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Climate change-induced hazards and local adaptations in agriculture: a study from Koshi River Basin, Nepal

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Abstract Changes in climate, associated hazards, local adaptations in agriculture, and socioeconomic factors affecting adaptation were investigated using data from a large survey of 2310 households (HHs) in the Koshi River Basin (KRB), Nepal. More than 80% of HHs had perceived changes in climate in the 10 years preceding the survey, and 20–40% had perceived increases in the occurrence of droughts, dry spells, floods, and livestock diseases. Around 36–45% of crop-growing HHs perceived a decline in the production of staple crops such as paddy, wheat, maize, and millets, which was mainly attributed to climate change and related hazards. The decline in local food production meant that HH dependence on external sources for food had increased. Only 32% of HHs had taken some form of adaptive actions in agriculture to address these challenges; actions included not planting certain crops, introducing new crops, changing farming practices, not rearing certain livestock species, and investing in irrigation. The factors affecting the likelihood of a household undertaking adaptive actions included literacy of the head of household, household size, size of owned agricultural land, diversification of income sources, and insurance. Based on these findings, the study has suggested some approaches in the KRB which could contribute to building agricultural resilience to climate change.

Keywords Climate change · Hazards · Local adaptation · Agriculture · Socioeconomic factors · Food security · Koshi River Basin · Nepal

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1 Introduction

People in the Hindu Kush Himalayan (HKH) region are highly vulnerable to food insecurity as a result of low agricultural productivity, a subsistence economy, terrain constraints, poor infrastructure, limited access to markets, physical isolation, vulnerability to natural hazards, and the high cost of food production and transportation (Tiwari and Joshi 2012; Giribabu 2013; Rasul et al. 2014). The rising impacts of climate change have further added to the challenge of food insecurity (Hussain et al. 2016). The rise in temperature in the HKH region is higher than the global average (Eriksson et al. 2009; IPCC 2013). Precipitation patterns have also changed, but without a uniform trend across the region, and hazards such as floods and droughts have become more frequent. The impacts of climate change are greater at smaller scale (e.g., sub-basin level) than at larger scale (e.g., basin level) (Bharati et al. 2016; Hussain et al. 2016). The occurrence of climate change-induced hazards in upstream areas is also leading to severe impacts downstream as they trigger migration to downstream areas, increase competition for food, accommodation, and income, and prompt pressure on natural resources and production systems to meet the food demand in downstream areas (ICIMOD 2008; Rasul and Hussain 2015).

Climate change in the Koshi River Basin (KRB) is severely impacting water resources, agriculture, food security, and local livelihoods (Hussain et al. 2016). There is a significant temporal and spatial variability within the basin in precipitation, actual evapotranspiration, and water availability (Bharati et al. 2011, 2016). Projections suggest that in general wet seasons are likely to become wetter and dry seasons drier, resulting in a decline in river discharge during low-flow months (Sharma et al. 2000; Bharati et al. 2011, 2016). The changes in extremes will increase the difference between high- and low-flow regimes, and the likelihood of both droughts and floods will increase (Dixit et al. 2009; NCVST 2009).

Frequent dry spells and prolonged droughts in the KRB are affecting crop productivity and contributing to degradation of rangelands and pasture with a loss of soil nutrients, water, and biomass and an accompanying decline in livestock productivity (MoE-Nepal 2010, 2012). Farmers in the basin are adopting different practices to cope with the severe impacts of these changes, such as changing from high water consumption crops (paddy), to high value, low water requirement fruits, and vegetables (potato, onion, and garlic) (Hussain et al. 2016). They are also making small changes to the cropping calendar and exploring improved seed varieties (Hussain et al. 2016), as well as introducing low water agricultural technologies such as drip irrigation for vegetables (Bartlett et al. 2010). A significant number of households have also started new off-farm income activities as an adaptation strategy to support their food security and livelihoods (Saikia 2012; Sarkar et al. 2012; Hussain et al. 2016).

Most farmers in the KRB are adapting autonomously to climate change. However, there are still thousands of subsistence and small farmers who face challenges in taking adequate adaptive action due to high costs, labor shortages resulting from outmigration, limited access to technology and inputs, and lack of awareness. Hussain et al. (2016) reported that a quarter of small farmers in the basin face frequent labor shortages during the critical periods for agriculture due to outmigration of household members and that close to 6% of cultivable land was left fallow or abandoned as a result, leading to low agricultural production. There is some evidence (e.g., Banerjee et al. 2011) that active household members prefer to migrate to diversify their sources of income and take advantage of new options that were not available to previous generations, indicating that there is a trade-off between agricultural production and non-farm income.

Evidence from the literature indicates that farm households' decisions on adaptation to climate change depend on a range of socioeconomic and physical factors. A study by Tiwari et al. (2014) in three different agro-climatic regions in Nepal indicated that factors such as resource availability, family labor availability, farm income, institutional activities, and involvement in community level organizations influenced farmers' decisions on taking adaptive actions. Provision of support services, such as credit, training, and extension also plays an important role in increasing the likelihood of adaptation by farmers (Deressa et al. 2009; Tesso et al. 2012; Mulatu 2013; Paudel and Thapa 2004). Surminski (2010) found that access to insurance for property damage, livestock death, or human health can also result in increased adaptive capacity and resilience. The gender of the household head also significantly affects household adaptation to climate change as does age of the head of household. Male-headed households are more likely to have information about new technologies and take risky decisions than female-headed households (Asfaw and Admassie 2004; Deressa et al. 2009; Legesse et al. 2013), while older farmers may have the experience and knowledge needed to assess available technologies (Gbetibouo 2009). Literate farmers are also likely to have more information on climate change, which might increase the probability of adopting adaptation strategies (Ndambiri et al. 2013). Farm and non-farm income can have a positive and significant influence on taking adaptive action as farmers with greater financial capacity are likely to have better access to information and are more able to consider planning for longer-term benefits (Deressa et al. 2008; Mulatu 2013).

Although there have been a number of studies on climate change adaptation in agriculture, there remains a dearth of large-scale good quality studies which have analyzed the changing climate, climate change-induced hazards, and local adaptations in agriculture. The present study used a large data set from 2310 households surveyed in 2011–2012 in the KRB of Nepal to investigate farming systems, household food security, and households' perception of and adaptation to climate change in agriculture, together with the socioeconomic factors that influence adaptation. To the best of our knowledge, no study has investigated the socioeconomic factors involved in adaptation, particularly using a large household data set and from this region. The findings can be used as an input for policy on formulating strategies to improve adaptation in agriculture and achieve sustainable food security in the KRB and other similar areas.

2 Methodology

2.1 Study area and sampling design

The KRB is a transboundary basin; the river originates in the southern part of the Tibetan Plateau in China, flows through Nepal from north to south, and then enters the northern part of Bihar in India before joining the Ganges. The basin has a total area of 87,481 km^2, 32% in China, 45% in Nepal, and 23% in India. It is home to 39.2 million people, with higher population densities in the southern part of Nepal and Bihar (Neupane et al. 2015). In Nepal, 27 districts are included in the KRB; they had a population of 11.7 million in 2011 (CBS 2014), an increase of 49% since 1991, equivalent to an average annual growth rate of 2% (1991–2011) (CBS 2003, 2014). Assuming the same growth rate, the current (2017) population of the KRB in Nepal is projected to be 13.2 million. Agriculture and livestock are the main livelihood options for communities in the basin with a direct link to water.

The data used in this study were collected in 2011–2012 from the Nepal part of the KRB by the International Centre for Integrated Mountain Development (ICIMOD) using a large-scale survey tool for poverty and vulnerability analysis (PVA). Six districts were selected for the survey (Khotang, Dolakha, Kavrepalanchok, Sunsari, Siraha, and Udayapur, see Fig. 1) based on their high vulnerability to climate change, and representativeness in terms of ecological aspects (mountains and plains). The sampling design has some limitations, and data may not be fully representative of the whole KRB because the Indian part was not considered and the districts in Nepal were selected purposively rather than by random sampling. Thus, the results should be considered indicative for the whole basin, and caution should be exercised in generalizing to basin level.

A total of 2310 households were interviewed, 385 in each of the six districts. The number of households surveyed per settlement within each district was taken to be proportional to the total population. Household selection followed a two-stage process. First, districts were stratified into several strata based on socioeconomic and ecological factors and a certain number of settlements selected randomly from each stratum. Second, households within a settlement were selected using a random route procedure in which one enumerator from the survey team began at the center of the settlement and the remaining enumerators at the periphery. The enumerators walked in a direction chosen at random and counted the houses until they reached a number determined before the start. This process was continued until the household quota set for the settlement was met. If a selected house was empty or the household did not wish to participate, the adjacent house was selected.

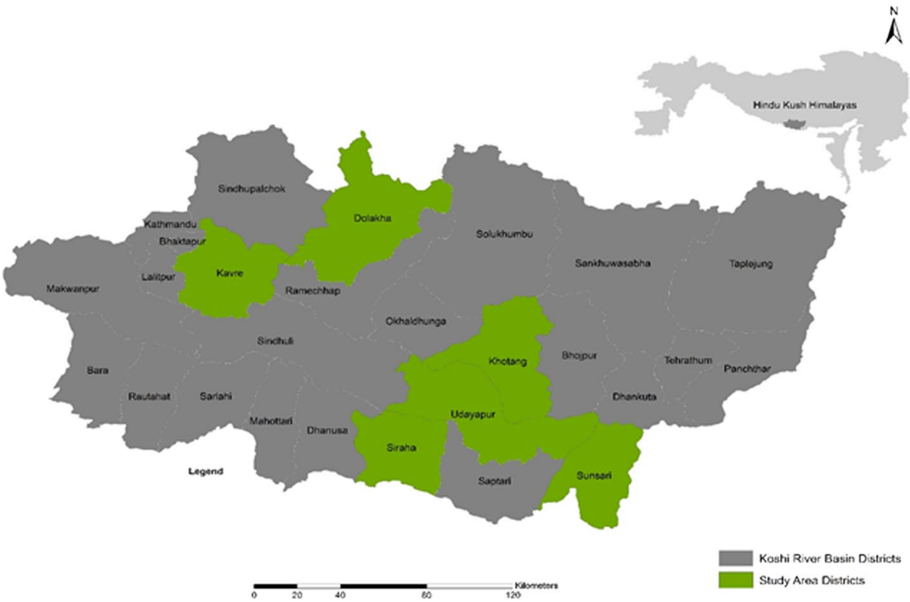

Fig. 1 Koshi River Basin, Nepal

2.2 Empirical model and selection of variables

A logistic regression model (LRM) was used to empirically analyze the relationship between socioeconomic factors and the dependent dichotomous variables for farmers' adaptive agricultural actions.

$$Pi = E(Y = 1|Xi) = \frac{1}{1 + \mathrm{e}^{-(\alpha + BiXi)}} \quad (1)$$

where Pi represents the probability of taking an adaptive action, α is a constant, Xi is the vector for independent variables, and Bi is the vector for coefficients of independent variables. For simplicity, we write this equation as

$$Pi = \frac{1}{1 + \mathrm{e}^{-Zi}} = \frac{\mathrm{e}^{Zi}}{1 + \mathrm{e}^{Zi}} \quad (2)$$

where

$$Zi = \alpha + BiXi$$

α is constant, Xi is the vector for independent variables, and Bi is the vector for coefficients of independent variables.

The probability of not taking an adaptive action is $(1 - Pi)$.

$$1 - Pi = \frac{1}{1 + \mathrm{e}^{Zi}} \quad (3)$$

Thus, the odds ratio in favor of taking an adaptive action (the probability that a household will take an adaptation action compared to the probability that it will not take an action) is presented in Eq. 4.

$$\frac{Pi}{1 - Pi} = \frac{1 + \mathrm{e}^{Zi}}{1 + \mathrm{e}^{-Zi}} = \mathrm{e}^{Zi} \quad (4)$$

To ensure the internal validity of the estimates, the most relevant socioeconomic factors in the context of the KRB were identified from a literature review. The variables identified as potentially having a strong influence on a farmer's decision to take an adaptive action were gender, age, and education of the household head, household size, size of owned agricultural land, diversity of income sources, insurance facilities, and outmigration.

'Gender of household head' was taken as a variable based on the assumption that male-headed households are more likely to have access to new technologies related to adaptation (Asfaw and Admassie 2004; Deressa et al. 2009; Legesse et al. 2013), 'age' because older farmers may have the experience needed to assess the available adaptation related technologies (Gbetibouo 2009), and 'education' because better educated farmers are more likely to take adaptation actions due to their better understanding of climate change (Ndambiri et al. 2013). 'Diversification of income sources' was taken as a proxy for non-farm income because financial capacity may result in longer-term adaptation planning (Deressa et al. 2008; Mulatu 2013), 'agricultural land' as a proxy for farm income and farm surplus (Hussain and Thapa 2015; Garrett and Ruel 1999; Ram et al. 1999), and 'insurance facility' as a proxy for institutional services which may influence farmers' behavior on adaptation (Tiwari et al. 2014). 'Household size' was taken as a variable based on the expectation that having more household members might increase the likelihood of taking adaptation actions (Abid et al. 2015). 'Sending at least one migrant' was taken as a variable to test two assumptions: first that outmigration may result in labor shortages for agriculture (Hussain et al. 2016) which might reduce the ability to take adaptive actions, and second that outmigration may result in increased income in the form of remittances, which could enhance the capacity to take adaptive actions (Banerjee et al. 2011).

3 Results

3.1 Socioeconomic characteristics of households

The findings on the socioeconomic characteristics of the households are summarized in Table 1. The average household size was six. The majority of households had access to agricultural land (96% of it owned, mostly by men) with small average landholdings (< 1 hectare); more than 80% also raised livestock. On average, more than three household members worked on the farm, but the dependency ratio was high at 58%. Farmers mainly cultivated crops with only a very small proportion of trees or orchards. Close to 26% of households faced regular labor shortages during prime periods for agricultural activities, and nearly 10% of land was either under grass or left fallow. More than 91% of the farming households reported that agriculture and livestock contributed to their household income, but only 18% that these were their main source of income. Income from agriculture and livestock seems to be minimal, and households rely on other sources of income.

3.2 Farming systems

Paddy was the main staple crop, cultivated by three quarters of farming households, followed by wheat and summer maize (Fig. 2). Millet and mustard are also important. Summer potato was the most important cash crop, cultivated by 41% farming households, followed by onion, garlic, and winter and summer vegetables (Fig. 3). More than 80% of households (Table 1) raised livestock, with both goats and cattle kept by more than 70% households (Fig. 4). Buffaloes were also raised by a substantial proportion of households as were poultry and other birds, but pigs and sheep were only kept by a few.

3.3 Production trends and household food security

The survey also recorded households' perception of production trends for the five main staple and cash crops over the preceding decade (2001–2011) (Table 2). There was considerable variation in response with both increases and declines in production reported for all crops. More households reported an increase in the production of paddy and wheat (45%) than a decrease (37%), but more households reported a decrease in the production of summer maize, millet, and mustard over time, although around a third also reported an increase. More households reported an increase in production of all five main cash crops (summer potato, onion, garlic, and winter and summer vegetables) than reported a decrease, although a significant percentage did report a decline, especially in vegetable production.

Farm production was the main source of food for only 46% households (Fig. 5), indicating that household dependence on external food items has increased since the time when subsistence farming predominated. This may be attributed in part to the decline in production of some of the major staple food crops and replacement with cash crops for income

Table 1 Household socioeconomic characteristics. *Source*: ICIMOD Survey (PVA), 2011–2012

Variables	Values
Household size, mean (SD)	5.7 (2.6)
Dependency ratio (%)[a]	57.9
Average landholding size (in hectares)	0.98
% households with access to agricultural land (owned and non-owned)	84.4
% households who own agricultural land[b]	95.9
Proportion of land under different practices (%)[b]	
Crop farming	83.3
Orchard/tree crops	1.6
Grassland/pasture	4.1
Kitchen garden	5.0
Fallow	5.4
Other use	0.5
% household who have irrigated land[b]	59.5
Land ownership[c] (%)	
Female	16.2
Male	81.5
Joint	1.2
Number of HH members working on farm, mean (SD)[b]	3.4 (2.0)
% of migrant sending households	38.6
% households 'always' facing labor shortages[b]	25.6
% households involved in transhumance in the last 12 months[d]	0.4
% households having income from crops, vegetables and fruits[b]	49.6
% households with income from livestock[d]	41.8
% households who reported that agriculture and livestock are their main sources of income	17.5
Average number of income sources per HH (SD)	2.3 (1.1)
% households who own any livestock	83.2
Average number of livestock raised by households[d]	
Cattle	2.7
Buffalo	2.0
Goat	4.5
Sheep	3.8
Pig	2.0
Poultry and other birds	8.4

[a] (HH members below 14 and above 64 years. of age/ Economically active members aged 15−64 years.) ×100

[b] Among those households who have access to agricultural land

[c] Among those households who own agricultural land

[d] Among those households who own livestock

rather than consumption, as well as increasing demand for food from the growing population which cannot be met by increased production from the small landholdings. Growing demand for processed food items, especially among young people, is another important factor adding to the dependence on external food items (Adhikari et al. 2017). The

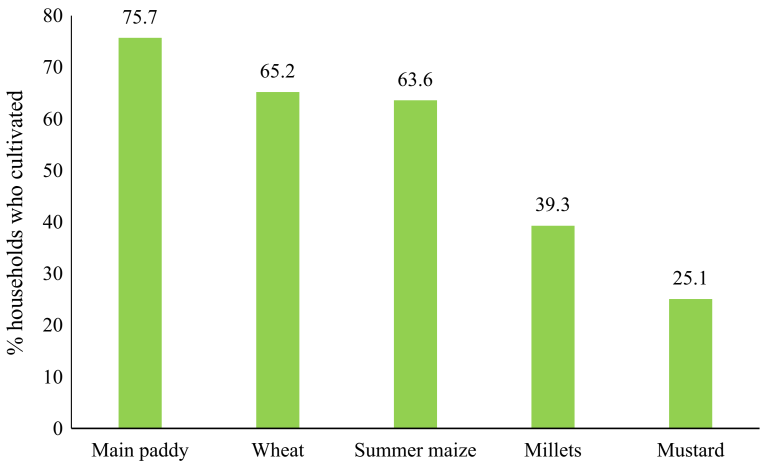

Fig. 2 Five main staple crops grown in preceding 12 months

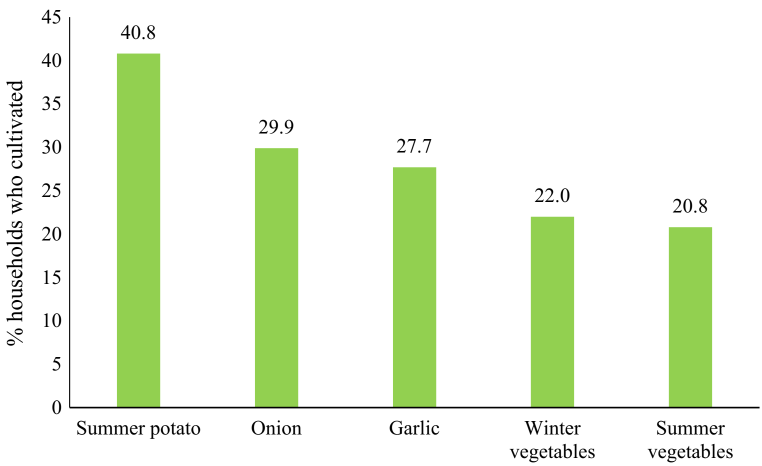

Fig. 3 Five main cash crops grown in preceding 12 months

increased dependence on food obtained from elsewhere is reflected in the reported distribution of household expenditure, with 58% required for food and only 42% for other items (Fig. 6). This move toward buying food items might contribute to high multidimensional poverty in the KRB if households are cutting down on non-food expenditure such as education, health, clothing, and housing to fulfill their food requirements.

3.4 Farmers' perceptions of climate change, associated climatic hazards, and agricultural adaptation

Households were asked about their perceptions of changes in climate and the occurrence of hazards attributed to climate change over the ten years prior to the survey; the results

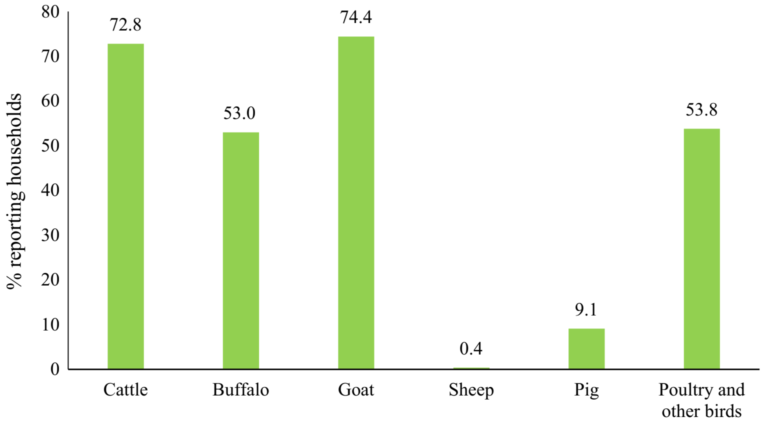

Fig. 4 Households (%) with different types of livestock

are summarized in Table 3. More than 80% of households considered that the climate had changed, and of these more than half reported an increase in erratic rainfall events. A significant proportion also noted an increase in extreme temperature events and changes in frost and hailstorm patterns. The most common hazards attributed to climate change were droughts and dry spells, reported by around 40% households, followed by increases in livestock disease, floods, insect attacks, and crop pests.

Households were also asked about any coping or adaptive agricultural actions that they had taken to address the impacts of climate change; the results are summarized in Table 4. Only 32% of households reported taking any adaptive actions, with two to three adaptive actions taken by each of these households on average. The most common actions were to stop planting some crops (44%) and/or introduce new crops (38%). These were followed by changes in farming practices, stopping rearing certain livestock, and investing in irrigation.

3.5 Socioeconomic factors of adaptation in agriculture

A logistic regression model was used to analyze the relationship between socioeconomic factors and the taking of adaptive actions related to agriculture. The results are summarized in Table 5. Neither sex nor age of household head had a statistically significant relationship with the taking of adaptive action; however, likelihood of taking an adaptive action was 47% more if the household head was literate. Likelihood of adaptive measures also increased with an increase in household size. Households with 4–6 and more than seven members were, respectively, 53 and 57% more likely to take adaptive actions compared to those with three or less members. Likelihood of taking adaptive actions also increased with an increase in the size of owned agricultural land. For instance, households with owned land 1.5 hectares or more were almost 5 times more likely to take adaptive actions, compared to those without owned land. Households with more than 0.5 hectares of owned land are almost 2 times more likely to take adaptive actions than those without owned land. Likewise, households with owned land 0.50–0.99 and 1.00–1.49 hectares were, respectively, 2.45 and 3.33 times more likely to take adaptive actions than those without owned land (Table 5).

Table 2 Household perception of crop production. *Source*: ICIMOD Survey (PVA), 2011–2012

Major staple crops	% households who perceived a decrease in production over previous 10 years	% households who perceived an increase in production over previous 10 years	Crop-growing households (number)	Major cash crops	% households who perceived a decrease in production over last 10 years	% households who perceived an increase in production over last 10 years	Crop-growing households (number)
Main paddy	36.8	45.2	1290	Summer potato	25.4	63.3	269
Wheat	36.8	45.2	1290	Onions	19.4	65.6	137
Summer maize	43.2	32.5	1287	Garlic	22.3	43.1	129
Millets	46.7	31.1	875	Winter vegetables	36.7	50.2	113
Mustard	44.9	30.8	400	Summer vegetable	33.5	56.1	103

'Previous 10 years' = 2001–2011

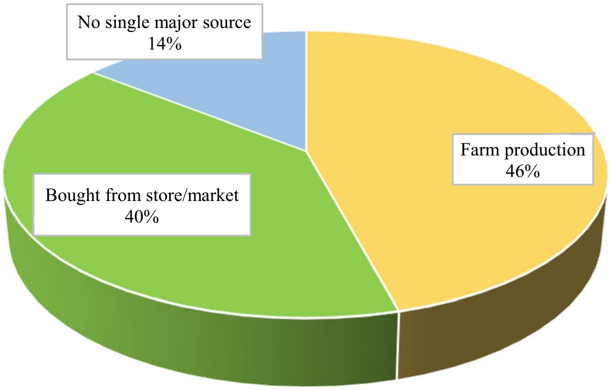

Fig. 5 Households (%) reporting their major sources of food consumption

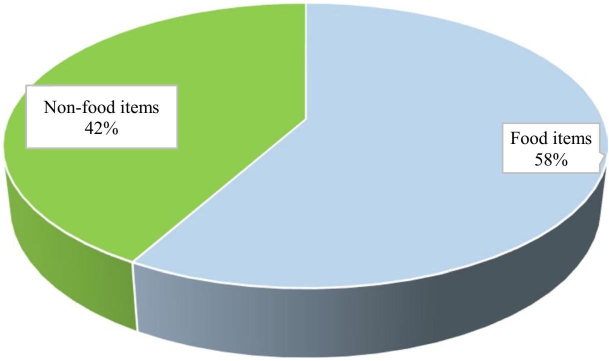

Fig. 6 Share (%) of expenditures made on food and non-food items

There were 42% higher chances of taking adaptive actions in those households who had more than one income sources compared to those with only one income source. It implies that diversification of income sources helps households in the form of financial sources to take adaptive actions. Households with any kind of insurance policy had 48% higher odds of taking adaptive actions than those who did not avail any insurance facility. Those households who sent at least one migrant had 21% less chances of taking adaptive actions, compared to those who did not send any migrant.

4 Discussion

Mountain farmers in the HKH region are highly vulnerable to food insecurity because of the lower agricultural productivity, biophysical constraints, poor infrastructure, inadequate access to markets, and high cost of food transportation (Rasul 2011; Tiwari and Joshi 2012). In the Koshi River Basin, as elsewhere, these factors are now compounded by the adverse effects of climate change on all sectors and particularly agriculture. This study attempted to investigate local people's perspectives on challenges related to climate change, agricultural adaptation measures, and the socioeconomic factors which may influence a households' decision to take adaptive action. Traditionally, agriculture contributed

Table 3 Household perception of changes in climate and climatic hazards. *Source*: ICIMOD Survey (PVA), 2011–2012

Climate change indicators	% households who perceived changes in previous 10 years
HHs who perceived changes in climate (overall)	81.1
Perceived climatic changes[a]	
High temperature	28.0
Low temperature	18.0
Erratic rainfalls	54.8
Changes in snowfall patterns	3.0
Changes in frost patterns	19.9
Unusual hailstorms	15.5
Hazards attributed to climate change[a]	
Drought	42.4
Dry spell	37.0
Flood	19.2
Avalanche	0.6
Landslide/erosion	9.8
Livestock disease	26.6
Insect attack	16.8
Crop pests	14.2

[a]Among those households who perceived a change in climate

Table 4 Household adaptation to climate changes. *Source*: ICIMOD Survey (PVA), 2011–2012

Variables	Rank based on number of households action	% households
% households who have taken any coping/adaptive action		32.2
Number of coping/adaptive actions taken, mean (SD)[a]		2.6 (1.1)
Commonly reported coping/adaptive actions[a]		
Stopped planting certain crops	1	43.6
Introduced new crops	2	38.2
Changed farming practices	3	29.6
Stopped rearing certain livestock	4	22.7
HH invested in irrigation	5	18.1

[a]Computed among households who have taken any actions

significantly to the food security and livelihoods of households in the KRB by providing a diversity of food and contributing to household income (Hussain et al. 2016; Adhikari et al. 2017). However, the contribution of agriculture to household food consumption and household income has declined significantly over time (ISET 2008).

A significant proportion of the households in the study considered that the production of staple food crops had declined over time, notwithstanding technological advances, leading to a decline in local food availability and household income. Decline in the production of staple crops by a significant proportion of households may be attributed to a range

Table 5 Results of binary logistic regression model

Variables	Frequency of HHs	% of HHs who took adaptive actions to cope with the perceived climatic changes	Adjusted odd ratio (95% confidence intervals)
Explanatory variables			
Sex of the household head			
Male	1732	32.0	Referent
Female	283	33.7	1.08 (0.81–1.45)
Age of the household head			
< 49	1023	31.3	Referent
50+	992	33.2	0.92 (0.74–1.13)
Literate household head			
No	1296	30.3	Referent
Yes	719	36.1	1.47** (1.17–1.84)
Household size			
≤ 3	327	22.6	Referent
4–6	1109	32.9	1.53** (1.13–2.09)
7+	579	36.6	1.57** (1.12–2.18)
Size of owned agricultural land			
No owned land	241	17.5	Referent
< 0.5 hectares	752	28.3	1.85** (1.32–2.58)
0.50–0.99 hectares	557	35.2	2.45** (1.72–3.48)
1.00–1.49 hectares	233	44.2	3.33** (2.22–5.01)
≥ 1.5 hectares	232	51.6	4.95** (3.27–7.49)
HH having more than one income source (income source diversification)			
No	461	23.1	Referent
Yes	1554	35.1	1.42** (1.1–1.85)
Household with any insurance			
No	1759	31.1	Referent
Yes	256	38.1	1.48** (1.13–1.94)
Household with at least one outmigrant member			
No	1190	33.8	Referent
Yes	825	29.7	0.79** (0.64–0.98)
Dependent variable			
Household took any adaptive action to cope with perceived climate change and climate change-induced hazards[a]			
No	1370	68.0	–
Yes	641	32.0	–
Number of observations (N)[b]	2015		
χ^2	132 (0.000)		
Pseudo R^2	0.05		

**Statistically significant (95% confidence interval (CI) used as an indication of statistical significance if it does not overlap the null value (e.g., OR = 1). A CI for the odds ratio that spans the null value was taken as indicating the lack of statistical significance.)

[a]Adaptive actions are presented in Table 4

[b]N is unweighted count

of socioeconomic and climatic factors. The most important socioeconomic factor is the shortage of labor resulting from outmigration; 39% of households had a migrant member (Table 1), most commonly one of the young and active members who would normally be involved in agriculture. Labor shortages may also be one of the reasons that 10% of agricultural land was left fallow or under grass (Table 1), as reported by others (Ghimire and Thakur 2014). The decrease in food production has increased households' dependence on food items purchased from elsewhere. On average, households had more than two sources of income (Table 1), which also indicates an increased dependence on non-agricultural income to buy food and other items.

Climate change impacts may be the main reason for the reported decline in production (Hussain et al. 2016). A significant proportion of households reported changed patterns in the incidence of droughts and dry spells, floods, livestock diseases, insect attacks, and crop pests (Table 3). The household perceptions were consistent with reports in the literature on climate change. For example, Bharati et al. (2012) have projected a rise of 0.79–0.86 °C in temperature in the 2030s for the Koshi basin compared to a 1976–2005 baseline. Increased temperature leads to greater evaporation and thus surface drying, which increases the intensity and duration of droughts (Devkota and Gyawali 2015). Similarly, the reported increase in livestock disease is consistent with the findings of studies by others that changes in temperature, rainfall patterns, and humidity are directly related to increased incidences of livestock disease (Singh et al. 2000; Basu and Bandhyopadhyay 2004; Sirohi and Michaelowa 2007). Similarly, changes in temperature and rainfall patterns may lead to an increase in weeds and pest attacks and diseases affecting grasses and crops (Sirohi and Michaelowa 2007).

Around one-third of households reported taking a range of different adaptive actions to cope with the impacts of climate change and related hazards, including replacing certain crops with new crops (Table 4). In Nepal in general, and the KRB in particular, farmers are shifting their cropping patterns from highly water consumptive crops such as paddy to fruits and vegetables which consume relatively less water (Gurung and Bhandari 2009; GWP-JVS 2014: p. 21; Dixit et al. 2009) and have a high market value (Hussain et al. 2016; Manandhar et al. 2013, 2014), with summer potato, onions, and garlic as the most important of these in the KRB (Hussain et al. 2016). The majority of households growing vegetables reported an increase in production over the previous decade (Table 2), notwithstanding the socioeconomic and climatic changes. Households also reported changes in farming practices such as small shifts in the cropping calendar, exploring improved seed and crop varieties (Hussain et al. 2016; Manandhar et al. 2011), and use of water efficient technologies (Bartlett et al. 2010). Households had also stopped rearing certain livestock. There is possibility that households are shifting from bigger animals to small ruminants (e.g., breeds of local goats) which are more resilient to water and fodder/forage stress, as reported by a study in drought affected areas in Pakistan (Shafiq and Kakar 2007). Finally, a significant percentage of households had invested in irrigation to address water shortages and ensure a stable water supply for agriculture.

The literacy of the head of household, household size, size of owned agricultural land, number of income sources, insurance provisions, and outmigration of a household member all had a positive statistically significant relationship with the probability of a household taking adaptive actions (Table 5). These results are also consistent with the findings of others. Literate farmers are known to be more likely to have better information on and understanding of climate change, its impacts, and possible adaptation options and thus more likely to take adaptive action (Ndambiri et al. 2013; Deressa et al. 2009; Tesso et al. 2012). More household members generally means greater availability of labor and thus increased ability to undertake adaptive actions, as at farm level, these tend to be labor intensive. Similarly, larger landholdings are more likely to provide more surplus and income (Hussain and Thapa 2015), providing farmers with the resources and financial capacity needed to invest in adaptive measures such as soil conservation, irrigation, changing crop patterns, and livestock production (Mulatu 2013). Diversification of income sources also helps households by providing the financial resources to take adaptive actions. Insurance (e.g., for property damage, livestock death, human health, and life) increases the adaptive capacity and resilience of households (Surminski 2010), and the sense of security it provides increases the likelihood that households continue to practice agriculture as well as the propensity to take risks in terms of costly adaptive measures. In contrast to the other factors, households with at least one migrant member were less likely to take adaptive actions, suggesting the negative impact of the resultant labor shortages during the main periods of agricultural activity (Hussain et al. 2016) outweighed the potential advantages provided by remittances which could help support adaptive actions (Hussain et al. 2016).

5 Conclusions

The farming community in the Nepal part of the Koshi River Basin is mainly comprised of smallholders (average landholding 0.98 ha) with diversified farming systems including crops, vegetables, fruit, livestock, and poultry. More than 80% of the surveyed households in the basin had perceived changes in climate, and a majority reported an increased incidence in climate related agricultural hazards such as droughts and dry spells, floods, livestock diseases, insect attacks, and crop pests. Despite technological advances, a significant proportion of households had noted a decline in the production of main staple crops in the period 2001–2011, which they mainly attributed to climate change. Traditionally, agriculture has contributed significantly to both food consumption and income of the farming households in the basin (Hussain et al. 2016). The study households reported that nearly 60% of their expenditure was made on food items and 40% that the majority of food consumed was bought not cultivated, indicating an increasing dependence on external food sources. The majority of farm households reported that agriculture and livestock were no longer their main sources of income, and their dependence on other sources of income has increased. The results suggest that overall climate change has negatively impacted both local food production and agricultural income.

One-third of households had undertaken one or more adaptive actions related to agriculture, such as replacing some traditionally grown crops with new crops, changing farming practices, giving up rearing certain livestock, and investing in irrigation. The study identified some key factors affecting the likelihood of adaptive actions being taken such as literacy or otherwise of the head of household, household size, size of owned agricultural land, diversification of income sources, outmigration, and insurance facilities.

Based on these findings, the following approaches are suggested to help build resilience to climate change at the local level and achieve sustainable food security and livelihoods in the KRB.

- Climate change has also brought some opportunities, which are not yet adequately capitalized. For example, a significant proportion of households noted an increase in the production of cash crops such as summer potato, onion, garlic, and vegetables. National and sub-national agricultural and food security policies should take these opportunities into account in areas which are suited agroecologically, and appropriate institutional services should be provided in support.

- There is a need to identify the specific zones within the basin where production of particular crops is declining. Strategies could focus on introducing alternative high value crops such as fruit and vegetables to improve farmers' income in such zones. In high-altitude areas such as Dolakha, traditional food crops such as beans and barley that are more resilient to climate change could be integrated into the local food systems (Adhikari et al. 2017).
- Landholding size plays an important role in decision making on farm-level adaptation because farmers with larger landholdings are likely to have higher farm income and thus more financial capital. Provision of insurance also increases the likelihood of taking adaptive action. To help marginal and small farmers cope with the financial constraints and climatic risks, the government should consider introducing financial products such as credit and agricultural insurance, together with other institutional services, such as agricultural extension, technology transfer, and market services.
- Households with more than one source of income are also more likely to take adaptive actions, indicating that diversification of income through non-agricultural enterprise may contribute positively to agriculture by ensuring financial resources. Area-specific opportunities such as ecotourism, handicrafts, beekeeping, and medicinal plants should be promoted and supported through institutional mechanisms. Increasing local income opportunities will also help reduce the rate of outmigration and thus labor shortages and will increase household income and thus food purchasing power.
- Literacy of the head of household also increases the probability of households taking adaptive actions in agriculture. Education is likely to provide farmers with better awareness and understanding of climate change. To increase awareness among nonliterate farmers, local governments should consider establishing field schools and demonstration sites to showcase successful climate resilient practices.

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Compliance with ethical standards

Conflicts of interest The authors declare no conflict of interest.

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