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Farmers' Perceptions of and Adaptations to Changing Climate in the Melamchi Valley of Nepal

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Knowledge of farmers' perceptions of and adaptations to climate change is important to inform policies addressing the risk of climate change to farmers. This case study explored those issues in the Melamchi Valley of Nepal through a survey of 365 households and focus group discussions in 6 communities using a Community-Based Risk Screening Tool–Adaptation and Livelihoods (CRiSTAL). Analysis of climate trends in the study area for 1979–2009 showed that mean annual temperatures rose by 1.02°C and the frequency of drought increased measurably after 2003. Farmers reported increases in crop pests, hailstorms, landslides, floods, thunderstorms, and erratic precipitation as climate-related hazards affecting agriculture. They responded in a variety of ways including changing farming practices, selling livestock, milk, and eggs, and engaging in daily wage labor and seasonal labor migration. With more efficient support and planning, some of these measures could be adjusted to better meet current and future risks from climate change.

Keywords: *Climate change; CRiSTAL; adaptation strategies; Melamchi Valley; Nepal.*

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Introduction

Findings of the Nepal's National Adaptation Programme of Action (NAPA) to climate change indicate that Nepal is highly vulnerable to climate change and variability (MoE 2010a; Tiwari et al 2014). (Here "climate change" refers to any change in climate over time, whether due to natural variability or anthropogenic forces, and "climate variability" refers to a climatic parameter of a region varying from its long-term mean [IPCC 2007a].) The average annual temperature of Nepal has increased at a rate of 0.06°C per year since the 1970s (Shrestha et al 1999; Sharma and Tsering 2009), with higher rates in winter than in summer. The increase is more pronounced in the Middle Hills and the High Himalayas (Xu et al 2009). Manifestations of climate change and variability observed in the mountains include erratic rainfall, an unpredictable onset of the monsoon season, and droughts (Gentle and Maraseni 2012), with negative impacts on agriculture as well as on food, livelihood, and water security (Kohler et al 2010; Macchi 2011; Gentle and Maraseni 2012).

Poor subsistence farmers depending on natural resources are most vulnerable to climate change (Morton 2007). About 83% of Nepal's population practices agriculture (CBS 2014), and more than 60% of the cultivated area is rain-fed (CBS 2006). Agricultural production is already under pressure from increasing demands for food and the depletion of land and water resources. Climatic impacts cause an additional risk to agriculture. Crop yields are predicted to decline by 5–30% by 2050 in the Himalayas due to warming, leading to severe food insecurity (IPCC 2007a). Most climate models show that higher temperatures will lead to lower rice yields as a result of shorter growing periods in Asia, including Nepal (IPCC 2014).

Impacts of climate change as well as the capacity to adapt to them are context- and location-specific (Smit and Wandel 2006). While most climate change projections using empirical models can be applied at global and regional levels, they are unable to specify climate change impacts at the local level (IPCC 2007b). It is therefore essential that large-scale initiatives to support farmers consider local priorities and integrate lessons from local adaptation efforts. However, with the exception of a few studies (Chaudhary and Bawa 2011; Manandhar et al 2011), knowledge is limited on how specific climate hazards impact on local livelihoods and how farming communities in the mountains of Nepal are responding to climate change.

To address the issue and meet the requirements of the UN Framework Convention on Climate Change, Nepal prepared both national and local adaptation plans. NAPA was the first comprehensive climate-change-related government document released to the public (HELVETAS 2011). It provides a basis for the government to guide further climate change governance and manage financial resources in a coherent and coordinated manner (MoE 2010b). Identifying the need for a bottom-up approach to adaptation planning, Nepal has come up with an innovative local planning process called the Local Adaptation Plan of Action (LAPA). LAPA calls for vulnerability assessment and adaptation planning, with participation by vulnerable communities and all gender groups, which enables communities to understand climatic impacts and formulate adaptation priorities. It complements NAPA to ensure that vulnerabilities of local communities are identified, and interventions are planned to channel 80% of financial resources to be spent at the local level for adaptation programs, as envisioned by NAPA (HELVETAS 2011).

Since farming communities' adaptation are determined by their perceptions of climate change, local perceptions and knowledge should be considered when planning adaptation strategies (Xu et al 2009; Xu and Grumbine 2014), which is in line with the concept of LAPA. Our case study aimed first to assess the magnitude and trends of climate change and climate-related hazards affecting farmers' livelihoods, second to analyze farmers' perceptions of climate change and their accuracy, and third to investigate farmers' current responses, which have the potential to develop into promising adaptation practices.

The 2015 earthquake in Nepal

Nepal is not only prone to climate change and climate variability and other hazards such as landslides and soil erosion, which are the subjects of this study, but also to earthquakes. In April and May 2015, Nepal was struck by a series of strong quakes (Avouac et al 2015). Sindhupalchok District, where this research was conducted, was particularly strongly affected. The District Disaster Relief Committee (DDRC) reported 3532 deaths (DFSN 2015), including 601 people from our study site. A further 1169 were injured, and 95% of the houses were damaged.

Our study was conducted in 2013, and the situation in the study area is now fundamentally different. People in the affected areas must focus first on rebuilding their homes and livelihoods. In this sense, the results of our research reflect a situation that no longer exists. This does not mean, however, that they are obsolete. Big earthquakes have a huge impact, but they occur at relatively long intervals. The last big shock felt in the study area occurred in 1988 (Anonymous 2015). Participants in our pre-earthquake study did not rank the risk from earthquakes as very high, probably because of the relatively long time since the previous one. This may also explain the low level of preparedness. While the effects of the recent earthquakes require an immediate response, this should not lead to neglect of adaptation to climate change and climate variability—processes that happen more slowly and less dramatically but will continue to affect the livelihoods of people after they recover from the earthquakes. In this sense, the results of this survey will remain relevant and may, in addition, provide a baseline against which the impact of the earthquakes can be assessed.

Method and materials

Study area

The study was conducted in the Melamchi Valley (Figure 1) from February to July 2013. The valley is located in the upstream reaches of the Indrawati River Basin in Sindhupalchok District. Sindhupalchok is highly vulnerable to landslides and moderately vulnerable to fluctuations in rainfall and temperature (MoE 2010a). The area is at risk from earthquakes, as the Main Central Thrust fault line runs across the Himalayan region (Upreti 1999). Geographically, the valley can be divided into upland, midhills, and lowland. The climate ranges from subtropical in the lower valley to cool temperate in the upper valley. Average annual precipitation in the Melamchi Valley is about 2800 mm. Almost 95% of households in the valley rely on agriculture and livestock for their livelihoods. The main cultivation systems are *khet* (irrigated land) in the lowland and *bari* (rain-fed land) in the upland parts of the valley. The main crops are rice, maize, wheat, and millet.

Household survey

A household survey (Figures 1C, 2) was carried out with 365 local household heads (37 female and 328 male, older than 30 to 80 years old) from 8 village development committees (VDCs—the lowest administrative units in Nepal). The survey used a pretested semistructured questionnaire that explored local perceptions of climate change and variability, the frequency and magnitude of climate-related hazards in the last 20 years, their impacts on livelihoods, and current responses. Quantitative descriptive statistics were supplemented by qualitative information in the form of participants' narratives about their experiences.

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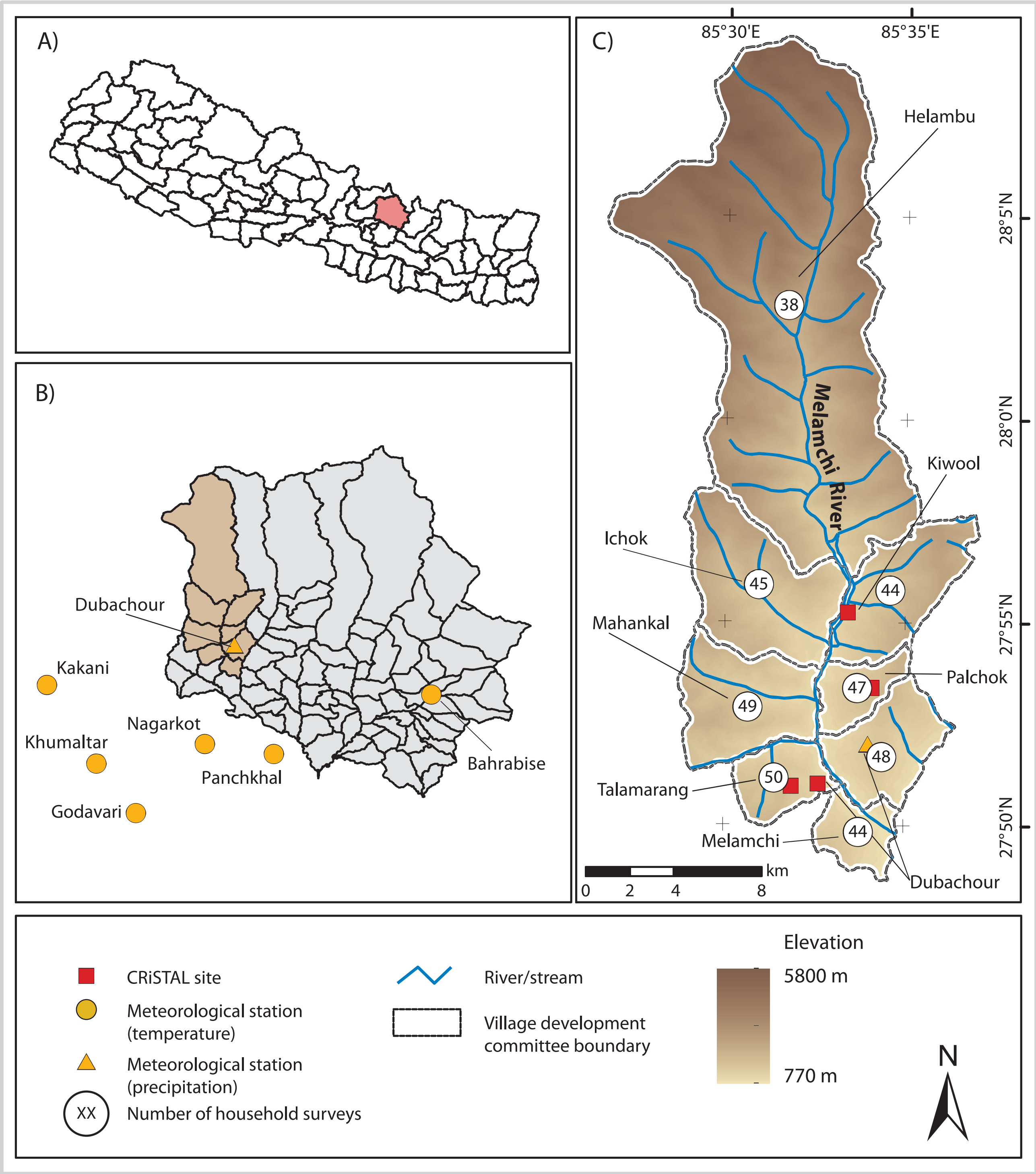
FIGURE 1 Map of the study area. (A) Nepal; (B) Sindhupalchok District, with the location of meteorological stations; (C) Melamchi Valley and surveyed VDCs. (Map by Rabin R. Niraula)



Participatory risk assessment and adaptation planning

We used CRiSTAL (Community-Based Risk Screening Tool–Adaptation and Livelihoods), a participatory risk assessment and adaptation planning tool, to analyze climate vulnerability and adaptive capacity (IISD 2012). CRiSTAL provides a framework to establish a community-level baseline on vulnerability and adaptation mechanisms.

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FIGURE 2 The first author interviewing a family near the border between Mahankal and Talamarang VDCs. (Photo by Sailesh Ranjitkar)

We chose to work with women and men separately (Figure 3) because of their different roles and responsibilities. Six focus group discussions were held, 3 for men and 3 for women. Each had 15 participants and included key informants (eg teachers and members of the local governing body), local farmers, people over 60 years old, and people between the ages of 20 and 30. Although people from diverse occupational backgrounds were invited, all participants engaged in farming to some extent. CRiSTAL enables local decision-makers to assess the impact that a project may have on the resources of a community and to modify projects in order to reduce vulnerability and enhance adaptive capacity. It provides project developers with an opportunity to cooperate with communities to incorporate climatic and other risks into project design and implementation.

We concentrated on analysis of livelihoods and climate risks, following the CRiSTAL methods step by step and using different participatory tools as described in Table 1. In addition, we discussed how current responses could be adapted to projected future climate changes.

Climate data

Monthly average precipitation data for 1979–2009 from the Dubachour meteorological station were used to assess the precipitation trend. As temperature data were not available from this station, temperature was interpolated (Equation 1) by calculating the lapse rate (ie the rate at which atmospheric temperature decreases with an increase in altitude, Equation 2) (Ranjitkar et al 2013) from elevation and temperature data from 6 nearby meteorological stations (Figure 1B):

$$t_{cal} = t_n + \left[l_m * \frac{(E_{cal} - E_n)}{100} \right] \quad (1)$$

$$l_m = \sum_{i}^{n} \frac{(t_n - t_i) * 100}{(E_n - E_i)} \quad (2)$$

where E is the elevation of the meteorological stations, t is the recorded temperature, i and n refer to the first and second stations, l_m is the lapse rate per 100 m calculated for each month, and E_{cal} and t_{cal} are the elevation and temperature of the location.

Meteorological drought—the degree of dryness compared to an average amount and the duration of the dry period—in the area was assessed using the Palmer Drought Severity Index (PDSI). We used 30 years of precipitation data and interpolated temperature data to calculate PDSI, using sc-PDSI software available at https://github.com/cszang/pdsi. Guttman (1998) defined PDSI values of +4.0 or higher as extremely moist, +3.0 to +3.9 as very moist, +2.0 to +2.9 as unusually moist, −1.9 to +1.9 as near normal,

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FIGURE 3 CRiSTAL exercises (led by Nani Maiya Sujakhu) with (A) a women's group; (B) a men's group. (Photo A by Nani Maiya Sujakhu; photo B by Sweta Bhattarai)

−2.0 to −2.9 as moderate drought, −3.0 to −3.9 as severe drought, and −4.0 or lower as extreme drought.

Results and discussion

Climate change

Temperature and precipitation trends: Over a 30-year period, temperatures rose by 1.02°C ($P = 0.07$, $r^2 = 0.109$) with variations up to 10.4% from the mean of the entire period. Separating this period into 3 time spans, we found that mean annual temperature rose by 0.18 and 0.9°C during 1978–1987 and 1988–1998, respectively, and by 1.56°C in the period after 1999. Average temperatures during winter have risen significantly (1.98°C; $P = 0.009$, $r^2 = 0.22$) over the last 30 years (Figure 4A). Maximum and minimum summer and winter temperatures changed significantly over time (for the summer maximum, $P = 0.007$ and $r^2 = 0.34$; for the summer minimum, $P = 0.004$ and $r^2 = 0.25$; for the winter maximum, $P = 0.008$ and $r^2 = 0.23$; for the winter minimum, $P = 0.000$ and $r^2 = 0.55$).

For precipitation, there was no clear trend over the 3 decades. Manandhar et al (2011) reported similarly erratic patterns from a study in western Nepal. Precipitation oscillated over the years, slightly decreasing in both summer and winter. Summer and winter food-crop yields were affected by mild to severe drought and crop pests.

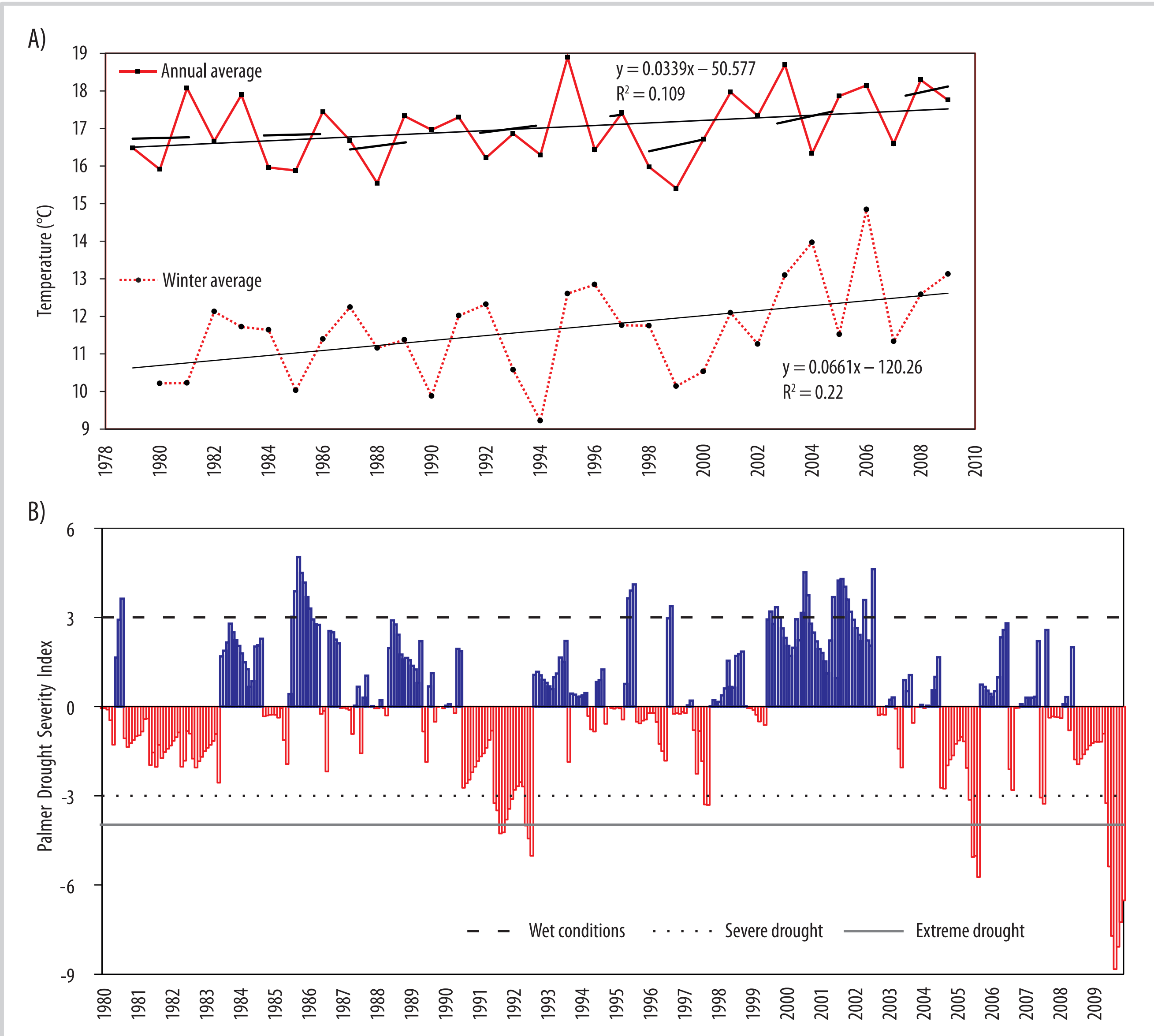
Drought index: The monthly PDSI reading for the meteorological drought index in Dubachour station showed that drought occurred in the study area (Figure 4B). Severe drought (PDSI between −3 and −4)

TABLE 1 Participatory tools used during the CRiSTAL exercise.

Tool	Objective of tool	Process and outcomes
Livelihood resource mapping	Identify the resources that are most important to the livelihoods of the focus communities.	Participants were asked to draft a map of their community showing its boundaries, key facilities, and resources (including crops, livestock, houses, schools, temples, health post [local health facility], roads, forested areas, and water bodies). Next, we linked the map to the most important livelihood resources, which were divided into 6 categories: natural, physical/infrastructure, financial, human, social, and political. The participants then prioritized the most important resources (ideally at least 2 from each category) and discussed who benefited from and who controlled each resource.
Seasonal cultivation calendars	Identify the timing of cropping patterns for major crops.	An empty calendar was prepared in advance on brown paper, including a legend with simple symbols for each activity. Participants identified their most important crops and then discussed when each was planted and harvested; one participant noted each activity on the calendar using the designated symbols. Next, the months in which each crop is watered and fertilized were noted, along with the insect and disease seasons. Finally, we asked participants to note any changes in cropping patterns over the past 5 years and any other important crop-related activity.
Hazard mapping	Identify and describe the major hazards, the time frame in which each occurs, and locations of the affected resources.	A general discussion was held to make sure that all participants understood the term "hazard." In an open discussion, a list of hazards, including social and non-climate-related risks (such as diseases and political problems) was created using meta cards.[a)] Participants then ranked all identified hazards according to their importance and selected the 3–5 most important hazards. The facilitator asked participants about each hazard's frequency, intensity, and impact on crops and livestock in extreme years and noted their answers. For more complex hazards, a month-by-month hazard calendar was created.
Vulnerability matrix	Determine the hazards with the most serious impact on livelihood resources, and rate the vulnerabilities of the resources.	We prepared a matrix listing hazards along the x-axis and the livelihood resources along the y-axis. Participants rated the impact of each hazard on the livelihood resource using 0 for neutral and 1–3 for negative impacts. On completion, participants summed up all the numbers for each hazard, compared the results, and confirmed whether they all agreed.
Climate risk analysis	Understand the impacts of current and potential hazards on livelihood resources.	Through guided discussions, participants determined the impacts of each hazard, and we noted them on meta cards.[a)] Then we explained and discussed the differences between the direct and the indirect impacts and arranged the cards accordingly. If no indirect impacts were listed, we asked the participants to think of some. Out of all the mentioned impacts, we asked participants to select the 3 most severe. Finally we asked for each impact whether it affected the listed resources negatively or positively.
Responses	Identify current coping strategies, evaluate their sustainability, and identify possible alternative strategies.	For each climate impact identified in the previous exercise, we asked participants to identify current coping strategies and evaluate their sustainability. Next, participants brainstormed a list of possible alternative strategies based on available resources in the village. We further discussed how current or alternative coping strategies might need to evolve given projected changes in climatic conditions. Finally, we asked participants which of the earlier identified resources were required to put current or alternative adaptation strategies into practice.

[a)]Meta cards are pieces of paper cut into A5 size (148 mm × 210 mm), onto which participants wrote and displayed their views during the discussion.

FIGURE 4 Climate variation in the study area: (A) temperature; (B) moisture status



was frequent. Extreme drought (PDSI ≥ −4) occurred from July to December 2009 and June to September 2005. While moderate drought occurred frequently, severe drought occurred only after the 1990s and in greater frequency after 2003.

Local perceptions: About 95% of respondents stated that temperature had increased over the previous 2 decades. But when the same respondents were asked about seasonal temperature changes, 55% stated that summer temperature increased, and 19% said that winters were getting warmer. About 60% reported a decrease of total annual precipitation, but when asked about seasonal rainfall change, 44% and 48% stated a decrease in summer and winter rainfall, respectively; and 38% reported a decrease in snowfall. There was thus less consensus among respondents regarding seasonal changes than annual changes. Nima Lama, a farmer from the upland part of Helambu VDC, said: "Winter snows are favorable for potato planting, but recently snowfall occurred late, in February, which was of no use as it quickly melted and flushed out the fragile fields." Erratic precipitation trends with delayed monsoons were reported for the last 20 years.

Community perceptions of drought agreed only partly with recorded meteorological data. During the CRiSTAL exercise, several respondents recalled significant reductions in crop production in 1992, 1993, 2005, 2008, and 2009, which they attributed mainly to drought. While other reasons for the reduction in crop yields could be declining soil productivity and the fragmentation of land due to increasing population, drought was seen by respondents as the principal reason.

Impacts of changing temperature and precipitation trends: Local perceptions coincide with the meteorological record of increasing temperatures in the Melamchi Valley. Flowering and fruiting of wheat and maize and of some common species such as *Prunus cerasoides*, *Rubus ellipticus*, *Rhododendron arboreum*, and *Myrica esculenta* were reported to have occurred 15–45 days earlier, and this was attributed to climate change. Ranjitkar et al (2013) attributed the earlier onset of rhododendron flowering in the eastern Himalayan region primarily to rising winter temperatures. Such climatic and phenological changes are common in the Himalayas (Ranjitkar et al 2013; Hart et al 2014). Changes in the phenology of crops as a result of climate change can contribute to reducing crop productivity because of earlier anthesis and grain maturity at warmer temperatures, thus shortening the duration of growth and reducing grain yields (Craufurd and Wheeler 2009; Anwar et al 2015). About 62% of household survey respondents and participants in the CRiSTAL exercise reported new crop pests due to increasing temperatures, resulting in crop yield decline and increased production costs (Deka et al 2010). Dawa Lama, a 56-year-old farmer from the upland part of Helambu VDC, said, "In my whole life, I had never seen an infestation of maize at such a high elevation [about 2700 m], and I don't know how to deal with such pests." Unprecedented occurrence of mosquitoes in the uplands was perceived as a consequence of warming in the study area as well as in other parts of the Himalayas (see Chaudhary and Bawa 2011; Manandhar et al 2011). Precipitation has declined in recent years. As most farmland in the study area is rain-fed, declining and untimely monsoon precipitation can impact livelihoods.

Major climate-related hazards and their impacts on livelihood resources

In this paper, we did not include the responses that were given a negligible rank in the CRiSTAL exercise and were reported only by very few respondents in the household survey. In addition, some resources presented in Table 2 (CRiSTAL exercise) were combined during the household survey reporting (eg houses and roads were combined into settlements and infrastructure). Participants in the household survey and CRiSTAL exercise listed similar problems, indicating matching information from different sources. Although major issues reported through the 2 different tools were similar, there were some differences in the ranking and perception.

A vulnerability matrix based on the CRiSTAL exercise (Table 2), which scored each hazard against impacted resources, indicated that farmers were very vulnerable to drought, landslides, crop pests, thunderstorms, hailstorms, and floods, most of all to drought. Drought periods increased in length from 2 months (2005) to 10 months (2009) and 9 months (2010, 2012).

Agriculture and food security: Most hazards have severe impacts on agriculture and, consequently, on food security, as confirmed by participants in the household survey (69% of respondents) and CRiSTAL exercise (Figure 5A, Table 2). They reported that the reduction in crop productivity is due to declining yields of winter crops (especially wheat) and vegetables caused by a reduction in winter precipitation and increase in winter temperatures. They also reported an increasing frequency of extreme events that destroy the harvest. Sivakumar and Stefanski (2011) calculated that a 0.5°C rise in winter temperature can reduce wheat yields by 0.45 t ha^{-1} in India, because wheat is already being grown close to its temperature tolerance threshold. They noted that a temperature rise of more than 2.5°C can lead to a significant decrease in yields of nonirrigated wheat and rice and consequently to a loss in farm-level net revenue of 9–25%. Food production in the study area is sufficient for 8 months only, which means that food has to be purchased, making farmers vulnerable to rising prices (Gum et al 2009). On the other hand, a reported increase in potato yields on irrigated land in the lowlands is probably due to an increase in summer minimum temperatures (Joshi et al 2011).

Water resources: About 33% of respondents stated that water was scarce, possibly due to decreased precipitation, population growth, and changing lifestyles. However, irrigated land has increased in Sindhupalchok (CBS 2010), including in the Melamchi Valley, where nearly 27% of respondents reported scarcity of water in the irrigation canals. This finding concurs with Sijapati and Bhatt (2012) and Pradhan et al (2015), who reported a decline in water supplies in recent years in the Melamchi Valley. Water scarcity can also be due in part to poorly maintained irrigation systems. The Intergovernmental Panel on Climate Change's fifth assessment report predicted that water scarcity caused by increased demand and lack of good management would be a major challenge for most of Asia (IPCC 2014).

Settlements and infrastructure: Even before the 2015 earthquakes, about 20% of respondents lived in houses damaged by landslide, flood, thunderstorm, or strong winds. The CRiSTAL exercise revealed loss of houses and roads. Weather events in the Melamchi Valley during the last 30 years damaged 10 houses and destroyed 14

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TABLE 2 Vulnerability matrix prepared for the Melamchi Valley during the CRiSTAL exercise.

Livelihood resource	Hazard[a)]						
	Drought	Landslides	Crop pests	Thunderstorms	Hailstorms	Floods	Total score (rank)
Agriculture and food security	2	3	2	1	2	1	**11 (I)**
Forests and biodiversity	2	2	1	1	1	1	**8 (II)**
Health	3	1	2	1	1	0	**8 (II)**
Livestock	2	2	2	1	0	1	**8 (II)**
Water	2	2	1	0	0	1	**6 (III)**
Houses	0	2	0	1	1	1	**5 (IV)**
Roads	1	3	0	1	0	0	**5 (IV)**
Irrigation channels	2	1	0	0	0	1	**4 (V)**
Wage labor	2	0	0	0	1	0	**3 (VI)**
Water mills	3	0	0	0	0	0	**3 (VI)**
Total score (rank)	**19 (I)**	**16 (II)**	**8 (III)**	**6 (IV)**	**6 (IV)**	**6 (IV)**	

[a)]Scores: significant impact = 3; medium impact = 2; low impact = 1; no impact = 0.

(www.desinventar.net/DesInventar/results.jsp). It is, however, important to point out that loss of life, livelihoods, and houses through geomorphic events such as landslides can only partly be attributed to climatic factors and is also determined by factors such as topography, geology, seismicity, and land use.

Social capital: Sixty-eight percent of female and 55% of male respondents reported conflicts over water resources, especially in the uplands. During the CRiSTAL exercise, participants reported that conflicts are due to poor management rather than physical scarcity of water. A female respondent said, "Drought has increased women's workloads because we have to walk longer distances to fetch water." Mountainous terrain with steep and fragile slopes makes collection and carrying of water, fuelwood, and fodder even more difficult and dangerous (Gum et al 2009). Although both men and women are vulnerable to climate change, the causes of their vulnerability, and their experience of it, are different, as is their capacity to respond and adapt. Some respondents reported that due to the hardships caused by drought and uncertain rainfall, many people have either changed their occupations or migrated, leaving women behind to face increased workloads. This process has also increased the number of female-headed households in the study area (CBS 2014).

Others: We found that 3.2% respondents mentioned an impact on forest/biodiversity and 2.2% on health of people/livestock (Figure 5A). Hazard scores were higher for these two livelihood resources in the CRiSTAL exercise (Table 2), which contrasts with the findings of the household survey. The differences in the results reflect the concern of the whole community during the CRiSTAL exercise, while the household survey records individual perception.

Adaptive practices

Our study revealed different adaptive practices such as changing farming practices, selling livestock, milk, and eggs, daily wage labor, seasonal or long-term labor migration, and leaving land fallow during the dry season (Figure 5B and Table 3). We found that female participants in both the household survey and the CRiSTAL exercise were less likely to adapt to changes than their male counterparts, due to less adaptive capacity and access to resources. Women and girls spend a lot of time assisting men, while males have more access to education, political affiliation, and membership in various organizations. Moreover, 89% of female respondents had no formal education, which along with less access to physical property decisively lowers their adaptive capacity. Tenge et al (2004) found that female household headship negatively influenced adoption of

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new technologies because female heads of households had less access to land and other resources due to traditional social barriers. Earlier gender studies (Quisumbing and Meinzen-Dick 2001; Meinzen-Dick et al 2010) also highlighted unequal distribution of assets between men and women in rural households and its effect on their adaptive capacities. However, we found no significant difference between male and female perceptions of climate change and climate variability. Therefore, the results for male and female respondents are not presented separately.

Changing farming practices: About 46% of respondents have altered their farming practices. In response to changing precipitation patterns, farmers (lowland to upland) have started less water-demanding agriculture practices such as plastic tunnel vegetable farming. Bal Bahadur Khadka, a farmer from Ichok VDC, shared his experience: "I was involved in paddy and vegetable farming in the lower valley of Melamchi. Late monsoon onset and longer droughts in recent years have affected paddy plantation, whereas a decrease in winter rainfall has reduced vegetable production. Recently, I have started vegetable planting in plastic tunnels."

In Nepal, some district-level offices such as the District Agriculture Development Office have initiated climate change adaptation activities focusing on water and soil conservation. Activities include agroforestry in the leasehold forestry program, small irrigation programs, and plastic tunnels for vegetable production (Tiwari et al 2014).

Rice is usually planted in May and June before the first rainfall. However, in drought years, farmers delay transplantation. As a response to drought, midhills farmers started planting Ghaiya and Khumal-4 rice (which is drought resistant and matures in 141 days), whereas lowland farmers adopted Makwanpur-1 and Malika rice (which requires less fertilizer and is flood-resistant). Such practices were also reported by Manandhar et al (2011) and Sada et al (2013).

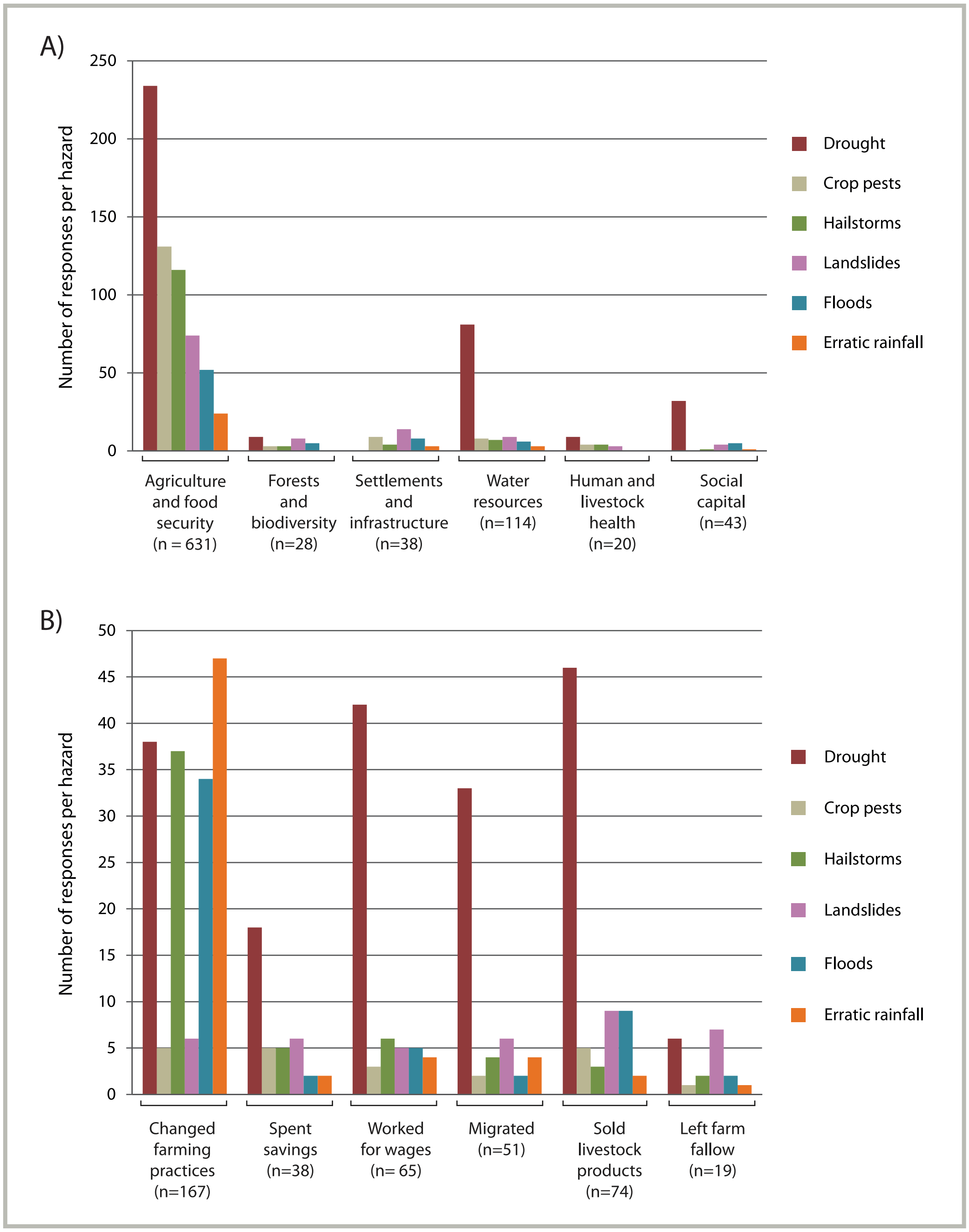
While such measures can be clearly linked to climate change, others are a response to a different or wider range of changes. During our survey, we also noticed continuation as well as reintroduction of traditional agroforestry practices that incorporate timber and fodder trees such as *Bauhinia variegata* and *Alnus nepalensis*. This is common in farming and farming/livestock systems in the midhills of Nepal (Tulachan and Neupane 1999) as an adaptation to the scarcity of leaf fodder for livestock caused by deforestation and forest degradation. Ram Bahadur Tamang, a 66-year-old farmer from Mahankal VDC in the midland, said, "I have a big alder tree and some smaller alder trees on my farm; they provide fuelwood for cooking and fodder for goats and buffalos. Once smaller trees get taller, I can cut and sell them in the local market." Similarly, crop diversification and multicropping (vegetable, potato, and cereal with fruit trees, and cash crops such as coffee and cardamom with fodder trees) were adopted by farmers according to their suitability for the relevant agro-ecological zone. Multicropping has advantages over more labor-intensive single cropping because it is more resistant to pest attacks, diversifies the diet, and reduces crop failure risk.

Selling livestock, milk, and eggs: The fact that measures adopted by farmers in the lowland and midhills can be adaptations to multiple changes applies especially to the selling of livestock, milk, and eggs in the Melamchi Valley. About 20% of respondents perceived a change in living standard from selling livestock and milk. Out of 365 respondents, 154 owned cows and 264 owned buffaloes. Milk production increased from 14 313 to 24 772 metric tons from 2004 to 2013 in Sindhupalchok district (MoAD 2013). There is tremendous potential in this area for increasing dairy livestock production and productivity because of high market demand (MoAD 2013). However, climate change can affect livestock productivity, directly as well as indirectly through changes in the availability of fodder (FAO 2007). Planting fodder trees on farmland as a source of nutrition for the increasing livestock population can help to offset fodder scarcity caused by climate change. In addition, shade from trees can reduce heat stress caused by climate warming, and planting timber trees can bolster farmers' livelihoods.

Wage labor and migration: Wage labor and migration are common adaptation strategies of poor households, particularly in upland and midhills areas. Graner (1996) reported that poor households sold their labor for 10–12 days per month, comparable to the present situation in the Melamchi Valley. In the past, local people migrated mainly because of poverty and to take advantage of new economic opportunities. However, migration can also be a strategy to adapt to a changing climate (de Moor 2011). Declining agricultural production due to drought conditions was identified by local respondents as one of the major drivers of migration. While seasonal migration has been a traditional strategy for a long time in the uplands (Bishop 1998), the number of households involved is increasing, in response to either impacts of climate change or socioeconomic changes. Almost 32% of all households reported a family member migrating for employment. Remittances are responsible for almost 20% of the poverty decrease since 1995 (Lokshin et al 2007). Hence, for the people living in poverty in Nepal, labor migration is one of the most powerful opportunities for prosperity.

Other strategies: Due to a shift in winter precipitation, farmers who used to plant winter crops leave their farmland fallow (4.5% of respondents) during winter,

FIGURE 5 (A) Impacts of major hazards as reported by households participating in the study; (B) household strategies to respond to the impacts of major hazards.



especially in the uplands. Some respondents reported using higher amounts of chemical fertilizer and pesticides than before to increase crop production, which is also reported in the national census report (CBS 2010). Excessive use of chemical fertilizers and pesticides gives good yield for the first year but reduces natural soil fertility and the resistance of plants to harmful micro-organisms. It also increases resistance of the target pests to pesticides in subsequent years. Only few respondents reported using previous savings (9.1% of respondents) as an adaptation strategy. Such a strategy could be useful in a community where food security and savings are good.

All of the practices described above, which are actually short-term responses, fit into the scope of coping strategies as defined by the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC 2014).

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TABLE 3 Climate risk analysis prepared during the CRiSTAL exercise, with current response strategies and possible strategies for improving adaptive capacity. (Table continued on next page.)

Hazard	Impacts	Current responses	Sustainable?	Strategies for improving adaptive capacity
Drought	Decline in crop yield	Land left barren during dry season	No—less food and less income	• Integrated water resources management and irrigation channel development • Integrating early-maturing and drought-tolerant varieties with new technologies • Integrated management of livestock, fodder trees, and crops; such agroforestry systems provide easy access to nutritious fodder for livestock
		Late sowing	Yes	
		Increased use of intercropping	Yes	
	Less water for household use and irrigation	Use of less water-intensive agriculture (plastic tunnel vegetable farming, use of improved varieties) Developed irrigation channels that connect the VDC with high water availability to the VDC with water scarcity	Yes	
		Livestock farming, sale of livestock products (milk and eggs)	Yes	
		Labor migration	Yes	
Crop pests and diseases	Decline in crop yield	Use of chemical fertilizers and pesticides	No—reduces natural soil fertility and resistance of plants to harmful micro-organisms; increases resistance of the targeted pests to pesticides	• Integrated pest and disease management • Scientifically sound mixed cropping based on experience in other areas
		Mixed cropping	Yes	
Floods	Destruction of houses and roads	Loans from friends, relatives, financial institutions, and co-operatives	No—requires high interest payments	• Promotion of flood-tolerant varieties and development of early flood warning systems for saving livestock • Adoption of fish farming in flood-prone areas
	Loss of lives and livestock	Nothing done		
	Damage to crops, specially rice	Use of flood-tolerant rice variety	Yes	
Landslides	Destruction of houses, roads and farmland	Daily wage labor as immediate alternative measure when cultivation activities are not possible	Yes	• Soil and water conservation technologies • Management of mountain slopes with improved agroforestry practices that diversify livelihoods
		Farmland left fallow until next year	No	
	Loss of lives and livestock	Nothing done		

TABLE 3 Continued. (First part of Table 3 on previous page.)

Hazard	Impacts	Current responses	Sustainable?	Strategies for improving adaptive capacity
Hailstorms	Loss or damage of major crops	Plastic tunnels to protect from hailstorms	Yes	• Increased use of agroforestry, which can help prevent crop damage
Erratic rainfall	Decline in crop yield	Crop diversification and increased intercropping	Yes	• Agroforestry based on integration of vegetables and cash crops with locally available nitrogen-fixing trees and fodder and fruit trees

These practices use available skills and resources with the aim of maintaining the basic functioning of an existing livelihood system. Rural livelihoods in mountain areas such as the Melamchi Valley are determined by availability of natural resources like water, forest, and land. Climate is an important driver of change of these resources, but other drivers of change include demographic changes such as population growth, rural–urban migration, and requirements for a healthy life (clean water, sanitation, and nutrition). Consequently, any adaptation strategies to cope with climate change and variability must also prove adaptive within a larger context of ongoing economic, political, technological, and environmental dynamics, many of which are not driven by climate (Crane et al 2010).

Some strategies reported by respondents, such as planting drought- and flood-resistant varieties and raising vegetables in plastic tunnels (Tiwari et al 2014), can be linked to climate. Other measures, such as day labor and labor migration, selling livestock and livestock products, leaving farmland fallow, and planting fodder trees are related to both climate and socioeconomic drivers that include nonclimatic variables such as market forces, resource exploitation, government policy, availability of labor, land and property rights, credit and insurance, access to technology, management capacities, and population density. These nonclimatic variables may either compound or reduce climate-related stress. Therefore, development of sustainable adaptation strategies must account for both climatic and nonclimatic factors (Arendse and Crane 2010).

Strategies for improving adaptive capacity

Based on the CRiSTAL exercise and direct observation, integrated water resources management, improving existing agroforestry along with livestock and agricultural management, and providing drought- and flood-tolerant crop varieties have been identified as suitable measures for enhancing the adaptive capacity of farming communities (Table 3). Our results show that while water resources are not scarce in this region, inefficient water allocation, and seasonal as well as regional fluctuations in supply and demand, require more efficient management. Another result from our study is the need to adjust farming practices to respond to climate change and other hazards and to better utilize the potential of activities that already show promise, such as livestock management and milk production as well crop diversification and cash-crop production. In this sense, farming practices need be adapted to changing phenological patterns of crops and crop pests, which also involves integrated pest management (Figure 6). Moreover, agroforestry practices that can be based on the integration of cash crops (eg *Amomum subulatum*) and medicinal plants with locally available nitrogen-fixing trees (eg *Alnus nepalensis*), or on the planting of fodder and fruit trees (eg *Choerospondias axillaris*, *Morus alba,* and *Phyllanthus emblica*) on farmland, can increase household income, mitigate climate change effects, and improve site conditions (Bernier et al 2013). For selecting the appropriate tree crop, the environmental conditions in the relevant agro-ecological zone must be considered (Ranjitkar et al 2016). Fodder trees (eg *Artocarpus lakoocha*, *Ficus semicordata*, *Litsea monopetala,* and *Bauhinia variegata),* which are already widely distributed and intercropped in the study area, yield nutritious fodder for more milk production and help to bridge the dry-season feed gap (Paudel and Tiwari 1992). Furthermore, fodder from fodder trees can be used to stall-feed livestock, reducing animal movement and risks related to soil erosion such as landslides, which are a major hazard in this region.

Conclusion

Understanding communities' perceptions and assessing their adaptive and proactive capacities are important strategies to establish successful risk-management programs (IPCC 2007a). The CRiSTAL tool and the household survey have helped to identify and prioritize climate risks and livelihood resources important for climate adaptation. The CRiSTAL exercise as an add-on to household surveys encourages people to consider

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FIGURE 6 Demonstration plots testing integrated pest management with different crops. The program, initiated by farmers, could evolve into a long-term adaptation strategy. An agroforestry practice is visible in the background. (Photo by Sailesh Ranjitkar)

strategies for adapting to environmental changes affecting their immediate surroundings.

The participatory process that is inherent in the CRiSTAL exercise generates a space for discussion among a wide range of local stakeholders, which makes CRiSTAL an appropriate tool not only for documenting current responses but also for developing promising adaptation practices using a bottom-up approach and supporting the development of resilient mountain communities as outlined in NAPA. Therefore, CRiSTAL can be recommended as valuable tool for LAPA.

The research revealed that farmers' strategies for adaptation to changes are mostly related to socioeconomic drivers and to some extent to climatic factors. Existing opportunities to cope with changes relate mostly to nonclimatic variables such as available resources, government policy, labor supply, market conditions, and property rights; therefore, these variables need to be considered during adaptation planning.

The mountain farmers' communities in our study area identified the need for more efficient water management and for adjusting farming practices to better utilize the potential of already promising activities such as livestock management, milk production, crop diversification, and cash-crop production to respond to climate change and other hazards. With better support and planning, these measures could be adjusted to meet future climate-change–related risks to mountain development.

As mentioned earlier, conditions in the study area were changed by the devastating earthquakes of 2015. In light of this disaster, some of the strategies identified in our study may not be an immediate priority while relief measures and rebuilding of infrastructure take precedence, but they should be considered when more effort can focus on rebuilding livelihoods.

A post-earthquake assessment in the study area by our team in April–June 2015 did show that adaptation options mentioned in this paper were implemented immediately after the earthquake. Some, like selling livestock and milk as well as outmigration, had already been practiced before the earthquake and may have even increased as a response to the disaster. Planting drought-resistant rice varieties on paddy land in the planting season right after the earthquake, on the other hand, is an adaptation to changed climatic conditions. Farmers who opted for this practice were obviously not put off by the disaster. A full assessment of the impact of the earthquake on adaptation strategies requires, however, a more detailed survey, for which the research presented in this paper can provide a valuable baseline.

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REFERENCES

Anonymous. 2015. Historic earthquake of Nepal: 1310 to 2072. *Nagarik Post.* 29 July 2015, pp. 1–3.
Anwar MR, Liu DL, Farquharson R, Macadam I, Abadi A, Finlayson J, Wang B, Ramilan T. 2015. Climate change impacts on phenology and yields of five broadacre crops at four climatologically distinct locations in Australia. *Agricultural Systems* 132:133–144.
Arendse A, Crane TA. 2010. *Impacts of Climate Change on Smallholder Farmers in Africa and Their Adaptation Strategies: What Are the Roles for Research?* Report No 221. Arusha, Tanzania: Centro Internacional de Agricultura Tropical (CIAT); Pan-Africa Bean Research Alliance (PABRA).
Avouac J-P, Meng L, Wei S, Wang T, Ampuero J-P. 2015. Lower edge of locked Main Himalayan Thrust unzipped by the 2015 Gorkha earthquake. *Nature Geoscience* 8:708–711.
Bernier Q, Franks P, Kristjanson P, Neufeldt H, Otzelberger A, Foster K. 2013. *Addressing Gender in Climate-Smart Smallholder Agriculture.* ICRAF Policy Brief 14. Nairobi, Kenya. World Agroforestry Centre (ICRAF).
Bishop NH. 1998. *Himalayan Herders.* Case Study in Cultural Anthropology Series. New York, NY: Harcourt Brace College.
CBS [Central Bureau of Statistics]. 2006. *Environmental Statistics of Nepal.* Kathmandu, Nepal: Government of Nepal.
CBS [Central Bureau of Statistics]. 2010. *District Profile of Sindhupalchok.* Thapathali, Kathamandu: Government of Nepal.
CBS [Central Bureau of Statistics]. 2014. *National Population and Housing Census 2011: General and Social Characteristics Tables.* Kathmandu, Nepal: Government of Nepal.
Chaudhary P, Bawa KS. 2011. Local perceptions of climate change validated by scientific evidence in the Himalayas. *Biological Letters* 7:767–770.
Crane TA, Roncoli C, Paz J, Breuer N, Broad K, Ingram KT, Hoogenboom G. 2010. Forecast skill and farmers' skills: Seasonal climate forecasts and agricultural risk management in the Southeastern United States. *Weather, Climate, and Society* 2:44–59.
Craufurd PQ, Wheeler TR. 2009. Climate change and the flowering time of annual crops. *Journal of Experimental Botany* 60:2529–2539.
de Moor N. 2011. *Labour Migration for Vulnerable Communities: A Strategy to Adapt to a Changing Environment.* COMCAD Arbeitspapiere–Working Papers 101. Bielefeld, Germany: Center on Migration, Citizenship and Development (COMCAD).
Deka S, Byjesg K, Kumar U, Chodhary R. 2010. Climate change and its impacts on crop pests—A critique. *In:* Panigrahy S, Ray SS, Parihar JS, editors. *Impact of Climate Change on Agriculture.* International Society for Photogrammetry and Remote Sensing [ISPRS] Archives 48.8/W3, Ahmedabad, India. pp 147–149.
DFSN [District Food Security Network]. 2015. *Food Security Bulletin.* Kathmandu, Nepal: District Agriculture Development Office, Government of Nepal and World Food Program.
FAO [Food and Agriculture Organization of the United Nations]. 2007. *Adaptation to Climate Change in Agriculture, Forestry and Fisheries: Perspective, Framework and Priorities.* Rome, Italy: FAO.
Gentle P, Maraseni TN. 2012. Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. *Environmental Science Policy* 21:24–34.
Graner E. 1996. *User Group Forestry—Poor Policy for Poor People? Nepal's Forest Legislation from a Political Ecology Perspective* [PhD thesis]. Freiburg, Germany: Freiburg University.
Gum W, Singh PM, Emmett B. 2009. *Even the Himalayas Have Stopped Smiling: Climate Change, Poverty and Adaptation in Nepal.* Lalitpur, Nepal: Oxfam Country Programme Office.
Guttman NB. 1998. Comparing the palmer drought index and the standardized precipitation index. *Journal of the American Water Resources Association* 34(1):113–121.
Hart R, Salick J, Ranjitkar S, Xu J. 2014. Herbarium specimens show contrasting phenological responses to Himalayan climate. *Proceedings of the National Academy of Sciences of the United States of America* 111: 10615–10619.
HELVETAS [HELVETAS Swiss Intercooperation Nepal]. 2011. *Nepal's Climate Change Policies and Plans: Local Communities' Perspective.* Lalitpur, Nepal: HELVETAS Swiss Intercooperation Nepal.
IISD [International Institute for Sustainable Development]. 2012. *CRiSTAL User's Manual Version 5.* Winnipeg, Canada: IISD.
IPCC [Intergovernmental Panel on Climate Change]. 2007a. Summary for policymakers. *In:* Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editors. *Climate Change 2007: The Physical Science Basis.* Geneva, Switzerland: IPCC Secretariat, pp 1–18.
IPCC [Intergovernmental Panel on Climate Change]. 2007b. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL. Cambridge, United Kingdom, and New York, NY: Cambridge University Press.
IPCC [Intergovernmental Panel on Climate Change]. 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, et al. Cambridge, United Kingdom, and New York, NY: Cambridge University Press.
Joshi NP, Maharjan KL, Piya L. 2011. Effect of climate variables on yield of major food-crops in Nepal—A time-series analysis. *Journal of Contemporary India Studies: Space and Society* 1:19–26.
Kohler T, Giger M, Hurni H, Ott C, Wiesmann U, Wymann von Dach S, Maselli D. 2010. Mountains and climate change: A global concern. *Mountain Research and Development* 30:53–55.
Lokshin M, Bontch-Osmolovski M, Glinskaya E. 2007. *Work-Related Migration and Poverty Reduction in Nepal.* Report No 4231. Washington, DC: World Bank.
Macchi M. 2011. *Framework for Community-Based Climate Vulnerability and Capacity Assessment in Mountain Areas.* Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD).
Manandhar S, Vogt DS, Perret SR, Kazama F. 2011. Adapting cropping systems to climate change in Nepal: A cross-regional study of farmers' perception and practices. *Regional Environmental Change* 11:335–348.
Meinzen-Dick R, Biermayr-Jenzano P, Wilde V, Noordeloos M, Catherine Ragasa, Beintema N. 2010. *Engendering Agricultural Research.* IFPRI Discussion Paper. Washington, DC: International Food Policy Research Institute.
MoAD [Ministry of Agricultural Development]. 2013. *Statistical Information on Nepalese Agriculture 2012/2013.* Kathmandu, Nepal: Government of Nepal, MoAD.
MoE [Ministry of Environment]. 2010a. *Climate Change Vulnerability Mapping for Nepal.* Kathmandu, Nepal: Government of Nepal, MoE.
MoE [Ministry of Environment]. 2010b. *National Adaptation Programme of Action to Climate Change.* Kathmandu, Nepal: Government of Nepal, MoE.
Morton JF. 2007. The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences of the United States of America* 104:19680–19685.
Paudel KC, Tiwari BN. 1992. Fodder and forage production. *In:* Abington JB, editor. *Sustainable Livestock Production in the Mountain Agro-Ecosystem of Nepal.* FAO Animal Production and Health Paper No 105. Rome, Italy: Food and Agriculture Organization. pp 131–154.
Pradhan NS, Sijapati S, Bajracharya SR. 2015. Farmers' responses to climate change impact on water availability: Insights from the Indrawati Basin in Nepal. *International Journal of Water Resources Development* 31: 269–283.
Quisumbing AR, Meinzen-Dick RS. 2001. *Empowering Women to Achieve Food Security.* A 2020 Vision for Food, Agriculture and the Environment, Policy Brief. Washington, DC: International Food Policy Research Institute.
Ranjitkar S, Luedeling E, Shrestha KK, Guan K, Xu J. 2013. Flowering phenology of tree rhododendron along an elevation gradient in two sites in the Eastern Himalayas. *International Journal of Biometeorology* 57:225–240.
Ranjitkar S, Sujakhu NM, Lu Y, Wang Q, Wang M, He J, Mortimer P, Xu J, Kindt R. 2016. Climate modelling for agroforestry species selection in Yunnan Province, China. *Environmental Modelling and Software* 75:263–272.
Sada R, Shrestha A, Lieke M, Shukla A. 2013. *People's Experience and Facts of Changing Climate: Impacts and Responses.* Peri Urban Water Security Discussion Paper Series, Paper No. 8, SaciWATERs. Secunderabad, India: SaciWATERs.
Sharma E, Tsering K. 2009. Climate change in the Himalayas: The vulnerability of biodiversity. *In:* Sharma E, Khadka I, Shakya B, editors. *Biodiversity and Climate Change in the Himalayas.* Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD), pp 10–12.
Shrestha AB, ***Wake CP***, ***Mayewski PA***, ***Dibb JE***. 1999. Maximum temperature trends in the Himalaya and its vicinity: An analysis based on temperature records from Nepal for the period 1971–94. *Journal of Climate* 12: 2775–2786.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00032.1

Sijapati S, Bhatt D. 2012. Perception and realities of the impact of global changes on water resources and agricultural practices-preliminary findings of AGloCAP project in Indrawati basin, Nepal. *Hydro Nepal: Journal of Water, Energy and Environment* (Special Issue: Conference Proceedings). 11(1):35–41.
Sivakumar MVK, Stefanski R. 2011. Climate change and food security in South Asia. *In:* Lal R, Sivakumar MVK, Faiz SMA, Mustafizur Rahman AHM, Islam KR, editors. *Climate Change and Food Security in South Asia.* Dordrecht, the Netherlands: Springer, pp 14–30.
Smit B, Wandel J. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16:282–292.
Tenge AJ, Graaff J De, Hella JP. 2004. Social and economic factors affecting the adoption of soil and water conservation in West Usambara highlands, Tanzania. *Land Degradation and Development* 15:99–114.
Tiwari KR, Rayamajhi S, Pokharel R, Balla MK. 2014. Determinants of the climate change adaptation in rural farming in Nepal Himalaya. *International Journal of Multidisciplinary and Current Research* 2:234–240.
Tulachan PM, Neupane A. 1999. *Livestock in Mixed Farming Systems of the Hindu Kush-Himalayas: Trends and Sustainability*. Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD).
Upreti B. 1999. An overview of the stratigraphy and tectonics of the Nepal Himalaya. *Journal of Asian Earth Sciences* 17:577–606.
Xu J, Grumbine RE. 2014. Integrating local hybrid knowledge and state support for climate change adaptation in the Asian Highlands. *Climatic Change* 124:93–104.
Xu J, Grumbine RE, Shrestha A, Eriksson M, Yang X, Wang Y, Wilkes A. 2009. The melting Himalayas: Cascading effects of climate change on water, biodiversity, and livelihoods. *Conservation Biology* 23(3):520–530.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00032.1