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Status and drivers of food insecurity and adaptation responses under a changing climate among smallholder farmers households in Bagmati Province, Nepal

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Abstract
Like other low-income countries in Asia and Africa, Nepal still suffers from food insecurity with a large proportion of food-insecure households being smallholder farmers who rely on rain-fed agriculture for their livelihood. Contributing factors include a lack of production, lack of resources, access to land and market, climate change, extreme events and underlying poverty. In this study, we aimed to examine the prevalence, cause of and response to food insecurity and assess how food security varies with respect to the regional variation. We also explored the role of changing climatic conditions in creating such adversities. Based on an analysis of the results from interviewing 384 farm households from three agro-ecological zones in Bagmati Province, we found that 56% of the farm households experienced food insecurity. The severity varied amongst the households with resource-poor, disadvantaged groups and those with limited land and income suffering the most severely from food insecurity. Households in the Mountains and the Hills zones were more food insecure than in the Terai zone. Climate change impacts were found to have amplified the risks of food insecurity amongst these rural households surviving under a largely subsistence agrarian economy. The results further suggest that the adaptive capacities of smallholder households can be increased by improving agricultural productivity through providing skills and training, better access to markets, extension services, credit and insurance schemes, along with access to climate-smart technologies, micro-irrigation, improved infrastructure, and storage facilities. Support from relevant governmental and non-governmental organizations is needed to help smallholder households, and their communities better manage the risks to their food security.

Keywords Food security · Climate change · Rural · Smallholders · Farm households · Nepal

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1 Introduction

There has been a substantial increase in food production associated with the expansion and the intensification of agriculture. However, food systems still confront surging demand from rising population numbers and global environmental change, including climate change (Myers et al. 2017) which undermines food production and consequently food security. Food security is defined as the 'situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (FAO 2002). Household food security is understood as the ability to obtain the food needed by members of the households (Pinstrup-Andersen 2009). For achieving food security, a household needs adequate food production and/ or adequate physical access (the nearness of markets and other distribution channels) and economic access that is adequate food purchasing power (Gillespie and Mason 1991). Food insecurity on the other hand is a household-level concept referring to households that are not food secure or households that contains one or more food insecure persons (National Research Council 2006).

Climate change is increasing the challenge of attaining food security in many regions across the world (Hirsch and Lottje 2009; Hussain et al. 2016; Ziervogel and Ericksen 2010; Shah et al. 2020), and this is particularly true for regions that are already food insecure (Richardson et al. 2018). Climate change affects the food system and food security by affecting crop production, supply chain infrastructure, food prices and market stability, as well as skewing growth and income distribution, and altering agro-ecological conditions (Gregory et al. 2005; Schmidhuber and Tubiello 2007). The impacts of climate change are complex, widespread, geographically and temporally variable and influenced by other socioeconomic conditions (Vermeulen et al. 2012) which further affect four aspects of food security: food availability; access; utilization; and stability (Porter 2014).

Climate change impacts potentially increase food inequalities from local to global levels (Wheeler and Von Braun 2013), and the economies of developing countries are sensitive to any losses of agricultural production induced by climate change because of the relatively high dependence on agriculture for livelihoods (Gebreegziabher et al. 2011). The poor and the vulnerable suffering from hunger and malnutrition predominantly in developing countries are therefore the most affected by climate change (Schmidhuber and Tubiello 2007; Hirsch and Lottje 2009) including smallholders whose household food security is further threatened (Niles and Salerno 2018).

South Asia holds some one-third of the most impoverished populations in the world despite the growth in its economies (Mani et al. 2018) whose vulnerabilities to climate change impacts are a function of the region's relatively high rates of poverty, population growth, food insecurity and natural resources degradation (Sivakumar and Stefanski 2011). South Asia recorded a serious level of hunger in 2017 (IFPRI 2018).

Nepal is a small (147,181 km^2) landlocked country in South Asia (Government of Nepal 2018) whose agricultural sector is dominated by subsistence-oriented farmers with more than 50% of smallholders cultivating a small area of land usually less than 0.5 ha per household (Central Bureau of Statistics 2011b) and who rely on those farms for food and income using family labour (Cornish 1998). Nepal is ranked 81st out of 113 countries with an overall score of 44.5 on the global food security index 2017 (The Economist Intelligence Unit Limited 2018). Despite Nepal experiencing a decline in undernourishment from 15.9% of the total population in 2004–2006 to 8.1% in 2015–2016, it remains included in low-income food-deficit countries (Fao et al. 2017), and 51.8% of the Nepalese households

are food insecure (Ministry of Health et al. 2016). Furthermore, more people are projected to be at the risk of hunger by 2030 and 2050 in a climate change scenario (IFPRI 2018).

Nepal is divided into three agro-ecological zones, namely Terai, Hills and Mountains (World Bank 2011) which cover 34,019 km^2, 61,345 km^2 and 51,817 km^2, respectively, of the country's total land area of 147,181 km^2 (Central Bureau of Statistics 2016). The agro-ecological zones of Nepal are likely to face the burden of a changing climate on various aspects of their agricultural productivity and food security because of the projected impacts on climatic extremes including sporadic rainfall trends, infrequent droughts, floods and heatwaves and cold snaps (Pokhrel and Pandey 2013) and various biophysical and socioeconomic conditions which affect people's vulnerabilities and adaptive capacities (Brown et al. 2015).

The reasons for food insecurity in Nepal are complex and the impacts of a rapidly changing climate require policy interventions (Poudel et al. 2017) and ongoing research.

This study aimed to assess the prevalence of household food insecurity in Bagmati Province (province three), Nepal, and assess whether regional variation (Sharma 2001) influences the perception of food security and adaptation responses. This question was investigated through surveys of smallholder farm households' experiences in three districts of Nepal, one from each of the three agro-ecological zones. For the purposes of this study, food security was defined in terms of food availability and food accessibility (Bergeron 1999). Food secure households in this study refer to households with access to available food. The issues of food utilization (nutrition) and food stability, and their role in food security, fell outside the scope of our study.

2 Materials and methods

2.1 Overview of approach

This study was focused on surveys of smallholder farm households in the Bagmati Province of Nepal. The data from the surveys were analysed to identify the households' experiences of food insecurity and related causal factors, including climate change impacts. The surveys were also designed to identify farm household's adaptation responses to address food insecurity problems and any evident limits to these adaptations. We used the IPCC (2014) definition of adaptation: 'The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities'. We also interpreted 'adaptation' to include responses that might be more generally termed 'coping strategies', i.e. the use of available skills, resources and opportunities to address, manage and overcome adverse conditions, to achieve basic functioning of people, institutions, organizations and systems in the short to medium term (IPCC 2014). An overview of the approach is given in Fig. 1, and further details are provided in the following sections.

This study used a perception-based case study as detailed by Yin (2003). Smallholder farmers were surveyed within the Bagmati province, Nepal. This province spans the three main agro-ecological zones of Nepal, and therefore, major differences in productivity, access and climatic conditions. Household surveys were complemented with focus group discussions and key informant interviews, and the information was used to address key issues related to causes of food security and adaptation responses. Household food security was assessed using the Household Food Insecurity Access Scale (Coates et al. 2007),

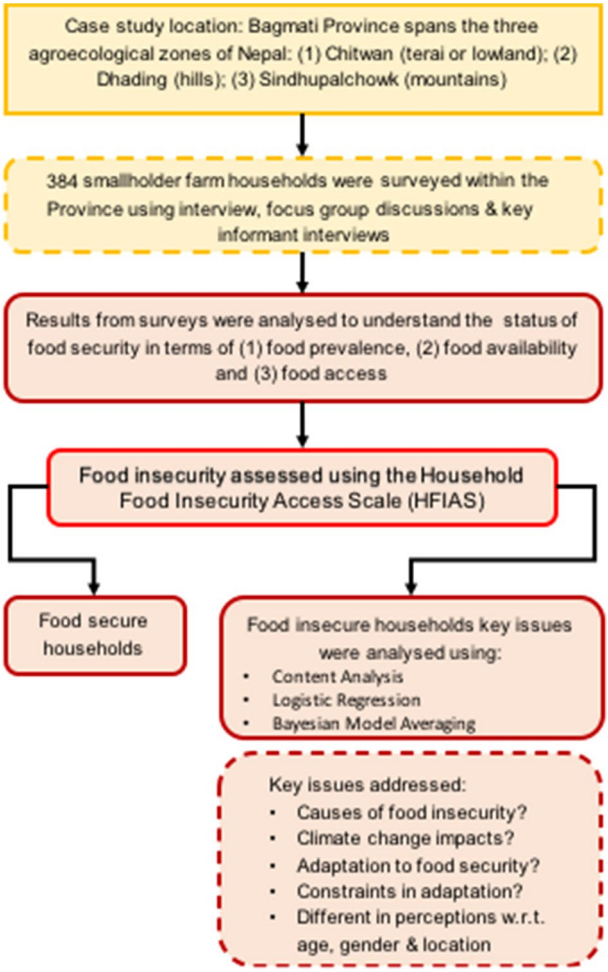

Fig. 1 Overview of the study approach and workflow

and key issues for households assessed as experiencing food insecurity were investigated performing content analysis using NVivo (QSR 2017) and statistical technique (logistic regression using the R library MCMC pack (Geyer and Johnson 2017). While food security is a broad concept, a case study approach helped shed light on the specifics of farmers' experience regarding the effects of climate change on agricultural productivity and their food security.

2.2 The locale of the study

Bagmati Province (also known as Province 3) is one of the seven provinces of Nepal. The provincial headquarters is Hetauda and the province comprises 13 districts, three metropolitan cities, one sub-metropolitan city, 74 rural municipalities and 41 urban municipalities. The province covers an area of two million hectares which is around 14% of the total area of Nepal and has a population of 55,29,452. Bagmati Province has 300,584 hectares

of agricultural land, out of which 289,662 hectares are cultivated. The total production of major cereal crops in the year 2017/2018 was 1,348,282 metric ton with the dominance of yield of maize, paddy and wheat.

For this case study, three districts (Table 1) were selected that are located in each of the three agro-ecological zones of Nepal (Fig. 2).

2.3 Sampling design

The approach used for this study was designed to provide a hierarchically representative sample of administrative units and major environmental gradients in Nepal. A five-step multistage sampling selection approach (Elder 2009) was used to select the case study locations. First, one province—Bagmati province—was randomly selected from a total of seven provinces in Nepal. Second, within Bagmati province, three districts were selected—Sindhupalchowk, Dhading and Chitwan—to represent Nepal's three main three agro-ecological zones. Third, three municipalities within each district and zone were then randomly chosen. Fourth, three wards—the smallest local administrative unit in Nepal—were randomly selected from each municipality in each district. Finally, stratified random sampling was applied to select households from the identified wards in each municipality; with the stratification of the households depending upon the total number of households in each ward. Thus, a total of 384 smallholder farm households, with 128 each from each district, were interviewed. The sample size of 384 was selected based on guidelines for sample size decisions developed by Krejcie and Morgan (1970). The term 'households' in this study refe*rs to* 'a person or group of related and/or unrelated persons who usually live together in the same dwelling unit(s) or connected premises, who acknowledge one adult member as the head of the household, and who have common cooking and eating arrangements' (Mehata et al. 2013).

In each household, the head of the farm household involved in agriculture was interviewed irrespective of their gender. If the household head was not available, then the next most senior member of the household was invited for the interview. Participation was voluntary. The ethical consent process was completed before each interview, with the researcher explaining the study procedures to the participants. The Nepali language was used for the interview, and the interview location was decided based on the convenience of the participants. The anonymity and confidentiality of the participants were maintained. Each interview lasted between 30 and 45 min, and the answers were recorded on the questionnaire sheet by the interviewer and transcribed as soon as possible. Interview instruments like semi-structured and formal structured interviews were used. In line with the study objectives, the households (n = 384) were asked questions related to their experience of food insecurity, climate change impacts, and the measures they have adopted to deal with such situations. The participants reported changes they have witnessed over the last decades as best they could remember. The Household Food Insecurity Access Scale (HFIAS) by Coates et al. (2007) was used to determine the prevalence of food insecurity amongst farm households based on a 12-month recall period. The HFIAS questionnaire consists of nine occurrence questions, and each occurrence question is followed by a 'frequency of occurrence' question (Supplementary data S2).

Three focus group discussions and 33 key informant interviews were simultaneously conducted along with the survey for purposes of data triangulation (Wilson 2006). Focus group discussion is an interactional discussion focusing on the considered issues (Hennink 2014). Considering the existence of patriarchal social norms and traditions (Panta and

Table 1 Key features of the selected study sites

Features	Chitwan (Terai)	Dhading (Hill)	Sindhupalchowk (Mountain)
Population	579,984	336,067	287,798
Area	2238.39 km^2	1926 km^2	2542 km^2
Literacy (%)	77%	63%	60%
Population % in poverty)	9%	19%	25%
Landholding number	88,242	64,517	58,998
Total area of holding (ha)	40,631.6	35,398	34,781.5
Total arable land area (ha)	35,745.4	31,608.3	30,905.5
Crop land (ha)	1377.2	935.3	1022.2
Agriculture production	Cereal: 87.38% Vegetables: 8.67% Horticulture-0.83% Other crops-0.15% Livestock, poultry and fishery: 2.97%	93.45% 5.47% 0.12% 0% 0.97%	97.4 0.15 0.21 0.26 0.6% (livestock)
Market access	48% travel 10–30 min	27% travel 1-2 hr	30% travel 1–2 h
Key commodity	Rice, Maize, Wheat, Mustard, beans, lentils, vegetables, mustard, black gram, millet, buckwheat	Rice, maize, wheat, sugar cane, millet, buckwheat, mustard, black gram, barley and potatoes	Potato, maize, paddy, millet, wheat, barley,
Major cropping pattern (in terms of AEZs they represent)	*Rice–wheat *Maize-mustard-fallow *Rice-mustard/lentil-wheat/vegetables/fallow *Mustard-legumes-lentils	*Maize/Millet-wheat *Maize-rice *Maize-rice–wheat *Rice-lentils-wheat *Lentils-wheat-fallow	*Maize-wheat-finger millet *Maize-potato-wheat-finger millet *Rice-barley *Buckwheat- barley *Potato-barley
Climate (in terms of AEZs they represent)	Tropical to sub-tropical	Sub-tropical to temperate	Warm temperate to arctic
Annual maximum temperature (°C)	28.8 °C	22.1 °C	16.8 °C
Annual minimum temperature (°C)	17.4 °C	11.8 °C	7.0 °C
Average annual precipitation (mm)	1783.7 mm	1683.9 mm	2034.9 mm

Table 1 (continued)

Features	Chitwan (Terai)	Dhading (Hill)	Sindhupalchowk (Mountain)
Climate change vulnerability (NAPA)[a]	High	High	Moderate

Source: Government of Nepal (2012), CBS (2011); https://nepalmap.org/compare/district-35/vs/district-30/,

*Market access denotes maximum time spent by a majority to reach one way of nearest agricultural market.

*Disaster-related deaths denote landslide, flood and heavy rainfall from 2011 march to Aug 2017 (Supplementary data S1).

The climate change vulnerability ranking was sourced from the Vulnerability Assessment for the National Adaptation Programme of Action (NAPA) ranking for (Ministry of Environment, 2010). The analysis was undertaken using district-level data from secondary sources and climate risk mapping to produce integrated vulnerability maps for each district. The ranking provides a high-level relative comparison between the three study sites.

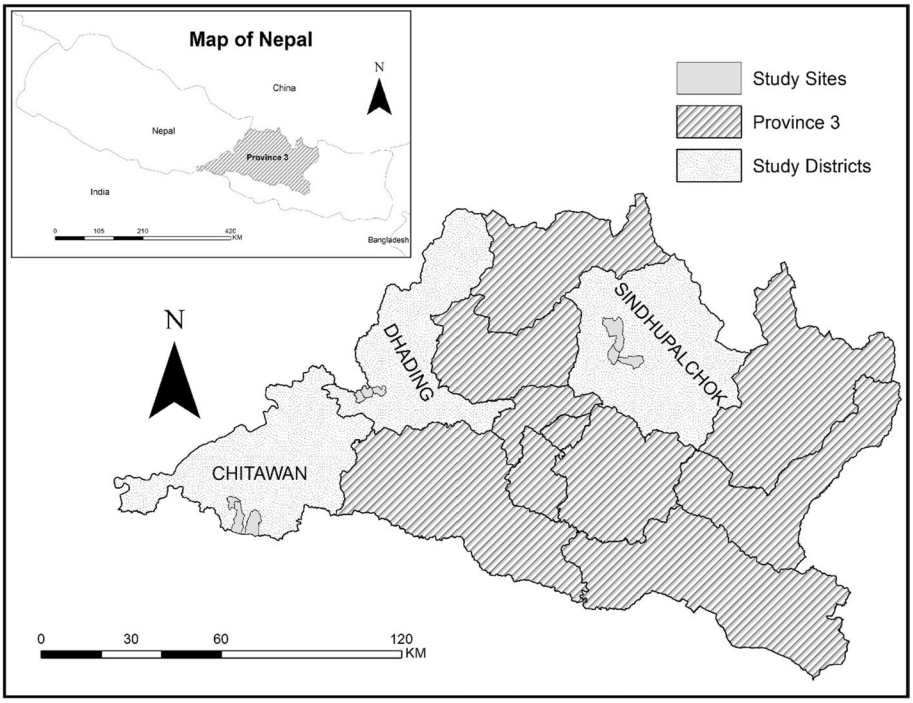

Fig. 2 Map of Nepal showing the three study sites within the study districts

Thapa 2018) and the restricted cultural roles of Nepalese women, it was deemed essential to recognize women's perspectives on climate change and related issues. Thus, focus group discussions were conducted with a group of local women in each district. Altogether, 22 women took part in the focus group discussion, sharing their experiences of food insecurity and their responses. In addition, 33 officials working in the sectors related to climate change, agriculture and food security were consulted and interviewed. This key informant interviewees were chosen purposively and included officials from various governmental organizations (n = 12), non-governmental organizations (NGOs, n = 9), international non-governmental organization (INGOs, n = 9) and teachers (n = 3).

The project was approved by the Human Research Ethics Committee of Griffith University (GU ref no: 2017/427).[1]

2.4 Data analysis

Mixed methods (Greene et al. 1989) were used to analyse the results of the surveys. The perception data were recorded using Microsoft Excel and analysed using the statistical software R (R Core Team 2018).

[1] As a requirement for ethical clearance, all human research (interview, surveys or focus groups; observation; online data collection from individuals; testing and clinical interventions, innovations and trials conducted under the auspices of Griffith University), must be designed and conducted in accordance with the ethical principles and standards, Accordingly, this research (GU ref no: 2017/427) conducted research was in accordance with the National Statement on Ethical Conduct in Human Research (2007).

Table 2 The dependent and independent variables in the study

Dependent Variables	Independent variables
Perception of food security	Age
Perception of adaptation	Gender
	Location (respective agro-ecological zones in our case)

The study variables comprised of the dependent and independent variables are listed in Table 2.

The dependent variables were modelled using logistic regression for both outcomes (Perception of food security and perception of adaptation), as these are both binary outcomes. Binary outcomes in this survey consisted of people perceiving they are likely to be food secure which was coded as 1, whereas those perceiving they are not likely to be food secure were coded as 0. Similarly, those perceiving that they are likely to follow adaptation measures were coded as 1 and 0 for those who do not perceive it. The explanatory variables in both the models were age, gender, location and associated interactions. Age is based on the last birthday of the household representative interviewed. In case of Gender, it is coded as 1 if the household representative interviewed is male/man and 0 if female/woman. Among three sites, Chitwan was considered as the control site.

For our logistic regression we used a Bayesian framework. We modelled both main effects and interactions using the R library MCMC pack (Geyer and Johnson 2017).

The logistic regression model using a Bayesian framework can be defined as:

$$y_i | x_i \text{Bernoulli}\left(p_i\right)$$

with the inverse link function

$$p_i = \frac{\exp\left(x_i\beta\right)}{1+\exp\left(x_i\beta\right)}$$

where y_i is the binary outcome, x_i are the independent variables for subject i, p_i is the probability of subject i having the response of 1 and β are they professions relating to the linear predictor.

A multivariate normal prior distribution is assumed to estimate the coefficients (β):

$$\beta \sim \text{MVN}\left(\alpha_\circ, A_\circ\right)$$

For our analyses, we set $\alpha_\circ = 0$ and $A_\circ = 0$, which becomes are uniform $[-\infty, \infty]$ prior.

The likelihood of the data is represented as a binomial distribution Bin ($n = y_i$, $p = p_i$). The subsequent posterior distribution of the parameter β is determined using a Monte Carlo Markov chain algorithm known as a random walk Metropolis sampler. The full model was run on both outcome variables and terms which had a posterior distribution which did not contained 0 in the 95% credible interval were retained in the reduced model. In the modelling process, only the location variable was deemed to be significant. As the consequence, the results are presented below in the form of the predictive posterior fit for each of these locations.

The Household Food Insecurity Access Scale (HFIAS) by Coates et al. (2007) suggests that a survey can capture and quantify the responses and reactions generated through the household's experiences of food insecurity. Therefore, households were categorized as 'severely food insecure' or 'moderately food insecure' or 'mildly food insecure' and 'food secure' (Supplementary data S3) (Coates et al. 2007).

In addition, the weighted average index (WAI) of Shrestha and Nepal (2016) was calculated to summarize the study participants' perceived severity of the impact of climate change on food availability. Participants were asked to indicate their answers using levels of severity: no impact; low impact; medium impact; or high impact. Specifically, the assessments were about their perceived impact of climate change on indicators of food availability, namely: reduced crop area; reduced crop productivity; increased drought and water scarcity; increased food diversity (diversity in terms of food and food groups/farm food products); crop storage (storing of crops after harvest); and disease and pest occurrence. A climate change impact food availability index (FAI) was calculated as follows:

$$\mathrm{FAI} = 4fH + 3fM + 2fL + fNC/n.$$

where *fH* is the number of households indicating the high impact of climate change; *fM* is the number of households who reported medium impact of climate change; *fL* is the number of households reporting the low impact of climate change; fNC is the number of households indicating no impact of climate change for a particular indicator of food availability; and n = total responses.

An FAI score of four was interpreted as indicating a high impact, a score of three medium impact, two low impact and one no change (Shrestha and Nepal 2016).

The content analysis of the data from the key informant interviews and the focus group discussion were undertaken using the NVivo software (QSR 2017; Bazeley 2007). Selected quotes from the interviews are presented in results below, and the alphanumeric codes HH N and KI N refer to the number of households and the number of key informants, respectively, while FGD-M, FGD-H and FGD-T refer to the focus group discussions from the Mountains, Hills and Terai regions, respectively.

3 Results

3.1 Profile of the study participants

Details of the key demographic characteristics of the study participants are presented in Table 3. Among the 384 study participants interviewed, there were 237 male participants and 147 female participants. Of the study participants, 182 were aged 30–40 age group, 158 were aged 41 to 65 and the remaining 44 were above 65 years. Some 47% of the study participants had not received any formal education.

3.2 Prevalence of food insecurity

When enquired about the prevalence of food insecurity in households, more than half of the study participants (56%) reported having experienced food shortages or a food insecurity situation. However, the severity of food insecurity varied among the households and the regions. Based on the statistical analysis, the location or zonal settings had a significant impact on food security status with people from the Chitwan (Terai region) more likely to feel food secure compared to people from Dhading (the Hills) and Sindhupalchowk (the Mountains) (Table 4). A key informant narrated (KI 19), 'Food insecurity exists in Nepal considering the evidence of stunting, wasting and low Body Mass Index. Food shortage happens every year in the Mountain areas and some years in the Hills and Terai.' Age and gender in the sample had no notable effect on the perception of food security.

Table 3 Demographic characteristics of the study participants who represented the farm households

	Total (N = 384)	Chitwan (Terai, n = 128)	Dhading (Hill, n = 128)	Sindhupalchowk (Mountain, n = 128)
Gender				
Male	237	52	96	89
Female	147	75	32	39
Age				
30–40	182	57	62	63
41–65	158	56	50	52
65+	44	15	16	13
Education				
No Education	181	51	64	66
Primary	101	41	32	28
Secondary (up to class 10)	77	28	22	27
Above secondary	25	8	10	7

Table 4 Predicted proportion (80% CrI) of study participants who were more likely to feel food secure

	Food secure Posterior mean (80% CrI)
Chitwan (Terai)	0.76 (0.70, 0.80)
Dhading (Hill)	0.34 (0.28, 0.39)
Sindhupalchowk (Mountain)	0.23 (0.19, 0.28)

* Credible interval (CrI) is an interval within which a parameter value has a given probability. The results are obtained from statistical analysis as mentioned above. Final outcome is only presented.

Based on the HFIAS category, the majority (76%) of the study participants in Chitwan reported being food secure, while in the other two regions most of the study participants had to or often had to worry about food the entire year (Fig. 3). In Chitwan, about 19% of the households were mildly food insecure, and 4% were moderately food insecure. In Dhading, 34% of the households were food secure, 31% were mildly food insecure, and 27% of the households were moderately food secure. Furthermore, a severe condition of food insecurity was reported by 9% (80% CrI, 5%-11%) of the study participants from Dhading.

In Sindhupalchowk, only 24% of the households were food secure and 28% mildly food insecure. The 41% of farming communities in Sindhupalchowk with moderately food secure had not faced a severe condition regarding the quantity of food supply but had started to compromise on food quantity and had forgone food quality by eating less-desired food or a more monotonous diet. Seven percent (80% CrI, 4%—10%) of the households in Sindhupalchowk were severely food insecure. A severe case of food insecurity as reported by the study participants from Dhading and Sindhupalchowk reflected that they had run out of food, cut back the number or the size of meals or experienced severe situations (Coates et al. 2007).

3.3 Causes of food insecurity

The key drivers of food insecurity in the study area were a combination of climatic (impacts of climate changes manifest through erratic rainfall, drought, climatic conditions,

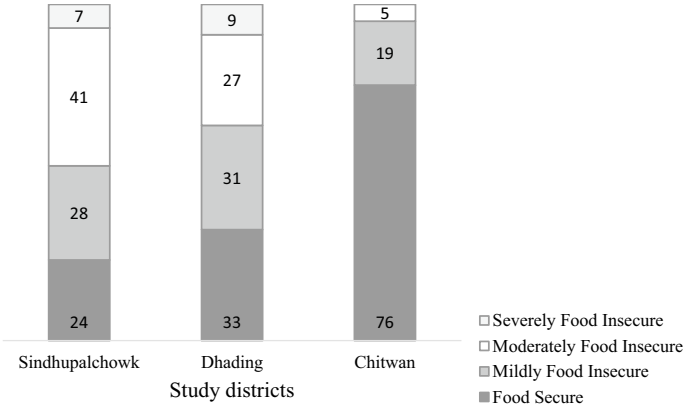

Fig. 3 Percentage of household food insecurity as measured by the Household Food Insecurity Access Scale (HFIAS)

pest infestation, low production), non-climatic (unproductive land, seasonal food insecurity) and institutional (the lack of farm inputs/technologies) factors. While noting insufficient and unprofitable production from their farm, the women's group also reported not being critically food insecure as the majority of their households were able to supplement on-farm production with food purchases. However, according to the women's group and key informants, the resources poor and low-income households in their region did experience food insecurity. Lack of money and land was also noted by the study participants as being relevant factors causing food insecurity. Most of these study participants were the ones falling under moderate and severe food insecure categories as per the HFIAS scale. These households belonged to the Cheppang communities (marginalized and backward indigenous communities) in Dhading and the resource-poor households in Sindhupalchowk. The key informants from Dhading shared a similar opinion on the existing food insecurity. A key informant noted the influence of socioeconomic factors on food security arguing that the resource-poor households and the Cheppang community in the regions were food insecure. He (KI 14) emphasized, 'Severe food insecurity doesn't occur in this location, but yes, resource-poor households and the households in the Cheppang communities have a severe problem. Households in the higher elevation of Dhading also experience severe food insecurity.' Other reasons for food insecurity mentioned during formal and informal discussions with the farmers include a lack of market access, soaring and inconsistent market prices, topography and the youth's lack of interest in agriculture, resulting in a lack of labour.

3.4 Climatic factors in causing food insecurity

The impacts of climate change on food security was mainly reported in terms of its impact on crop production. A key informant (KI 21) stated, 'Food insecurity occurs during the dry season or in the drought-affected areas.' Farm households cited that their food security depended upon the appropriate climate/ season at the time of plantation followed by the time of harvesting which favours crop production and availability. A farmer (HH 157) stressed, 'As we completely rely on rain-fed agriculture, food security is determined by favourable climate. If the monsoon rain is favourable, then OK; otherwise, we have food

Table 5 The perceived impact of climate change on the assessed indicators of food availability as experienced by farm households

Indicators	Food Availability Index (FAI)		
	Sindhupalchowk (Mountain)	Dhading (Hill)	Chitwan (Terai)
Increased drought and water scarcity	3.0	4.0	3.1
Disease/insect or pest occurrence	4.0	3.8	3.7
Reduced crop area	2.9	3.3	3.5
Reduced crop productivity	3.7	3.5	3.4
Increased food diversity	3.6	3.0	2.6
Crop storage	2.4	3.2	3.5

FAI: 1 = no change, 2 = low impact, 3 = medium impact and 4 = high impact

insecurities.' Moreover, the importance of favourable weather conditions during different stages of crop growth and development was emphasized by households considering the loss they had encountered due to unpredictable rain, flood and drought events.

3.5 Climate change impacts on food availability

Based on the food availability index adopted from Shrestha & Nepal (2016), climate change had a higher impact on food availability through drought in the hilly region Dhading (FAI: 4.0), followed by a medium impact in the Terai region Chitwan (FAI: 3.1) and in the mountain region Sindhupalchowk (FAI: 3.0). In terms of pest infestation, impacts perceived by the study participants were at a high level with an FAI score of 4 in Sindhupalchowk, followed by a score of 3.8 in Dhading and 3.7 in Chitwan (FAI: 3.7). A medium impact FAI was reported regarding the reduction in the cropped area for Chitwan (3.5) and Dhading (3.3) and of 2.9 for Sindhupalchowk. Similarly, a majority of study participants noted high impacts of climate change on crop production: Sindhupalchowk (78%); Dhading (74%); and Chitwan (71%). The farm households in Chitwan experienced higher impacts of climate change on food diversity followed by those in Dhading and Sindhupalchowk with medium to lower impact FAI scores of 3.6, 3.0 and 2.6 reported, respectively. For crop storage, the FAI value was low (2.4) in the case of Sindhupalchowk while Dhading and Chitwan had medium FAI values of 3.2 and 3.5, respectively (Table 5).

Households experienced an increase in the frequency and intensity of natural disasters, such as floods, landslides, droughts, earthquakes, fires, cold waves and snow. These disasters affected their agricultural practices and production. Altogether, 70% of the farm households from Chitwan cited experiencing flood events. The devastating flood in August 2017 and the yearly flood during the monsoon period in Terai were reported to have destroyed crops, adversely affecting the farmers' food security. Nearly 60% of the farm households from Dhading reported landslides as an increasingly concerning issue. The study participants from Sindhupalchowk and Dhading reported earthquakes to be one of the significant disasters affecting their region as they suffered severely from the devastating earthquake in 2015.

Table 6 Predicted proportion (80% CrI) of study participants who more likely to follow adaptation measures

	Posterior means (80% CrI)
Chitwan (Terai)	0.28 (0.23, 0.33)
Dhading (Hill)	0.63 (0.58, 0.68)
Sindhupalchowk (Mountain)	0.74 (0.69, 0.79)

Table 7 Percentage (%) distribution of the households by their adaptation measures taken to directly respond to food insecurity

Adaptation measures	Total	Chitwan	Dhading	Sindhupalchowk
Purchase	45	28	50	58
Borrow	26	0	40	38
Loan	20	0	39	22
Shared cropping	6	4	7	7
Barter	5.5	0	11	16
Sell Produce	5	0	11	5
Labour	5	0	12.5	2
Wild edible	1	0	4	0

3.6 Adaptation in response to food insecurity

Based on the statistical analysis, people from Sindhupalchowk were more likely (74%) to adapt in response to food insecurity measures compared to Dhading (63%) and Chitwan (28%) (Table 6). Age and gender did not affect the adoption of these measures.

As assessed via the HFIAS questionnaire, the households encountering severe food insecurity stated that they consumed less preferred food and reduced the number and the quantity of meals. Thus, the following adaptation responses include responses other than those evaluated via the HFIAS questionnaire (Table 7). Most study participants experiencing a food-insecure situation (45%) reported that they had to buy food during times of food scarcity or shortages. Furthermore, 75% of the total study participants reported spending more of their income on food than before, 21% reported spending the same as before, and the rest mentioned having spent less of their income on food than in the previous years. The second most common adaptation measure followed among the farming communities was borrowing food (26%). The women's group (FGD-H) from the hilly district noted: 'We exchange food with, borrow from and share food amongst our neighbours and relatives during shortages.' Around 20% of the study participants reported that they had taken loans either from relatives, neighbours or community-based networks to buy food. A lower percentage of the study participants reported having followed share-cropping (6%), bartering (5.5%), selling livestock/harvests to meet food requirements (5.2%) or working as a labour (5%), and a few study participants reported that they had to rely on wild edibles at times in food-scarcity situations. A household (HH 274) narrated: 'We barter our produces with food, particularly rice, during the time of food shortages.' This demonstrates the significance of rice in these households' food habits and shows how households determined their food security mainly in terms of rice.

The key informant (KI 32) highlighted buying, sharing and borrowing of food among family and relatives: 'Those who have money buy it. Others share food with

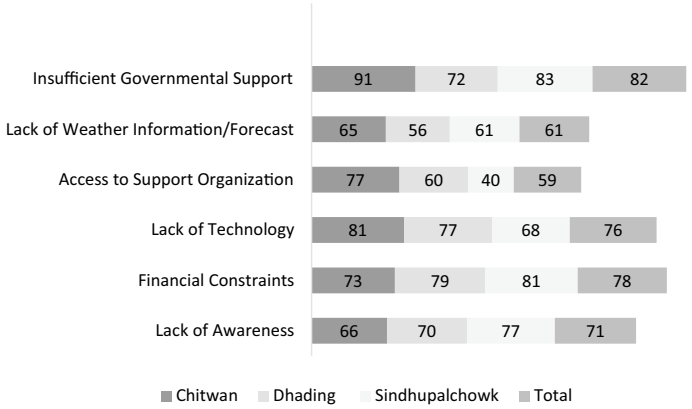

Fig. 4 Percentage distribution of the farmers by their reported constraints to adapting to climate change (n = 384)

or borrow food from relatives and neighbours. At higher altitudes where they cannot grow paddy, they exchange their produces like potatoes, radish with the paddy.'

Along with the adaptation measures directly used to tackle the food insecurities, the farm households stated using various adaptation measures including crop types and varieties, use of fertilizers, changing farm operation time, use of new technologies, conserving soil, managing water resources, migration and diversifying income sources to increase food production and consequently food security and mitigate the adverse impacts of climate change.

Similarly, households reported various factors constraining adaptation (Fig. 4) in their agricultural practices in response to climate change. The key constraints reported by the study participants were insufficient support from the government (as reported by 82% of the total study participants), financial constraints (78%) and lack of technology to adapt to the impacts of climate change (76%). Similarly, farmers also reported not being aware (70%) and not receiving weather information and forecast or information about climate change (61%). It is important to note that though only 38% of households reported being familiar with the term climate change or being aware of climate change and its notion, farmers in all the study sites had experienced its impacts. Altogether 59% of the study participants reported not being able to access support organization in order to adapt to the impacts of climate change.

4 Discussion

The notion of food security is flexible, making it context-sensitive and difficult to measure (Shrestha and Nepal 2016). While a single survey instrument/indicator cannot represent all the dimensions of food security (Carletto et al. 2013), they can provide contextual insights that are critical for understanding adaptation responses experienced at the local level. This study examined food security among farm households based on surveys of their experiences. The findings suggested that the smallholder farm households in the study sites experienced food insecurity with this being more pronounced in the Dhading (hilly) and Sindhupalchowk (mountain) districts. Chitwan was food secure compared to these districts.

Only 24% of the households in Chitwan were food insecure with no severe food insecurity based on HFIAS. Additionally, several factors including the impacts of climate change were reported as a threat to their food security.

The western mountains of Nepal have been documented as experiencing severe chronic food insecurity (20%) requiring immediate interventions (Ministry of Agricultural Development et al. 2016). The food insecurity in the case study area was not as severe as that documented for the western highlands of Nepal. However, our findings showed that the households in the study area had nonetheless been experiencing food insecurity in one way or another.

The prevalence of food insecurity was higher in the Mountains and Hills compared to the Terai agro-ecological zones. This finding is consistent with the previous studies from Nepal (Dhital et al. 2016; Joshi and Joshi 2016; Maharjan and Joshi 2011). Farmers living in the plains are more food secure than those residing on sloped hills and mountains (Adane et al. 2015). This could be due to a range of socioeconomic (population density), institutional (food storage, distribution and markets) and biophysical factors (climate, weather, soil, topography, vegetation, water availability) which characterize each of these regions and determine the provision of food (Brown et al. 2015). Terai constitutes 57% of the total arable land of Nepal and its alluvial soils are more fertile compared to those of the Hills and the Mountains (Leclerc and Hall 2007), better favouring crop production. Furthermore, irrigation facilities have been more developed in Terai in comparison to the other agro-ecological zones with around 83% of arable lands in Terai irrigated compared to 24.3% in the Hills and 28.4% in Mountain zones (Joshi et al. 2017b). The usage of agricultural inputs such as chemical fertilizers and improved seeds is highest in Terai followed by the Hills and Mountain zones. The effects of climate change are more pronounced in the Mountains and Hills zones compared to Terai (Paudel 2016; Poudel and Shaw 2017). Poor infrastructure, inadequate transportation facilities, limited market and out-migration have all been found to affect food security in the mountainous regions (Rasul et al. 2014). The limited economic opportunities, harsh biophysical conditions, fragility and seasonality are more likely to threaten food security in the Mountain zone (Wester et al. 2019). As smallholders mainly produce food for consumption, an increase in crop production translates to enhanced food security (Kabubo-Mariara and Mulwa 2019). This suggests that supporting increasing farm productivity of these smallholders is vital to ensure greater food security as well as improving the livelihood of the farmers. In contrast with the findings from Asghar and Muhammad (2013), Abdullah et al. (2019) who highlighted age and gender as important factors determining food security, our study did not find any strong association between these demographic variables and food security.

The high preference for rice amongst other staple food crops as reported in our case study raises a concern as this underutilization of other food crops in the region. Gartaula et al. (2012) reported the usage of rice as a metaphor for food in a study from rural Nepal. People prefer rice as the staple food and thus bypass other potential indigenous crops (Ministry of Agricultural Development 2016). These neglected and underutilized food crops, therefore, have the potential to contribute to food and nutrition security and therefore help improve the local economies in the mountain regions (Adhikari et al. 2017). Furthermore, some neglected and underutilized food crops are more tolerant to climate impacts than traditional cereal crops and cash crops (Padulosi and Hoeschle-Zeledon 2004; Chivenge et al. 2015).

The higher levels of food security reported for Terai is consistent with it being considered the 'breadbasket' of Nepal. More than half (56%) of total cereal production of Nepal comes from Terai though it covers only 23% of the total land area (Ministry of Agriculture

and Co-operatives 2010). The high level of food availability in Terai is mainly because of its favourable soil, availability of irrigation and access to agricultural inputs. An assessment of input use in three agro-ecological zones of Nepal by Joshi et al. (2017a, b) reported that Terai led in all the indicators of input use considered vital to higher and better crop yield. The low development of irrigation facilities and less usage of improved seeds and chemical fertilizers in the Hills and Mountains zones have been contributing factors to Nepal's overall food deficits (Joshi et al. 2017a, b).

Another contributing factor could be the higher number of out-migration as reported by the farm households in Chitwan (Terai) than in the other two districts as this might have contributed to household incomes. Gartaula et al. (2017) reported that food purchasing capacity is enhanced by an increased male out-migration and off-farm work. The inflow of remittance provides the means to buy food when needed and aids in ensuring food security. A study by Regmi and Paudel (2017) in Chitwan, Nepal, reported international remittance to have a significant contribution to the food security of the households in Chitwan, Nepal.

Despite being considered the national 'breadbasket,' the prevalence of moderate and mild food insecurity in Terai and the prevalence of food insecurity in other study regions suggests that the food security ranking of a region does not guarantee the security of all the households in that region. The diminishing food security being broadly experienced across the three study regions could be caused by climatic factors especially extreme flood events, erratic rainfall and droughts, as reported by the households. Climate change and the associated climatic hazards decrease the production of cereal crops, such as paddy, maize, millet and wheat (Hussain et al. 2018), and affect the livelihoods of households (Warner and van der Geest 2013). Climate variability, mainly recurring extreme events, droughts and late monsoon, have been found to have affected food production and food security in Nepal (Gautam and Andersen 2017; Shrestha and Nepal 2016; Joshi et al. 2017a). The diminishing food availability resulting from the declined production as reported by most of the study participants in this study agrees with results from other Nepalese studies (Shrestha and Nepal 2016; Hussain et al. 2018; Poudel et al. 2017). Climate change is resulting in increasingly intense and frequent extreme events such as droughts and floods, with negative consequences on food security in the most vulnerable communities (Met Office and World Food Programme 2012). The disastrous flood in 2017 impaired agricultural production and threatened food security in India and Bangladesh as well as Nepal (Food Security Information Network 2018). Flood induced loss of physical assets is more likely to cause food insecurity (Shah et al. 2020). The reliance on rain-fed agriculture and the annual summer monsoon for the major food crops is a major factor determining the vulnerability of the smallholder farmers in the study area.

Food security is exacerbated by the coexistence of complicated interactions between sociocultural, economic and political processes (Sapkota et al. 2016) and institutional barriers (Bishokarma and Sharma 2013) that govern the vulnerability of rural Nepal to the impacts of climate change. Multiple factors were linked with food insecurity. The severe food-insecure conditions amongst resource-poor, disadvantaged groups and those with limited land and income as reported by key informants and women in FGD in this study highlight the interplay of socioeconomic and climatic factors in securing food for these rural farmers. This result confirms the findings of other studies conducted in Pakistan and Nepal (Pervaiz et al. 2017; Gautam and Andersen 2017; Merrey et al. 2018). Similar to the findings of our study, Aryal (2016) and Luni et al. (2011) reported food insecurity amongst the Cheppang communities in Nepal. Though the impacts of climate change are experienced everywhere and by everyone, the underlying socioeconomic conditions and institutional arrangements increase the vulnerability of the poor and disadvantaged communities like

Cheppangs in our study area to climate change impacts and reduce their capacity to adapt, producing a magnified effect (Bishokarma and Sharma 2013; Poudel et al. 2020; Sujakhu et al. 2019). Climate change alone does not trigger food insecurity, but factors such as entitlement, social relations and socio-institutional change determine these communities' vulnerabilities and their capacity to adapt (Gautam and Andersen 2017). The lack of finances not only contributes to food insecurity in rural communities (Ghimire 2014) but also constrains their ability to adapt to climate change. Additionally, an increasing abandonment of agriculture by the youth and escalating out-migration catalyse the decrease in the production (Rasul et al. 2014), further undermining food security at the household and community level.

The farmers in this study reported dealing with food insecurity through various adaptation responses. As assessed in the HFIAS questionnaire, some of the members of the households took less preferred food or reduced meals. When their production did not meet their food demands, and when they could not take their preferred food, the most common strategy was to buy food from the market. Borrowing food or money from the community-based network, relatives and neighbours and taking loans as reported in this study were in line with the other findings in Bangladesh, Bhutan, Burkina Faso, Cameroon, China, Ethiopia, India, Kenya, Micronesia, Mozambique, Nepal, Pakistan and Gambia (Zemedu and Mesfin 2014; Warner and van der Geest 2013; Molua 2012; Bhatta and Aggarwal 2016; Ahamad et al. 2013; Gautam and Andersen 2017; Hussain et al. 2016; Gentle and Maraseni 2012). Using assets including labour and the selling of livestock cited in this study were adaptation measures also noted in other studies from Bangladesh and Nepal (Ahamad et al. 2013; Bhatta and Aggarwal 2016; Ghimire 2014; Alston and Akhter 2016). Most of these adaptation measures, however, could unintentionally serve to increase household vulnerability. Measures such as borrowing money and taking loans from informal sources through moneylenders and with no fixed rates could push these people into a cycle of interest repayments. This prospect raises concerns that adaptation responses taken to cope at a time of adversity may subsequently serve to further diminish household food security (Burke and Lobell 2010; Bhatta and Aggarwal 2016). This suggests the need for more strategic planning and sustainable, innovative and even transformative solutions when addressing food insecurity challenges.

Support from governmental and non-governmental organizations is likely to influence household food security with those receiving support being more likely to be food secure compared to non-supported farmers (Islam et al. 2018; National Planning Commission 2018). Nepal is targeting to end hunger, malnutrition and food insecurity by 2030 (Sustainable Development Goal 2) through a programme called the Zero Hunger Challenge. Several plans and strategies including the Agriculture Development Strategy (ADS) 2015–2035, the Food and Nutrition Security Plan of Action (FNSP) 2013–2022 and the Multi-Sectoral Nutritional Plan (MSNP) 2018–2022 and Nepal: Zero Hunger Challenge National Action Plan (2016–2025) further demonstrate the commitment of the Nepalese Government to alleviating hunger and food insecurity (Ministry of Agriculture; Land Management and Cooperatives 2018).

Despite these government food security-related commitments, plans and policies, the high percentage of farmers reporting insufficient support from the government could be due to ineffective implementation, low access to extension services, a small number of support staff at rural areas and a gap in service delivery, information generation and dissemination. The new institutional arrangements under the new constitution of Nepal offer an opportunity for better horizontal (between departments and ministries) and vertical (from central to local levels) coordination and collaboration to implement plans and policies

related to food security. However, the institutional arrangements need to be revisited considering the ongoing restructuring processes, policies need to be scaled up and localized, and data monitoring system should be sound and accountable to achieve zero hunger by 2030 (National Planning Commission 2018). The lack of information and its access and appropriate technology for adapting to climate change noted here is in line with findings from other studies (Pandey et al. 2018; Regmi and Bhandari 2013).

5 Conclusion

This study has established that food insecurity is prevalent among more than half of the smallholder farm households in the Bagmati Province of Nepal. These households reported experiencing a varying degree of food insecurity with the households in Chitwan district (Terai-lowlands agro-ecological zones) being more food secure than those in the Dhading (Hills) and the Sindhupalchowk (Mountains) districts. Multiple factors were related as the drivers of food insecurity including low productivity, pest infestation, lack of resources, socioeconomic factors and environmental factors including climate change. Climate change among these factors acts as a catalyst for amplifying the risk of hunger and food insecurities. The rural farmers depending upon the monsoonal rainfall for their agriculture, mainly the poor and otherwise disadvantaged households as in this study, are predominantly vulnerable. Farmers are adapting to food insecurities by purchasing and borrowing food, taking loans, shared cropping, barter, working as a labourer and doing side jobs.

As smallholder farmers comprise a majority of the Nepalese population, the government should focus on empowering these farming communities to help improve their livelihood as well as to attain food security. Many policy and programmatic initiatives could be taken by governments to help improve food security, particularly prioritize assisting farm households with limited land and income. Farmers can be provided with skills and measures to maximize their agricultural productivity such as training, better access to markets, extension services, credit, climate-smart technologies, micro-irrigation, infrastructures, storage facilities and insurance schemes. Farmers' organization and networks can be strengthened to facilitate information dissemination, knowledge transfer, sharing of inputs and resources. As the impact of human-induced climate change is a unique challenge faced by this generation of farmers, any adaptation interventions must be carefully designed to align with the underlying biophysical, socioeconomic, climatic, political conditions and institutional arrangements of each agro-ecological zone. The government of Nepal can help ensure that new institutional arrangements clearly specify organizational roles and responsibilities, and the effective allocation of resources for capacity building and implementation of plans and programmes for food security. The need is evident for government and non-government organizations, along with all relevant stakeholders, to collaborate in increasing the adaptive capacities of smallholder farming communities to better manage current and future climate impacts and associated risks to food security.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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