crops grown by household***	1.02	0.63	0.44	0.37	0.62	0.87
*Sub-index of financial assets****	0.27	0.16	0.13	0.10	0.17	0.12
No. of assistance received during and after hazard period	1.13	1.07	1.04	1.09	1.08	0.33
Influence of household in local government decision making***	3.18	2.76	2.55	2.15	2.67	1.29
Access to loans	0.17	0.24	0.20	0.12	0.18	0.39
*Sub-index of social assets****	0.35	0.34	0.31	0.24	0.31	0.18
Sub-index of adaptive capacity***	0.43	0.37	0.33	0.27	0.35	0.09
V = (E + S + (1 − AC))/3***	0.38	0.43	0.47	0.51	0.45	0.05

* Indicates significant difference (normalized values were used) between vulnerability classes in ANOVA test; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Adaptive capacity

The results show the adaptive capacity of Garam Chashma's households at 0.49 ± 0.07 and Melamchi's at 0.35 ± 0.09. The ANOVA test indicated that vulnerability classes were significantly different ($p < 0.001$ to $p < 0.05$) across sub-indicators such as education status of the household head, percentage of economically active members of the family, amount of technological equipment used, access to irrigation for farming, total annual savings, share of non-agricultural income, total number of cash crops grown, and influence of the household in decision making at the community level in both locations (Tables 2 and 3).

Among the four human capital sub-indicators, 'highest education status of household head' is highly significant ($p < 0.001$) in both sites. Households with less education were at greater risk, indicating that education increases the capacity to cope with water-induced hazards. The literature shows that female-headed households are more vulnerable and less adaptive than male-headed households (Nadeem et al., 2009; Opiyo, Wasonga, & Nyangito, 2014). Household head's sex is significant in Garam Chashma ($p < 0.05$) and in Melamchi ($p < 0.01$), indicating that the adaptive capacity of a household might be affected depending on whether the head is male or female. The absence of a male household head increases livelihood vulnerability by limiting the household's ability to cope with extreme events as well as its access to livelihood assets and strategies (Islam et al., 2013).

Technologies used was identified as one of the major sub-indicators ($p < 0.001$) of adaptive capacity: less vulnerable households used more technologies than highly vulnerable households in both communities. Access to climate-related information facilitates household adaptation through technologies such as radio and television (Deressa, Hassan, Ringler, Alemu, & Yesuf, 2009; Gbetibouo, 2009), and access to proper information during emergency periods. In the ANOVA results, wall and roof (type of house) were important in Garam Chasma but were not significant in Melamchi.

Among the three sub-indicators of natural capital, none were significant in Garam Chasma (Table 2). In Melamchi, all three sub-indicators of natural capital were highly significant ($p < 0.001$) (Table 3). Irrigation is directly linked to climate shocks as it minimizes the risks posed by droughts (Sujakhu et al., 2016). Farmers with irrigation facilities can sow their seeds at the same time each year, while those without such facilities have to rely on rainfall. A higher proportion of irrigated land means lower dependence on natural rain for farming, which is becoming more unpredictable with climate change (Gbetibouo, 2009). A higher proportion of more productive irrigated land also means higher food self-sufficiency and thus higher adaptive capacity. The presence of bullocks makes farming activity easier and more efficient, increasing the adaptive capacity of the household.

Among the four sub-indicators of financial capital, the household's total share of income from non-agricultural activities was highly significant ($p < 0.001$) in both locations. Households that had a higher share of total income from non-agricultural activities were less affected in years with adverse weather conditions. In particular, vulnerable households have the lowest percentage of non-agricultural income. In the case of Garam Chasma, remaining sub-indicators of financial capital were not significant, while they were highly significant for Melamchi. Livestock is an additional source of income in the Melamchi Valley (Sujakhu et al., 2016). Higher savings indicate higher household income and better adaptive capacity (Piya et al., 2016). Financial saving, an indicator of adaptive capacity, is necessary for coping with unexpected hazards such as the devastating earthquake in Nepal in 2015, which affected the entire Sindhupalchok District, including the study site in the Melamchi Valley. Households with savings also make productive investments such as in family education or use their savings as a buffer during emergencies. On the other hand, lack of savings increases the household's vulnerability. The most vulnerable classes of households are not able to augment their livelihood assets due to lower income and savings. Highly vulnerable household classes grew fewer cash crops in both locations (Tables 2 and 3). Potato farming and the sale of potatoes contributed to higher savings in Garam Chashma. However, savings get exhausted due to the increasing frequency of hazards. Savings are therefore not useful as sustainable livelihood strategies but only as short-term coping strategies.

Among the three sub-indicators of social assets in both locations, the influence of a household in local government decision making was highly significant ($p < 0.001$). This shows that highly vulnerable households have less influence on the local government's decision making compared to less vulnerable households (Tables 2 and 3). Zhao (2013) has shown that social networks play a major role in risk management. Highly vulnerable households have lower institutional access than those who are less vulnerable and more powerful or better-off (Agrawal, 2010). Smit and Wandel (2006) showed that involvement in a social organization enhances adaptive capacity. Therefore, in both locations, social networks need to be strengthened. Social assets provide bonding, bridging and linking capital that enables people to cope better (Bernier & Meinzen-Dick, 2014).

Vulnerability

In the ANOVA results, the overall vulnerability for Garam Chashma was 0.38 ± 0.04 and 0.44 ± 0.05 for Melamchi. Vulnerability differs significantly ($p < 0.001$) between household classes within each community (Tables 2 and 3). Ordered logistic regression analysis (Table 4) showed that different sub-components of adaptive capacity determine the differentiation of vulnerability classes among the farming community in two sites. The ordered regression analysis revealed that education status of the household head, proportion of land under irrigation, and share of non-agricultural income were highly significant ($p < 0.001$). The number of technologies used was significant ($p < 0.01$) for both sites. These four sub-indicators of adaptive capacity play a major role in determining household vulnerability classes in both study sites. The education level of the household head is not only an important determinant of vulnerability in the Asian Highlands but also in the South African region (Baiyegunhi & Fraser, 2014).

In addition to the four sub-indicators, there were other sub-indicators responsible for the determination of vulnerability in the two sites. The house's wall type ($p < 0.001$), total amount of cash crop grown ($p < 0.01$), number of economically active members, membership in community-based organizations, and assistance received during hazards ($p < 0.05$) were statistically significant for Garam Chasma. In Melamchi, membership in community-based organizations, the presence of a male household head, possession of bullocks, annual savings, access to loans ($p < 0.001$), and influence of the household in local government decision making ($p < 0.01$) were other determinants of vulnerability.

Nkondze et al. (2013) found that livestock influences households to move from low vulnerability to moderate vulnerability or high vulnerability. Panthi et al. (2016)

reported that the integration of livestock rearing with crops reduced the vulnerability of smallholder farmers in Dhading, Nepal. For such integration, possession of livestock is very important. Edoumiekumo et al. (2013) used a logistic regression model to show that the major determinants of poverty in Nigeria were household size, per capita expenditure on education, health, and food, in addition to female-headed household and engagement in agriculture activity only. These reports resemble our findings in the Melamchi Valley regarding annual saving, sex of household head, and possession of bullocks.

In our study sites, farmers have limited adaptive capacity because of the lack of human, physical, natural, financial and social capital. These factors are interconnected, e.g. lack of human capital (education) and natural capital (irrigated and productive land) limits engagement in alternative livelihood strategies and the opportunity for a higher income from farming. Lower revenue and savings limit financial capital. Because of their lower financial status, farmers cannot purchase fertilizers and improved varieties of seeds for agriculture or diversify their livelihoods. Our finding indicates that the most vulnerable households and communities are also poor, consistent with the results of studies by Deressa, Hassan, and Ringler (2011), Islam et al. (2013) and Paavola (2008).

This case study indicates that similar factors are responsible for the differentiation of vulnerability classes in communities regardless of geographical and social differences. Educating the farmers, diversifying non-farming livelihood activities for income generation, and developing irrigation systems in the community can help make farming communities resilient to climate change and variability by enhancing adaptive capacity.

Climate change is not the sole driver of vulnerability – livelihood vulnerability is also closely linked to population growth, socio-economic trends, ongoing needs for human development, and new technological changes.

Table 4. Determinants of vulnerability classes in the farming communities. Highlighted variables were significant at both study sites.

	Garam Chashma			Melamchi		
Explanatory variables	Coeff.	z	$P > z$	Coeff.	z	$P > z$
Highest education status of household head	−0.1343	−5.37	0***	−0.1561	−3.95	0***
Percentage of economically active members in household	−0.0099	−2.08	0.037*	−0.0008	−0.14	0.889
Membership in community-based organizations	−1.4215	−2.11	0.035*	−0.9504	−3.71	0***
Presence of male household head	−0.6901	−1.52	0.129	−1.68	−3.89	0***
Wall type of house	−0.7318	−4.26	0***	−0.5428	−1.3	0.192
Roof type of house	−1.0201	−2.4	0.017	0.03767	0.1	0.917
No. of technologies used	−0.1996	−2.81	0.005**	−0.2682	−2.66	0.008**
Share of irrigated land owned by household	−0.0141	−4.03	0***	−0.0165	−5.6	0***
Total land owned by household	−0.0375	−0.32	0.749	0.08431	0.45	0.653
Possession of bullock	−0.3673	−0.93	0.353	−1.5556	−5.37	0***
Total livestock units owned by household	−0.1136	−1.48	0.139	−0.0322	−0.25	0.8
Total annual saving	−0.0023	−1.5	0.133	−0.0023	−3.71	0***
Share of non-agricultural income	−0.0326	−7.83	0***	−0.0314	−5.61	0***
Total no. of cash crops grown	−0.4335	−3.07	0.002**	−0.1472	−0.96	0.338
Total no. of assistance received during and after hazards periods	−0.2122	−2.14	0.033*	−0.3658	−1	0.319
Influence of household in local government decision making	−0.1539	−1.8	0.072	−0.3221	−3.32	0.001**
Access to loans	−0.4484	−1.84	0.066	−1.3552	−4.16	0***

Source: Ordered logistic regression.

Conclusions and recommendations

The vulnerability of agriculture-based livelihoods to climate and water-induced hazards was analyzed using a composite index and qualitative methods. Exposure, sensitivity, and adaptive capacity were found to be highly context- and location- specific. The most important climate-related elements of exposure are flash floods in Garam Chashma and landslides in Melamchi. The key factor determining the sensitivity of individual households in both study areas is the dependence on agriculture (farming and livestock) for livelihoods. The combination of human, natural and financial capital strengthened adaptive capacity. Various factors influence livelihood vulnerability in Garam Chashma, Pakistan, and Melamchi, Nepal. Regardless of socio-economic and geographical differences, communities in both sites show similar sub-components of adaptive capacity (education of the household head, irrigated land, additional non-agricultural income, and technologies) as major determinants of vulnerability. Improving the indicators identified in this study could help reduce the livelihood vulnerability of these two mountain communities, and possibly other mountain communities in the Asian Highlands.

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

Effective water governance. The concerned government should prioritize effective water governance to facilitate farmers' access to irrigation and other facilities to obtain water.

Diversified livelihoods. Our results indicate that the share of non-agricultural income and the use of technologies are important for reducing vulnerability. Therefore, it is recommended to train farmers to diversify livelihood options rather than depending solely on agriculture-based income, or diversify their farming practices through the adoption of modern technologies.

Education and information access. Our results indicate that education of the household head is very important in reducing household vulnerability. Provision of an education programme for the middle-aged population, including vocational training, would help increase adaptive capacity. Similarly, access to technology that helps people receive information updates on climate, agriculture, and innovative ways to improve agriculture would help improve adaptive capacity and reduce vulnerability.

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