Science of the Total Environment 796 (2021) 148853

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Climate change adaptation for managing non-timber forest products in the Nepalese Himalaya

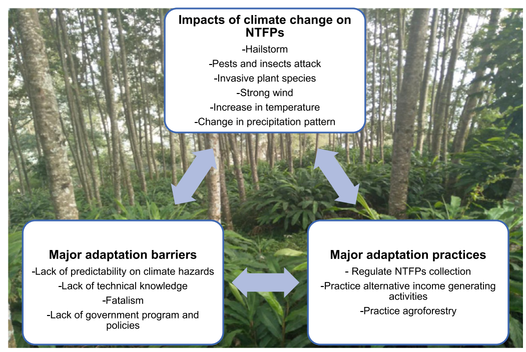
Lila Jung Gurung *, Kelly K. Miller, Susanna Venn, Brett A. Bryan

Centre for Integrative Ecology, School of Life and Environmental Sciences, Deakin University, Burwood, Victoria, Australia

HIGHLIGHTS

- Climate change is impacting the availability of NTFPs in mountain communities.
- Climate change has increased invasive plant and insect pests, threatening NTFPs.
- Agro-forestry, self-regulation, and off-farm income are common adaptation practices.
- Lack of climate predictability and technical knowledge are major adaptation barriers.
- Our results can guide policy decisions and programs for managing NTFPs.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 February 2021
Received in revised form 7 June 2021
Accepted 30 June 2021
Available online 3 July 2021

Editor: Martin Drews

Keywords:
Ecosystem services
Perceptions
Agroforestry
Adaptation barriers
Mountain communities

ABSTRACT

Non-timber forest products (NTFPs) contribute to the well-being of mountain communities in many ways but their availability is being impacted by climate change. Policy and programs to enhance adaptation can alleviate these impacts, but to be effective they require an understanding of mountain community perceptions of climate change impacts on NTFPs and the perceived barriers to climate change adaptation. Here, we explored mountain communities' adaptation responses to the perceived impacts of climate change on NTFPs and people's barriers to adaptation using a structured questionnaire delivered as a field-based survey of 278 forest-dependent households from the Upper Madi Watershed of Nepal. We present a quantitative graphical exploration of the results to provide a simple overview of climate change impacts of NTFPs and local adaptation. The most common adaptation practices adopted by the mountain communities in the study area include the self-regulation of over-collection of NTFPs, alternative income generating activities, improved stoves, agroforestry, and sourcing alternative tools and materials. However, adaptation options to deal with increased invasive plant species and pest insect outbreaks appear to be challenging despite having the highest perceived impact on NTFPs. Adaptation practices are constrained by several factors such as the lack of predictability of extreme events and climate-related hazards, lack of technical knowledge, fatalistic beliefs and perceived lack of agency, and limited government support. Our results can inform policies and programs required for addressing the impacts of climate change on mountain communities in Nepal and other developing nations.

1. Introduction

Climate change, including more frequent extreme weather events, is one of the most important environmental challenges of the 21st century and its impacts are already evident (IPCC, 2019). Climate change is

* Corresponding author.
E-mail address: ljgurung@deakin.edu.au (L.J. Gurung).

https://doi.org/10.1016/j.scitotenv.2021.148853

occurring rapidly in the Nepalese Himalaya, with temperature increases of 0.6 °C per decade along with changes in precipitation patterns observed for the period 1971–94 (Rasul, 2007), as well as extreme events such as glacier melts, flooding, and droughts (Byers et al., 2014). The changes in climate patterns and extreme events ultimately impact the provision of non-timber forest products (NTFPs) which provide mountain communities with food, fuel, materials, and many other benefits, consequently affecting their livelihoods and well-being (Chakraborty et al., 2018; Kohler et al., 2010; Liu et al., 2006; Maroschek et al., 2009; Penuelas et al., 2017; Shahzad et al., 2019).

Local people from the Himalayan region rely on various NTFPs for food, medicine, spice, cultural purposes and income generation despite recent climate change. Aryal et al. (2018) recorded 99 wild edible plants from the Darchula district of western Himalaya which significantly contribute to the daily food and nutrition requirements of households, medicine, rituals, and income generation. Wild edible plants also greatly improve the nutrition and food security of mountain communities in Sikkim Himalaya (Sundriyal and Sundriyal, 2001). Some NTFPs may provide opportunities for off-farm employment and income for Himalayan communities. For instance, NTFPs have been found to contribute around 74% of total household income in Nanda Devi Biosphere Reserve of western Himalaya (Yadav et al., 2019). Pant et al. (2012) estimated the total annual benefits of US$125 million from several forest ecosystem services, with 80% of these from NTFPs in three districts of Nepal. In addition, NTFPs have been found to contribute up to 65% of total household cash income in the mountain village of Jumla, Nepal (Shrestha et al., 2019b).

Climate change and associated extreme events impact Himalayan forest resources and the people who depend on them. Increases in temperature and changes in precipitation patterns can reduce the availability of NTFP ecosystem services (Applequist et al., 2020; Ibe, 2018; Pandey et al., 2018) by adversely influencing the life-cycles of plants and animals (Maikhuri et al., 2018; Negi et al., 2017; Sushant, 2013) and altering species phenology and community composition, facilitating invasions from lower altitude species and increasing the risks of local extinction (Lamsal et al., 2017; Steinbauer et al., 2018). It is also predicted that the increase in temperature and change in precipitation patterns increase exposure to other risks such as more frequent and severe forest fires, storms, landslides, and floods which threaten the provision of NTFPs and the livelihoods of mountain people (Kohler et al., 2010). There is a lack of understanding about climate vulnerability and its impacts on forest in the Himalayas (IPCC, 2007). Kumar et al. (2019) reported that 80% forests of the Uttarakhand, a part of Indian Western Himalayan region are vulnerable to climate change. The fragile and remote geography of the Himalaya, with few dispersed settlements and inadequate infrastructure has hindered research (ICIMOD, 2010). Limited knowledge on climate change, its impacts, and adaptation is the biggest challenge for the planning and implementation of adaptation measures in mountain regions (Byers et al., 2014). Ecosystems and people in the mountains of Nepal are considered relatively more vulnerable to climatic risks than in other countries due to the fragile economic and environmental base (Gentle and Maraseni, 2012) and adaptation to both observed and future changes in climate is needed (Bhatta et al., 2015; Gentle and Maraseni, 2012).

Adaptation is increasingly necessary for managing climate change impacts globally (Lesnikowski et al., 2015; Noble et al., 2014). Climate change adaptation refers to adjustments in the human-environment system in response to actual or anticipated climate effects or impacts (Wheeler et al., 2013). Adaptation actions can be considered along a continuum ranging from autonomous and reactive or planned and anticipatory (Smit et al., 2000). Autonomous and reactive actions are spontaneous adjustments in response to changing climate and are vital to enable a bottom-up approach for encouraging future sustainable solutions and to gather knowledge for informed policy (Biggs et al., 2013). Planned and anticipatory actions follow the systematic assessment of climate change scenarios and a design of interventions that help in reducing risks and impacts of climate change, and realize opportunities associated with climate change (Walker et al., 2013). Research in adaptation requires thoughtful consideration of variation in exposure, vulnerability, and adaptive capacity and the timing and extent of change in practices need to consider incremental and transformative options, their costs and benefits, and appropriate implementation pathways (IPCC, 2014). Adaptation in a socio-ecological system depends greatly on adaptive capacity which is related to specific local contexts and differs between regions, communities, individuals, and households, and changes over time (Smit and Wandel, 2006). Local responses at the individual or household level can be used to anticipate capacity for future adaptation and inform appropriate policy responses (Adger and Vincent, 2005). However, adaptation planning and implementation are influenced by multiple barriers such as a lack of information, limited financial resources and competing priorities (Archie, 2014; Shackleton et al., 2015), which can lead to the failure of adaptation processes (Wang et al., 2020). Identification of barriers to the effective implementation of climate change adaptation is important in mountain communities, particularly in developing countries which typically have limited access to resources and technology (Wang et al., 2020).

Research on climate change adaptation in mountain regions is usually focused on agro-ecosystems (Lamsal et al., 2017) and many studies recommend using NTFPs as one of the major options for climate change adaptation for agro-ecosystems (Ali et al., 2017; Ingxay et al., 2015; Macchi et al., 2015). For example, Pandey et al. (2016) reported that people from poor and marginalized communities from Nepal collect wild food (e.g., fruits, vegetables, yams, tubers) as a supplementary source of food during times of reduced agricultural production. However, little attention has been paid to the impacts of climate change on NTFPs themselves, nor to measures taken by local communities for adapting to a change in supply of NTFPs (Fandohan and Cuni Sanchez, 2014, Maroschek et al., 2009). Chitale et al. (2018) emphasized an immediate need to identify and implement appropriate climate change adaptation strategies to conserve NTFPs in central Nepal. Similarly, few studies have assessed adaptation strategies and barriers in the context of NTFPs. Exceptions include Kunwar et al. (2014) and Maikhuri et al. (2018) who reported that traditional healers from Nepal and Central India were adjusting the collection period and using substitute species of medicinal plants which are undergoing climate-driven phenological changes. Nevertheless, in-depth empirical research on how mountain communities perceive the impacts of climate change on NTFPs and how their perceptions are linked to their adaptive responses in managing NTFPs is limited (Keenan, 2015).

In this study, we aimed to: 1) explore the perceived impacts of climate change on NTFPs; 2) understand the perceived probability of future occurrence of climate-related risks and extreme events and impacts on NTFPs; 3) investigate the current state of climate change adaptation for managing NTFPs by mountain communities; and 4) identify the barriers to climate change adaptation by local people. To achieve these aims, we conducted a questionnaire-based field survey, interviewing 278 household heads in the Upper Madi watershed in Nepal as a case study and asked them about how they perceive the impacts of climate change on NTFPs, probability of future occurrence of climate related risks and extreme events and impacts on NTFPs, and their adaptation practices and adaptation barriers. Results are used to evaluate the policies and programs required for addressing the impacts of climate change on NTFPs in Nepal and for adaptation to climate change in mountain ecosystems more broadly.

2. Theoretical approach

This study focuses on people's perception of climate change impacts on NTFPs and their adaptive responses in managing NTFPs. Communities whose lives and livelihoods depend on ecosystem services, particularly forest-dependent communities, are aware of changes and have local knowledge which may stretch back in time over decades, as shown in previous studies from the Himalayas (Chaudhary and Bawa, 2011; Chaudhary et al., 2011). Understanding community views about climate change is crucial, as people's perceptions of climate change, its impacts, and potential adaptation strategies are key components of the adaptation planning process (Macchi et al., 2015; Maddison, 2007). Local perceptions of climate change, taken together with scientific data, can inform the development of effective climate change policy and adaptation strategies (Chaudhary and Bawa, 2011). However, local people's observations and their understanding about climate change and adaptation, especially in mountain ecosystems, is mostly absent from scientific studies (Byg and Salick, 2009; Howe et al., 2013). Without an understanding of mountain people's and communities' perceptions of the impacts of climate change, any proposed adaptation strategies are unlikely to be effective.

Local knowledge of adaptation is also crucial to formulate successful adaptation strategies (IPCC, 2007). Adaptation strategies are situation-specific and change over time and from place to place, and even vary within specific communities (Singh et al., 2018; Smit and Wandel, 2006), and thus, local level adaptations cannot be based on global level studies (Thakur et al., 2020). Adaptation options therefore, should be assessed cautiously at the local scale (Mina et al., 2017). While there are some examples of local adaptations to a changing climate in mountain communities, such as changing plant collection periods and using substitute species for the treatment of ailments to cope with the changing phenophases of medicinal plants in Nepal and India (Kunwar et al., 2014; Maikhuri et al., 2018), adjusting the planting and harvest dates in China (Li et al., 2013), and replacing firewood with biogas in Nepal and Bhutan (Adhikari et al., 2018; Suberi et al., 2018), there remain significant knowledge gaps surrounding mountain communities' perceptions about NTFPs and the motivations for adapting to climatic change.

3. Methods

3.1. Study area

The Upper Madi watershed is located on the southern slope of the Annapurna and Lamjung Himalayan range, in the Madi Rural Municipality, Kaski, Nepal (84°2′35″E-84°16′41″E, 28°18′37″N-28°32′20″N) and covers an area of approximately 361 km^2 (Fig. 1). The Upper Madi watershed falls within the largest protected area of Nepal—the Annapurna Conservation Area (ACA)—which contains rich biological diversity and cultural heritage (NTNC, 2009). The watershed has a topographic elevation from 1082 m to 7937 m a.s.l. With increasing elevation, the climate of the study area spans subtropical, temperate, and alpine from south to north. Between 1990 and 2018, mean precipitation in summer was approximately 744.6 mm and 66 mm in winter (DHM, 2019). Over this period, summer rainfall increased by 1.7 mm yr^{-1} and winter rainfall decreased by −0.88 mm yr^{-1} (DHM, 2019). Mean annual maximum and minimum temperatures were 26.38 °C and 15.11 °C respectively, recorded at the nearby city of Pokhara (located approximately 32 km southwest of the study area) (DHM, 2019). The mean annual temperature increased by 0.46 °C per decade (DHM, 2019).

Following climatic and altitudinal zones, the study area supports subtropical schima-castonopsis forest, lower temperate mixed broadleaved forest with alder and oak, upper temperate mixed broadleaved forest with rhododendron and birch, and arid bushes. Frequency of extreme events such as floods has increased by a factor of 1.18 in the study region between 1984 and 2013 (DesInventar, 1999). The study area comprises approximately 909 households and around 75% of these are *Gurung* ethnic communities, with the rest from other castes such as *Damai*, *Kami*, *Nepali*, *Chhetri*, and *Brahmin* (MRM, 2018). Most people rely on several types of NTFPs such as medicinal plants, wild vegetables and fruits, fibers, and bamboo products for their household

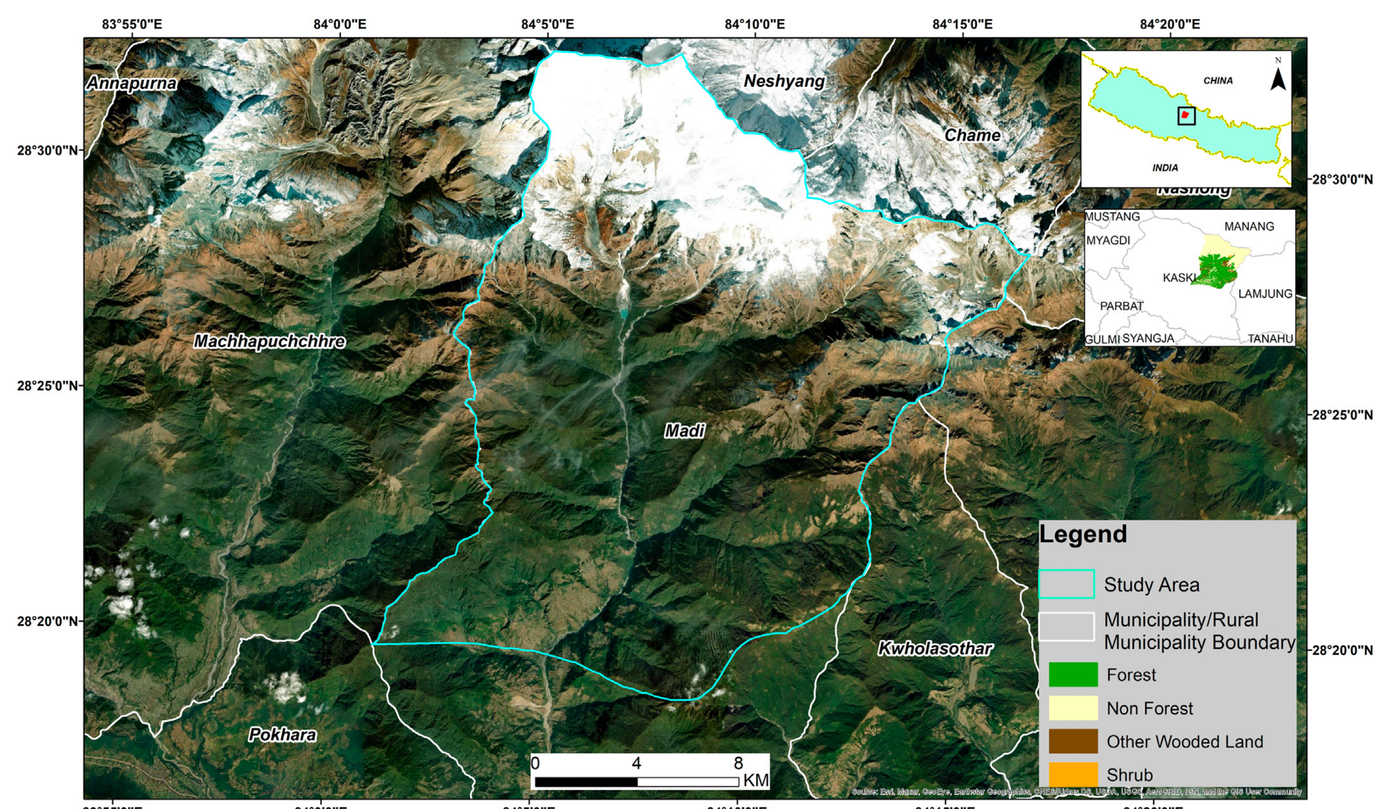


Fig. 1. The study area: Upper Madi watershed, Nepal.

consumption or subsistence income (Gurung et al., 2008; Gurung et al., 2020), and the provision of NTFPs are impacted by increased in temperature, change in precipitation, extreme events such as hailstorms and strong winds, and climate induced hazards such as landslides and floods (Gurung et al., 2020).

3.2. Sampling procedure and data collection

In our study, the household was the unit of analysis and the household head or their representative was the respondent. To provide a statistically reliable sample from the target population of the study area (Suleiman et al., 2017), a sample size of 278 households (31% of the 909 households in the study area) was determined by using the formula proposed by Yamane (1967). The Statistical Package for the Social Sciences (SPSS 21) software was used to select a random sample of 278 households.

We conducted a face to face household survey (Pandey et al., 2018) to collect data for this study during September–December 2019. A structured questionnaire containing both closed and open-ended questions developed after careful review of the published research on people's perception (Bhatta et al., 2020; Muhamad et al., 2014; van Oort et al., 2015), climate change adaptation, and barriers (Alam et al., 2017; Archie, 2014; Bhatta et al., 2015; Pandey et al., 2018), was used to interview the selected household heads (or their representatives). To check the clarity of the survey questions, they were pre-tested (Lhoest et al., 2019) with 10 households prior to the survey implementation. The questions were prepared in the local Nepali language and all the participants were clear on the survey questions. The survey included 6 main sections: 1. socio-demographic information of respondents; 2. currently collected and utilized NTFPs in the study area; 3. local perceptions of climate change; 4. perceived impacts of climate change on NTFPs; 5. perceived probability of future occurrence of climate related risks and extreme events such as prolonged drought, extreme rainfall and landslides, extreme wind and hailstorms, increase in pest and insects, increase in invasive plant species, and their impacts on NTFP availability; and 6. climate change adaptation practices, and perceived adaptation barriers. This paper is based on the sections 4, 5, and 6 (Supplementary information). The 5-point Likert scale (Robson and McCartan, 2015) was used to quantify the responses. Regarding the perceived probability of future occurrence of risks and extreme events and their impacts on NTFPs: the responses ranged from very unlikely to occur to very likely to occur. In the case of climate change adaptation practices, the respondents were asked about their range of adaptation practice from *not practiced* to *well-practiced*; and for perceived adaptation barriers, the respondents were asked to estimate the perceived level of barriers from *not a barrier* to *very significant barrier*.

Ethics approval was obtained from the Faculty of Science Engineering and Built Environment Human Ethics Advisory Group, Deakin University (reference number STEC-31-2019-GURUNG) for this study. A plain language statement (PLS) of the project was provided to all participants in their preferred language (Nepali) and each participant signed a consent form before the survey. The PLS included information about the significance of the study, that participation was voluntary, and that participants could withdraw from the survey at any time of the research. Confidentiality and anonymity of the respondents and their responses were maintained.

3.3. Data analysis

The data obtained from the household survey were visualised graphically and analysed quantitatively using descriptive statistics. The data were coded to facilitate data entry and numerical codes were given to responses for systematic organization of data into categories (Robson and McCartan, 2015) using SPSS 21. The open-ended questions were framed to supplement the results of closed questions. Qualitative information collected from the open-ended questions were analysed using thematic coding analysis (Robson and McCartan, 2015).

4. Results

4.1. Characteristics of sample households

In the study area, household heads are typically male which meant that our sample consisted of more males (62.2%) than females (37.4%). Nearly half of the respondents (50.3%) were aged over 60 years, while respondents aged 36–60 and 18–35 years formed 43.9% and 5.8% of the sample, respectively. The majority of the respondents were of Gurung ethnicity (78.8%), followed by Dalit (19.4%), and 1.8% were of other ethnicity. Most respondents (61.5%) had no formal education, 34.9% had primary education, 3.6% had secondary education, and no one was tertiary educated. Almost all were farmers (97.5%), with 2.5% of respondents employed in the business sector. Among the respondents, 34.2% had an average annual household income greater than 100,000 Nepalese Rupees (NPR) (USD 967.5), 29.9% had an income of NPR 51,000–100,000 (USD 493–967.5), 27% had an income of NPR 25,000–50,000 (USD 242–484), and 8.9% reported incomes of less than NPR 25,000.

4.2. Utilization of NTFPs and impacts of climate change on NTFPs in the study area

The study area is rich in NTFP utilization. Different categories of NTFPs such as fuelwood, wild vegetables, wild fruit, fodder, bamboo products, agricultural tools, medicinal plants, ornamental plants, nettle products, and ritual plants which contribute to mountain people's well-being and livelihoods in multiple ways (Table 1 and Fig. 2).

More detail of NTFP use and the full dataset is presented in Gurung et al. (2020). Mountain communities in the study area used NTFPs both for subsistence and cash income. The most common NTFPs use for cash income were medicinal plants, bamboo products, and nettle products (Gurung et al., 2020).

People perceived an increase in invasive plant species, insect and pest species outbreaks, and an increase in extreme weather events such as hailstorms and strong winds, as well as natural hazards such as landslides and floods, as being associated with recent increased temperatures and changes in precipitation patterns, and that these have all negatively impacted the availability of NTFPs for mountain communities over the last 20–30 years (Fig. 3).

4.3. Local perception of probability of future occurrence of climate related risks and extreme events and impacts on NTFPs

Most respondents (68%) perceived the probability of occurrence of invasive plant species and their impacts on NTFPs will likely occur in the future (Fig. 4), and nearly a half of the respondents (43.5%) agreed on the probability of occurrence of pests and insects and their impacts on NTFPs. However, the majority of the respondents were not sure about the probability of occurrence of deficit rainfall and water stress and its impacts on NTFPs (98.2%), occurrence of extreme rainfall and landslides and its impacts on NTFPs (95.7%), occurrence of prolonged drought and occurrence of forest fire and impacts on NTFPs (95.3%), occurrence of extreme rainfall and floods and impacts on NTFPs (95%), occurrence of erratic rainfall and its impacts on NTFPs (92.8%), occurrence of strong wind and extreme hailstorms and impacts on NTFPs (89.2%) and occurrence of extreme hailstorm and its impacts on NTFPs (88.8%).

4.4. Adaptation practices

Respondents reported adopting several climate change adaptation practices. Among these were the self-regulation of over-collection of NTFPs, alternative income generating activities, agroforestry, the use

Table 1
List of major NTFP species collected in Upper Madi watershed.

NTFPs use categories	Common name	English name	Scientific name	Part used
Fuelwood	Uttis	Alder	*Alnus nepalensis* D. Don	Stem
Wild vegetables	Ghude	Himalayan Small Bamboo	*Thamnocalamus spathiflorus* (Trin.) Munro	Shoots
	Niuro	Edible Fern Shoot	*Dryopteris cochleata* (D. Don) C. Chr.	Shoots
	Malinge	Himalayan Small Bamboo	*Himalayacalamus cupreus* Stapleton	Shoots
Wild fruit	Paiyu	Himalayan Cherry	*Prunus cerasoides* D. Don	Fruit
	Malah	N/A	*Viburnum mullaha* Buch. -Ham.ex D. Don	Fruit
	Aiselu	Golden Evergreen Raspberry	*Rubus ellipticus* Sm.	Fruit
	Bhutro	Nepal Barberry	*Berberis aristata* DC.	Fruit
Fodder	Ghude	Himalayan Small Bamboo	*Thamnocalamus spathiflorus* (Trin.) Munro	Leaf
	Dudhilo	N/A	*Ficus neriifolia* Sm.	Leaf
	Kharsu	Brown Oak of Himalaya	*Quercus semiserrata* Roxb.	Leaf
	Gogan	N/A	*Saurauia napaulensis* DC.	Leaf
	Malinge	Himalayan Small Bamboo	*Himalayacalamus cupreus* Stapleton	Leaf
	Chuletro	N/A	*Brassaiopsis hainla* (Buch. -Ham.) Seem.	Leaf
Bamboo products	Ghude	Himalayan Small Bamboo	*Thamnocalamus spathiflorus* (Trin.) Munro	Stem
	Malinge	Himalayan Small Bamboo	*Himalayacalamus cupreus* Stapleton	Stem
Agricultural tools	Paiyu	Himalayan Cherry	*Prunus cerasoides* D. Don	Stem
	Chilaune	Needle Wood	*Schima wallichii* (DC.) Korth.	Stem
	Laligurans	Rhododendron	*Rhododendron arboreum* Sm.	Stem
Medicinal plants	Kudki	N/A	*Picrorhiza scrophulariiflora* Pennell	Rhizome
	Siltimur	Pepper	*Lindera neesiana* (Wall. ex Nees) Kurz	Fruit
	Panch Amle	Orchid	*Dactylorhiza hatagirea* (D. Don) Soo	Rhizome
	Padamchal	Himalayan Rhubarb	*Rheum australe* D. Don	Rhizome
	Satuwa	N/A	*Paris polyphylla* Sm.	Rhizome
	Yarshya Gumba	Caterpillar Fungus	*Ophiocordyceps sinensis* (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora	Whole plant
Ornamental plants	Laligurans	Rhododendron	*Rhododendron arboreum* Sm.	Flower
	Sungava	Orchid	*Coelogyne cristata* Lindl.	Flower
Nettle products	Allo	Himalayan Nettle	*Girardinia diversifolia* (Link) Friis	Bark
Ritual plants	Titepati	Mug Wart	*Artemisia dubia* Wall. ex Besser	Leaf
	Paiyu	Himalayan Cherry	*Prunus cerasoides* D. Don	Stem, leaf
	Malah	N/A	*Viburnum mullaha* Buch. -Ham.ex D. Don	Stem
	Dudhilo	N/A	*Ficus neriifolia* Sm.	Leaf, stem

of alternative energy, and improved stoves (using gas rather than fuelwood). The use of alternative tools and weaving materials were also commonly adopted adaptation practices (Fig. 5). Most respondents (72.3%) reported the self-regulation of over-collection of NTFPs as being a well-practiced adaptation practice. Respondents collected NTFPs with consideration of their availability. Alternative income generating activities included plumbing, carpentry, and foreign services in order to reduce the pressure on NTFP species. In addition, agroforestry activities such as planting valuable NTFP species for fuelwood, fodder, medicinal plants, and bamboo on their own agricultural land as well as in forests and fringe areas were reported as being well practised (37.4%) and practiced in part (17.6%). Respondents agreed on the use of improved stoves to reduce the need for firewood collection (30.9% well practiced, 20.5% practiced in part), and the use of alternative tools and materials for weaving NTFPs based handicrafts (19.1% well practiced, 24.1% practiced in part). However, most respondents reported forest fire management (95.3%), change of harvesting time (89.2%), removal and reuse of invasive plant species (82.7%), and NTFP species nursery establishment (77.7%) as not practiced.

4.5. Adaptation barriers

Almost all the respondents reported barriers to adaptation in managing NTFPs (Fig. 6). Most respondents (75.9%) perceived a lack of predictability of climate hazards, lack of technical knowledge (64%), and a belief in fate and lack of personal agency (55.4%). Moderate barriers included lack of human resources (46.4%), lack of finances (43.5%), lack of government programs and policies (42.8%) as considerable adaptation barriers, and lack of nursery establishment knowledge (33.1%). Light barriers included a lack of agroforestry knowledge (41%) and a lack of timely access of weather information (29.5%). However, 44.6% of the respondents reported a lack of market access was not a strong barrier.

5. Discussion

Mountain communities from the Nepalese Himalaya used different NTFP ecosystem services for their livelihood and wellbeing. They used NTFPs both for subsistence and cash income. The most common NTFPs used for cash income were medicinal plants, bamboo products, and nettle products. The mountain communities perceived that these services were negatively impacted by climate change and extreme events. Most respondents expressed uncertainty about the future occurrence and impacts of climate and extreme events on NTFPs. Several adaptations were practiced by the mountain communities with respect to NTFPs. Among them, self-regulation of NTFP collection, the practice of alternative income generating activities, and agroforestry were the most common adaptation practices. They perceived a lack of predictability of climate hazards, poor access to technology, a belief in fate, a lack of government policies and programs, limited access to finance and labour, and lack of timely access to weather information to be some of the major barriers for adaptation.

5.1. Perceived current and future impacts of climate change on NTFPs

Hailstorms have impacted the provision of almost all NTFPs in the study area. Botzen et al. (2010) reported that hailstorm damage may increase in the future with climate change. An increase in pests and insect attack has impacted most of NTFPs. Pests and insects consume leaves of NTFP plants, defoliate trees, and otherwise kill plants. Climate change influences on the outbreak of bark beetles and insects that defoliate and otherwise impact forest ecosystems (Pureswaran et al., 2018). Invasive plant species prevent regeneration and degrade the habitat of NTFPs (Shrestha et al., 2019a), mostly affecting fodder, fuelwood, nettle products, and wild vegetable species in the study area. Respondents from the study area anticipate future occurrences of invasive plant invasions and their impacts on NTFPs. The

Fig. 2. Examples of some NTFPs use in the study area a) fuelwood collection b) bamboo collection c) weaving of nettle product d) weaving of bamboo products e) an edible fruit (Viburnum mullaha) f) wild vegetable collection (photographs, with permission from participants: a, c & f by G. Gurung, b, d & e by L. J. Gurung).

range of the invasive plant species is rapidly shifting to higher elevations with the advent of accelerated warming in the mountains of central Nepal (Lamsal et al., 2017) and are predicted to increasingly invade mountain ecosystems as climatic conditions become more suitable (Lamsal et al., 2018).

5.2. Climate change adaptation and adaptation barriers for managing NTFPs

Local communities in the study area were found to be adjusting to the negative impacts of climate change via their NTFP management.

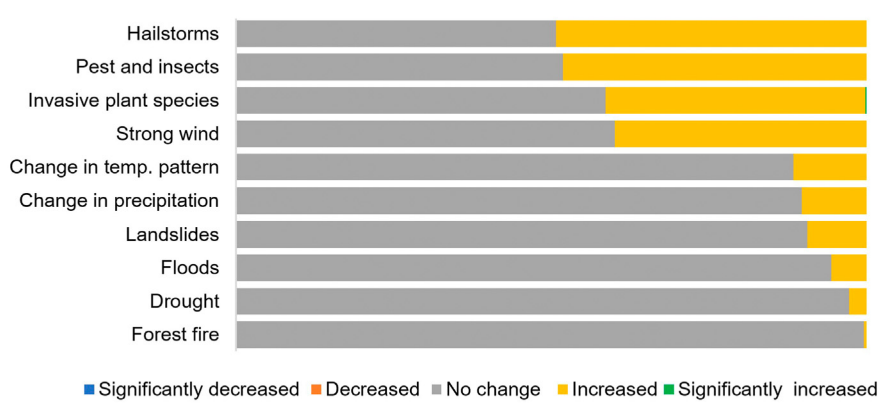


Fig. 3. Perceived overall impacts of climate change on NTFPs ($n = 278$).

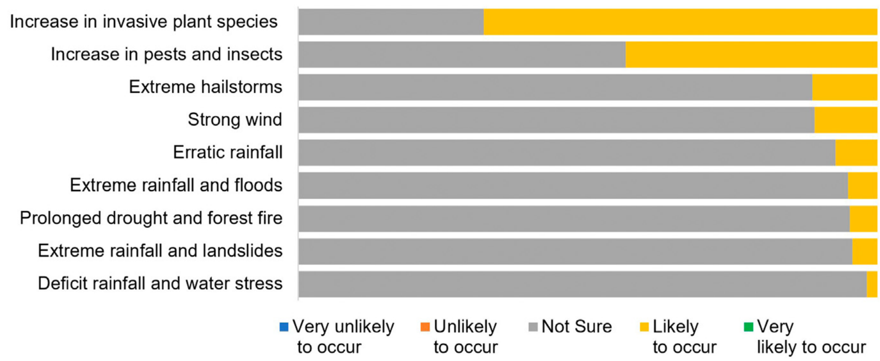


Fig. 4. Perceived probability of future occurrence of climate related risks and extreme events and impacts on NTFPs ($n = 278$).

These practices relating to adaptation were mostly determined by their skills, local knowledge, judgement, vulnerability and available resources. Most respondents practiced agroforestry, self-regulating the collection of NTFPs, and alternative income generating activities such as plumbing, carpentry, and foreign services. The use of alternative energy and weaving materials were also commonly practiced. Other studies have also found similar adaptations to be practiced in other mountain regions (Adhikari et al., 2018; Karki et al., 2020; Tembo et al., 2018). For instance, Adhikari et al. (2018) reported the use of biogas instead of fuelwood as a household level adaptation practice in the Panchase Mountain Ecological Regions of Nepal. Most respondents self-regulated the collection of NTFPs as a major adaptation option, but this has been rarely reported in similar studies.

Agroforestry was also a very common adaptation activity practiced by the respondents. MOE (2010) suggested agroforestry as a priority adaptation activity for managing NTFPs in its National Adaptation Program of Action (NAPA) document of Nepal. Agroforestry can help to overcome a range of ecological and social problems (Rigueiro-Rodríguez et al., 2009), agroforestry systems can enhance ecological benefits through reductions in soil loss, increasing carbon sequestration, enhancing biodiversity, and managing fire risks in specific areas (Pandey, 2007). The use of agroforestry practices can generate additional income for forest dependent communities by cultivating NTFPs with other crops in their farmlands, forests and forest-fringe areas, and can support the restoration of NTFP species (Adhikari et al., 2018; Dey et al., 2018; Sharma and Sharma, 2018) and enhance NTFP diversity (Rigueiro-Rodríguez et al., 2009). Pandey et al. (2017) reported that people from the Tehri-Garhwal district of Uttarakhand, a Himalayan State of India, use agroforestry as a tool for improving the livelihoods and resilience to climate change via the provision of diversified agricultural and forest products.

Most respondents indicated that the practice of alternative income generating activities such as plumbing, carpentry, homestays, and foreign services such as labour in gulf countries and joining the Indian and British armies were among the most common adaptations. These activities generate extra income and reduce pressure on NTFP utilization (Adhikari et al., 2018). Use of improved stoves to reduce fuelwood consumption was also a widely practiced adaptation by the respondents. Less demand for fuelwood also reduces the workload required to collect the fuelwood, improves the health of household members via reducing exposure to indoor smoke from traditional cooking stoves (Adhikari et al., 2018; Suberi et al., 2018). Some studies identified the removal or use of invasive plant species in preparation of organic manure and bio-briquette (Adhikari et al., 2018), or changes in harvest time (Kunwar et al., 2014; Maikhuri et al., 2018) as major adaptation strategies for NTFP management. Removal of invasive species enhances the resilience of NTFP species (Rigueiro-Rodríguez et al., 2009). However, our respondents rarely practiced these. Local development and implementation of strategies for climate change adaptation is insufficient and must be supported by external policy and programs implemented by government and non-government organisations.

People consume and trade NTFPs to adapt to the changing climate (Ingxay et al., 2015; Macchi et al., 2015) as NTFPs buffer the loss of income from low crop yields (Ali et al., 2017). People from poor and marginalized communities in Nepal also collect wild fruits, vegetables, yams, and tubers as a supplementary source of food during times of crop failure (Pandey et al., 2016). Thus, there is a great need for the sustainable management and supply of NTFPs for the mountain communities (Balama et al., 2017).

Impacts of climate change on NTFPs can be reduced and the adaptive capacity of local communities can be enhanced by removing adaptation barriers (Wang et al., 2020). Numerous factors were found to be responsible for hindering local adaptation for better managing NTFPs under climate change. The lack of technology and technical knowledge cited here as a significant barrier aligns with the findings of climate change adaptation studies in other mountain areas (Bastakoti et al., 2017; Heyojoo et al., 2017; Loria and Bhardwaj, 2016). A lack of climatic information and predictability of climate related risks and extreme events among forest-dependent communities in mountain ecosystems arise from a gap in the way information is generated and disseminated, and a failure

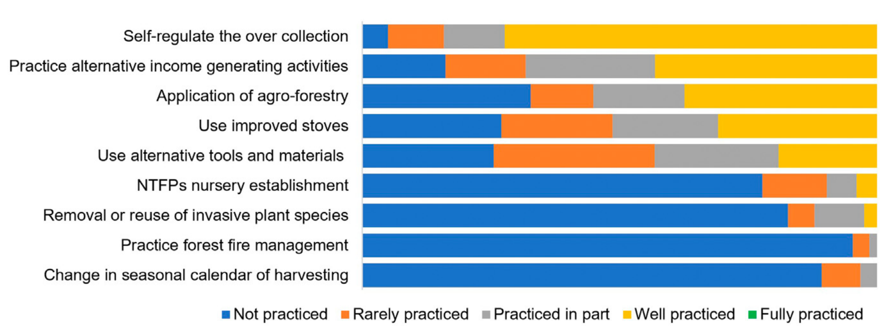


Fig. 5. Adaptation practices by the respondents ($n = 278$).

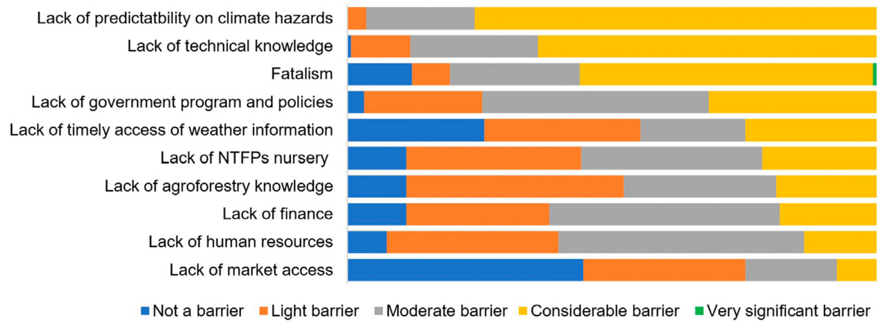


Fig. 6. Perceived adaptation barriers by respondents ($n = 278$).

in communication to mountain communities (Karki et al., 2020). This information gap could also be linked to the lower level of education among respondents. The NAPA also mentioned inadequate financial, technical, human resources, and inadequate implementation of existing plans and policies as barriers in the forestry sector (MOE, 2010). Successful adaptation to climate change among mountain communities requires these multiple barriers to be addressed via policy and planning.

5.3. Policy implications

Climatic variables and climate induced extreme events such as hailstorms, strong wind, spread of invasive plant species and outbreak of pests and insects have been degrading the provision of NTFP ecosystem services. Our study found inadequate management and adaptation initiatives for reducing these risks and events and identified major adaptation barriers including a lack of information and technical knowledge, fatalism and lack of government program and policies for managing NTFPs. Some mountain communities including some in Nepal and India have developed climate change policies and adaptation plans. India has developed a National Action Plan on Climate Change (NAPCC) which recognizes the importance of sustaining mountain ecosystems (GOI, 2008). Nepal has developed several adaptation plans including NAPA and the Local Adaptation Plan for Action (LAPA) (MOE, 2010; MOE, 2011). NAPA assesses national-scale climatic vulnerability and strategic adaptation measures whereas LAPA has been developed to target and direct NAPA planning and implementation at the local level tailored through a bottom-up approach. However, the inclusion and implementation of NTFP-related adaptation practices at a local level remains a challenge. To ensure long-term sustainability of NTFPs, place-specific mechanisms for adaptation could be the best fit for mountain regions given the diverse and heterogenous demographic, geographic, cultural, and economic characteristics of mountain areas. Awareness raising programs related to climate change, government/non-government support via subsidies, or technology support to manage climate related risks and extreme events and impacts on NTFPs. For example, the promotion of mixed-species NTFPs that are more resistant to pest and insect damage (Field et al., 2020), or the identification and promotion of utilization values of invasive plant species (Everard et al., 2018) could be advanced through coordination among local stakeholders.

5.4. Contribution

Our study provides a comprehensive understanding of adaptation practices and barriers to promote the management and sustainability of NTFPs in the mountain environment of Nepal. Few studies have assessed adaptation in mountains and those that do have focused mainly on medicinal plants (Kunwar et al., 2014; Maikhuri et al., 2018). Our study assessed the perceived probability of future occurrence of climate related risks and extreme events and impacts on NTFPs, existing adaptation practices and adaptation barriers in managing NTFPs in the mountains. The findings will help inform long-term adaptation strategies of NTFPs management and policy in mountain ecosystems. Local government and communities can consider the present and future perceived impacts of climate change on the availability of NTFPs and adaptation barriers for managing the NTFPs while formulating their regular development planning process. The plans can be implemented through the financial support of government and non-government agencies, which will help them to reduce the negative impacts of climate change on NTFPs and increase the adaptive capacity of the local communities. Additionally, our study will help to understand local perceptions on climate change impacts, adaptation strategies in mountain ecosystem which is mostly absent from scientific studies. The findings also inform policies and programs required for addressing the impacts of climate change on mountain communities globally not just in Nepal.

6. Conclusion

This study found that mountain communities in the Nepalese Himalaya believe that climate change is impacting the availability of NTFPs and have adopted several adaptation practices in response. To inform long-term adaptation strategies and the sustainability of mountain communities and NTFPs ecosystems, local adaptation practices and adaptation barriers were explored. Our study reveals that despite the perceived impacts of climate change on NTFPs, adaptation practices have not been fully adopted by mountain communities. Adaptation options to deal with increased invasive plant species and pest insect outbreaks are challenging despite having the highest perceived impacts on NTFPs. Agroforestry, self-regulating the collection of NTFPs, the practice of alternative income-generating activities, and the use of alternative energy and weaving materials were the most widely practiced adaptation practices. We identified major adaptation barriers including a lack of predictability of climate hazards, technical knowledge, government support, finance and labour, and timely access of weather information, in addition to fatalistic beliefs and a perceived lack of agency around climate change impacts. Our findings help to fill a research gap in understanding local people's knowledge and perceptions about climate change and adaptation in managing NTFP ecosystem services in mountain ecosystem which is mostly absent from scientific studies. This new understanding of local climate change adaptation strategies can support policy makers in both government and non-government organisations to improve the sustainability of NTFPs in mountain ecosystems and the benefits that accrue to local people under future climate change.

CRediT authorship contribution statement

Lila Jung Gurung: Conceptualization, methodology, data collection, analysis, visualization and writing of the manuscript.

Kelly Miller, **Susanna Venn**, **and Brett A Bryan:** Conceptualization, methodology, review and editing the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors acknowledge the support of the Australia Awards Scholarship Program and Deakin University. We would like to thank all participants involved in household surveys and government authorities that supported the field work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.148853.

References

Adger, W.N., Vincent, K., 2005. Uncertainty in adaptive capacity. Compt. Rendus Geosci. 337, 399–410.
Adhikari, S., Baral, H., Nitschke, C., 2018. Adaptation to climate change in panchase mountain ecological regions of Nepal. Environments 5, 18.
Alam, G.M.M., Alam, K., Mushtaq, S., 2017. Climate change perceptions and local adaptation strategies of hazard-prone rural households in Bangladesh. Clim. Risk Manag. 17, 52–63.
Ali, A., Rahut, D.B., Mottaleb, K.A., Erenstein, O., 2017. Impacts of changing weather patterns on smallholder well-being: evidence from the Himalayan region of northern Pakistan. Int. J. Clim. Chang. Strateg. Manag. 9, 225–240.
Applequist, W.L., Brinckmann, J.A., Cunningham, A.B., Hart, R.E., Heinrich, M., Katerere, D.R., Van Andel, T., 2020. Scientists' warning on climate change and medicinal plants. Planta Med. 86, 10.
Archie, K.M., 2014. Mountain communities and climate change adaptation: barriers to planning and hurdles to implementation in the Southern Rocky Mountain Region of North America. Mitig. Adapt. Strateg. Glob. Chang. 19, 569–587.
Aryal, K.P., Poudel, S., Chaudhary, R.P., Chettri, N., Chaudhary, P., Ning, W., Kotru, R., 2018. Diversity and use of wild and non-cultivated edible plants in the Western Himalaya. J. Ethnobiol. Ethnomed. 14, 10.
Balama, C., Augustino, S., Eriksen, S., Makonda, F.B.S., 2017. The role of priority non-timber forest products in enhancing local adaptive capacity to climate change stresses in Kilombero district, Tanzania. Clim. Dev. 9, 231–243.
Bastakoti, R.C., Bharati, L., Bhattarai, U., Wahid, S.M., 2017. Agriculture under changing climate conditions and adaptation options in the Koshi Basin. Clim. Dev. 9, 634–648.
Bhatta, L.D., van Oort, B.E.H., Stork, N.E., Baral, H., 2015. Ecosystem services and livelihoods in a changing climate: understanding local adaptations in the Upper Koshi, Nepal. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 11, 145–155.
Bhatta, L.D., Udas, E., Khan, B., Ajmal, A., Amir, R., Ranabhat, S., 2020. Local knowledge based perceptions on climate change and its impacts in the Rakaposhi valley of Gilgit-Baltistan, Pakistan. Int. J. Clim. Chang. Strateg. Manag. 12, 222.
Biggs, E.M., Tompkins, E.L., Allen, J., Moon, C., Allen, R., 2013. Agricultural adaptation to climate change: observations from the Mid-Hills of Nepal. Clim. Dev. 5, 165–173.
Botzen, W.J.W., Bouwer, L.M., Van Den Bergh, J.C.J.M., 2010. Climate change and hailstorm damage: empirical evidence and implications for agriculture and insurance. Resour. Energy Econ. 32, 341–362.
Byers, A.C., Mckinney, D.C., Thakali, S., Somos-Valenzuela, M., 2014. Promoting science-based, community-driven approaches to climate change adaptation in glaciated mountain ranges: HiMAP. Geography 99, 143–152.
Byg, A., Salick, J., 2009. Local perspectives on a global phenomenon—climate change in Eastern Tibetan villages. Glob. Environ. Chang. 19, 156–166.
Chakraborty, A., Saha, S., Sachdeva, K., Joshi, P.K., 2018. Vulnerability of forests in the Himalayan region to climate change impacts and anthropogenic disturbances: a systematic review. Reg. Environ. Chang. 18, 1783–1799.
Chaudhary, P., Bawa, K.S., 2011. Local perceptions of climate change validated by scientific evidence in the Himalayas. Biol. Lett. 7, 767–770.
Chaudhary, P., Rai, S., Wangdi, S., Mao, A., Rehman, N., Chettri, S., Bawa, K.S., 2011. Consistency of local perceptions of climate change in the Kangchenjunga Himalaya landscape. Curr. Sci. 101, 504–513.
Chitale, V., Silwal, R., Matin, M., 2018. Assessing the impacts of climate change on distribution of major non-timber forest plants in Chitwan Annapurna Landscape, Nepal. Resources 7, 12.
Fandohan, A., Cuni Sanchez, A., 2014. Local perceptions of climate change and its impacts on indigenous fruit trees: water, adaptation and sustainability in Benin. Adaptation to climate Change Through Water Resources Management Capacity, Equity and Sustainability. Taylor and Francis, London and New York.
DesInventar. 1999. UNDRR DesInventar Sendai website. https://www.desinventar.net/DesInventar/profiletab.jsp?countrycode=npl [Online]. [Accessed 2/11/2020].
Dey, T., Pala, N.A., Shukla, G., Pal, P.K., Das, G., Chakarvarty, S., 2018. Climate change perceptions and response strategies of forest fringe communities in Indian Eastern Himalaya. Environ. Dev. Sustain. 20, 925–938.
DHM, 2019. Office of Hydrology and Meteorology. Pokhara, Nepal.
Everard, M., Gupta, N., Chapagain, P.S., Shrestha, B.B., Preston, G., Tiwari, P., 2018. Can control of invasive vegetation improve water and rural livelihood security in Nepal? Ecosyst. Serv. 32, 125–133.
Field, E., Castagneyrol, B., Gibbs, M., Jactel, H., Barsoum, N., Schönrogge, K., Hector, A., 2020. Associational resistance to both insect and pathogen damage in mixed forests is modulated by tree neighbour identity and drought. J. Ecol. 108, 1511–1522.
Gentle, P., Maraseni, T.N., 2012. Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. Environ. Sci. Pol. 21, 24–34.
GOI, 2008. National Action Plan on Climate Change (NAPCC). India, New Delhi.
Gurung, L., Rajbhandary, S., Ranjitkar, S., 2008. Medicinal plants in mid-hills of Nepal: a case study of Sikles area of Kaski district. Medicinal Plants in Nepal: An Anthology of Contemporary Research. Ecological Society, Kathmandu, Nepal.
Gurung, L.J., Miller, K.K., Venn, S., Bryan, B.A., 2020. Dataset of non-timber forest products use and impacts of recent climate change in the Upper Madi Watershed, Nepal. Data Brief 33, 106404.
Heyojoo, B.P., Yadav, N.K., Subedi, R., 2017. Assessments of climate change indicators, climate-induced disasters, and community adaptation strategies: a case from high mountain of Nepal. In: Li, A., Deng, W., Zhao, W. (Eds.), Land Cover Change and Its Eco-environmental Responses in Nepal. Springer, New York.
Howe, P.D., Markowitz, E.M., Lee, T.M., Ko, C.-Y., Leiserowitz, A., 2013. Global perceptions of local temperature change. Nat. Clim. Chang. 3, 352–356.
Ibe, G.O., 2018. Climate variation, its impact on non timber forest products and livelihood of Ohafia people, Abia State Nigeria. Glob. J. Agric. Sci. 17, 91.
ICIMOD, 2010. Climate Change Impact and Vulnerability in the Eastern Himalayas – Synthesis Report. Kathmandu, Nepal.
Ingxay, P., Yokoyama, S., Hirota, I., 2015. Livelihood factors and household strategies for an unexpected climate event in upland northern Laos. J. Mt. Sci. 12, 483–500.
IPCC, 2007. Climate Change. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, p. 2007.
IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
IPCC 2019. Summary for policymakers. In: Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. (in press).
Karki, S., Burton, P., Mackey, B., 2020. Climate change adaptation by subsistence and smallholder farmers: insights from three agro-ecological regions of Nepal. Cogent Soc. Sci. 6, 23.
Keenan, R.J., 2015. Climate change impacts and adaptation in forest management: a review. Ann. For. Sci. 72, 145–167.
Kohler, T., Giger, M., Hurni, H., Ott, C., Wiesmann, U., Von Dach, S.W., Maselli, D., 2010. Mountains and climate change: a global concern. Mt. Res. Dev. 30, 53–55.
Kumar, M., Savita, Singh, H., Pandey, R., Singh, M.P., Ravindranath, N.H., Kalra, N., 2019. Assessing vulnerability of forest ecosystem in the Indian Western Himalayan region using trends of net primary productivity. Biodivers. Conserv. 28, 2163–2182.
Kunwar, R., Lamichhane Pandey, M., Mahat, L., Bhandari, A., 2014. Medicinal plants and ethnomedicine in peril: a case study from Nepal Himalaya. Evid. Based Complement. Alternat. Med. 2014, 7.
Lamsal, P., Kumar, L., Atreya, K., Pant, K.P., 2017. Vulnerability and impacts of climate change on forest and freshwater wetland ecosystems in Nepal: a review. Ambio 46, 915–930.
Lamsal, P., Kumar, L., Aryal, A., Atreya, K., 2018. Invasive alien plant species dynamics in the Himalayan region under climate change. Ambio 47, 697–710.
Lesnikowski, A.C., Ford, J.D., Berrang-Ford, L., Barrera, M., Heymann, J., 2015. How are we adapting to climate change? A global assessment. Mitig. Adapt. Strateg. Glob. Chang. 20, 277–293.
Lhoest, S., Dufrêne, M., Vermeulen, C., Oszwald, J., Doucet, J.-L., Fayolle, A., 2019. Perceptions of ecosystem services provided by tropical forests to local populations in Cameroon. Ecosyst. Serv. 38 (11).
Li, C., Tang, Y., Luo, H., Di, B., Zhang, L., 2013. Local Farmers' perceptions of climate change and local adaptive strategies: a case study from the middle Yarlung Zangbo River valley, Tibet, China. Environ. Manag. 52, 894–906.
Liu, X.D., Yin, Z.Y., Shao, X.M., Qin, N.S., 2006. Temporal trends and variability of daily maximum and minimum, extreme temperature events, and growing season length over the eastern and central Tibetan Plateau during 1961-2003. J. Geophys. Res.-Atmos. 111, 19.
Loria, N., Bhardwaj, S.K., 2016. Farmers' response and adaptation strategies to climate change in low-hills of Himachal Pradesh in India. Nat. Environ. Pollut. Technol. 15, 895–901.
Macchi, M., Gurung, A.M., Hoermann, B., 2015. Community perceptions and responses to climate variability and change in the Himalayas. Clim. Dev. 7, 414–425.
Maddison, D., 2007. The Perception of and Adaptation to Climate Change in Africa. The World Bank, Policy Research Working Paper, p. 4308.
Maikhuri, R.K., Phondani, P.C., Dhyani, D., Rawat, L.S., Jha, N.K., Kandari, L.S., 2018. Assessment of climate change impacts and its implications on medicinal plants-based traditional healthcare system in Central Himalaya, India. Iran. J. Sci. Technol. Trans. A Sci. 42, 1827–1835.
Maroschek, M., Seidl, R., Netherer, S., Lexer, M., 2009. Climate change impacts on goods and services of European mountain forests. Unasylva 60, 76–80.

Mina, M., Bugmann, H., Cordonnier, T., Irauschek, F., Klopcic, M., Pardos, M., Cailleret, M., 2017. Future ecosystem services from European mountain forests under climate change. J. Appl. Ecol. 54, 389–401.
MOE, 2010. National Adaptation Programme of Action (NAPA) to Climate Change. Government of Nepal, Kathmandu, Nepal.
MOE, 2011. National Framework on Local Adaptation Plans for Action (LAPA). Government of Nepal, Kathmandu, Nepal.
MRM, 2018. Profile of Madi Rural Municipality. Kaski, Nepal.
Muhamad, D., Okubo, S., Harashina, K., Parikesit, Gunawan, B., Takeuchi, K., 2014. Living close to forests enhances people's perception of ecosystem services in a forest–agricultural landscape of West Java, Indonesia. Ecosyst. Serv. 8, 197–206.
Negi, V., Maikhuri, R., Pharswan, D., Thakur, S., Dhyani, P., 2017. Climate change impact in the Western Himalaya: people's perception and adaptive strategies. J. Mt. Sci. 14, 403.
Noble, I.R., Huq, S., Anokhin, Y.A., Carmin, J., Goudou, D., Lansigan, F.P., Osman-Elasha, B., Villamizar, A., 2014. Adaptation needs and options. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., Maccracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 833–868.
NTNC, 2009. Management Plan of Annapurna Conservation Area 2009–2012. Latitpur, Nepal.
Pandey, D.N., 2007. Multifunctional agroforestry systems in India. Curr. Sci. 92, 455–463.
Pandey, S.S., Cockfield, G., Maraseni, T.N., 2016. Assessing the roles of community forestry in climate change mitigation and adaptation: a case study from Nepal. For. Ecol. Manag. 360, 400–407.
Pandey, R., Aretano, R., Gupta, A.K., Meena, D., Kumar, B., Alatalo, J.M., 2017. Agroecology as a climate change adaptation strategy for smallholders of Tehri-Garhwal in the Indian Himalayan Region. Small Scale For. 16, 53–63.
Pandey, R., Kumar, P., Archie, K.M., Gupta, A.K., Joshi, P.K., Valente, D., Petrosillo, I., 2018. Climate change adaptation in the western-Himalayas: household level perspectives on impacts and barriers. Ecol. Indic. 84, 27–37.
Pant, K., Rasul, G., Chettri, N., Rai, K., Sharma, E., 2012. Value of forest ecosystem services: a quantitative estimation from the Kangchenjunga landscape in eastern Nepal. ICIMOD Working Paper 2012/5. ICIMOD, Kathmandu.
Penuelas, J., Sardans, J., Filella, I., Estiarte, M., Llusia, J., Ogaya, R., Carnicer, J., Bartrons, M., Rivas-Ubach, A., Grau, O., Peguero, G., Margalef, O., Pla-Rabes, S., Stefanescu, C., Asensio, D., Preece, C., Liu, L., Verger, A., Barbeta, A., Achotegui-Castells, A., Gargallo-Garriga, A., Sperlich, D., Farre-Armengol, G., Fernandez-Martinez, M., Liu, D. J., Zhang, C., Urbina, I., Camino-Serrano, M., Vives-Ingla, M., Stocker, B. D., Balzarolo, M., Guerrieri, R., Peaucelle, M., Maranon-Jimenez, S., Bornez-Mejias, K., Mu, Z. B., Descals, A., Castellanos, A. & Terradas, J. 2017. Impacts of global change on Mediterranean forests and their services. Forests, 8, 37.
Pureswaran, D.S., Roques, A., Battisti, A., 2018. Forest insects and climate change. Curr. For. Rep. 4, 35–50.
Rasul, G., 2007. Climate change, the Himalayan Mountains, and ICIMOD. ICIMOD Newsletter.
Rigueiro-Rodríguez, A., Fernández-Núñez, E., González-Hernández, P., McAdam, J. H. & Mosquera-Losada, M. R. 2009. Agroforestry systems in Europe: productive, ecological and social perspectives. *In*: Rigueiro-Rodróguez, A., McAdam, J. & Mosquera-Losada, M. R. (eds.) Agroforestry in Europe: Current Status and Future Prospects. Dordrecht: Springer Netherlands.
Robson, C., McCartan, K., 2015. Real World Research. 4th edition. Wiley, Chichester, United Kingdom.
Shackleton, S., Ziervogel, G., Sallu, S., Gill, T., Tschakert, P., 2015. Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. WIREs Clim. Chang. 6, 321–344.
Shahzad, L., Tahir, A., Sharif, F., Ul Haq, I., Mukhtar, H., 2019. Assessing the impacts of changing climate on forest ecosystem services and livelihood of Balakot mountainous communities. Pak. J. Bot. 51, 1405–1414.
Sharma, G., Sharma, E., 2018. Agroforestry Systems as Adaptation Measures for Sustainable Livelihoods and Socio-economic Development in the Sikkim Himalaya. Anecdotal to Modern Science. Springer Nature Singapore, Agroforestry.
Shrestha, B.B., Shrestha, U.B., Sharma, K.P., Thapa-Parajuli, R.B., Devkota, A., Siwakoti, M., 2019a. Community perception and prioritization of invasive alien plants in Chitwan-Annapurna Landscape, Nepal. J. Environ. Manag. 229, 38–47.
Shrestha, U.B., Dhital, K.R., Gautam, A.P., 2019b. Economic dependence of mountain communities on Chinese caterpillar fungus Ophiocordyceps sinensis (yarsagumba): a case from western Nepal. Oryx 53, 256–264.
Singh, C., Rahman, A., Srinivas, A., Bazaz, A., 2018. Risks and responses in rural India: implications for local climate change adaptation action. Clim. Risk Manag. 21, 52–68.
Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Glob. Environ. Chang. Hum. Policy Dimens. 16, 282–292.
Smit, B., Burton, I., Klein, R.J.T., Wandel, J., 2000. An anatomy of adaptation to climate change and variability. Clim. Chang. 45, 223–251.
Steinbauer, M.J., Grytnes, J.A., Jurasinski, G., Kulonen, A., Lenoir, J., Pauli, H., Rixen, C., Winkler, M., Bardy-Durchhalter, M., Barni, E., Bjorkman, A.D., Breiner, F.T., Burg, S., Czortek, P., Dawes, M.A., Delimat, A., Dullinger, S., Erschbamer, B., Felde, V.A., Fernandez-Arberas, O., Fossheim, K.F., Gomez-Garcia, D., Georges, D., Grindrud, E.T., Haider, S., Haugum, S.V., Henriksen, H., Herreros, M.J., Jaroszewicz, B., Jaroszynska, F., Kanka, R., Kapfer, J., Klanderud, K., Kuhn, I., Lamprecht, A., Matteodo, M., Di Cella, U.M., Normand, S., Odland, A., Olsen, S.L., Palacio, S., Petey, M., Piscova, V., Sedlakova, B., Steinbauer, K., Stockli, V., Svenning, J.C., Teppa, G., Theurillat, J.P., Vittoz, P., Woodin, S.J., Zimmermann, N.E., Wipf, S., 2018. Accelerated increase in plant species richness on mountain summits is linked to warming. Nature 556, 231–234.
Suberi, B., Tiwari, K.R., Gurung, D.B., Bajracharya, R.M., Sitaula, B.K., 2018. People's perception of climate change impacts and their adaptation practices in Khotokha valley, Wangdue, Bhutan. Indian J. Tradit. Knowl. 17, 97–105.
Suleiman, M., Wasonga, V., Mbau, J., Suleiman, A., Elhadi, Y., 2017. Non-timber forest products and their contribution to households income around Falgore Game Reserve in Kano, Nigeria. Ecol. Process. 6, 1–14.
Sundriyal, M., Sundriyal, R., 2001. Wild edible plants of the Sikkim Himalaya: nutritive values of selected species. Econ. Bot. 55, 377–390.
Sushant, 2013. Impact of climate change in Eastern Madhya Pradesh, India. Trop. Conserv. Sci. 6, 338–364.
Tembo, F., Tadesse, T., Wales, S., 2018. Perceptions and choices of adaptation measures for climate change among teff (Eragrostis tef) farmers of Southeast Tigray, Ethiopia. J. Agric. Ext. Rural Dev. 10, 11–19.
Thakur, S., Negi, V.S., Pathak, R., Dhyani, R., Durgapal, K., Rawal, R.S., 2020. Indicator based integrated vulnerability assessment of community forests in Indian west Himalaya. For. Ecol. Manag. 457, 117674.
van Oort, B., Bhatta, L.D., Baral, H., Rai, R.K., Dhakal, M., Rucevska, I., Adhikari, R., 2015. Assessing community values to support mapping of ecosystem services in the Koshi river basin, Nepal. Ecosyst. Serv. 13, 70–80.
Walker, W.E., Haasnoot, M., Kwakkel, J.H., 2013. Adapt or perish: a review of planning approaches for adaptation under deep uncertainty. 5, 955–979.
Wang, W., Zhao, X., Cao, J., Li, H., Zhang, Q., 2020. Barriers and requirements to climate change adaptation of mountainous rural communities in developing countries: the case of the eastern Qinghai-Tibetan Plateau of China. Land Use Policy 95.
Wheeler, S., Zuo, A., Bjornlund, H., 2013. Farmers' climate change beliefs and adaptation strategies for a water scarce future in Australia. Glob. Environ. Chang. 23, 537–547.
Yadav, P.K., Saha, S., Mishra, A.K., Kapoor, M., Kaneria, M., Kaneria, M., Dasgupta, S., Shrestha, U.B., 2019. Yartsagunbu: transforming people's livelihoods in the Western Himalaya. Oryx 53, 247–255.
Yamane, T., 1967. Statistics: An Introductory Analysis. Harper & Row, New York.