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ORIGINAL PAPER

Cryospheric hazards and risk perceptions in the Sagarmatha (Mt. Everest) National Park and Buffer Zone, Nepal

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Abstract
Glacial lake outburst floods (GLOFs) are among the most serious cryospheric hazards for mountain communities. Multiple studies have predicted the potential risks posed by rapidly expanding glacial lakes in the Sagarmatha (Mt. Everest) National Park and Buffer Zone of Nepal. People's perceptions of such cryospheric hazards can influence their actions, beliefs, and responses to those hazards and associated risks. This study provides a systematic approach that combines household survey data with ethnography to analyze people's perceptions of GLOF risks and the socioeconomic and cultural factors influencing their perceptions. A statistical logit model of household data showed a significant positive correlation between the perceptions of GLOF risks and livelihood sources, mainly tourism. Risk perceptions are also influenced by spatial proximity to glacial lakes and whether a village is in potential flood zones. The 2016 emergency remediation work implemented in the *Imja Tsho* (glacial lake) has served as a cognitive fix, especially in the low-lying settlements. Much of uncertainty and confusions related GLOF risks among locals can be attributed to a disconnect between how scientific information is communicated to the local communities and how government climate change policies have been limited to awareness campaigns and emergency remediation efforts. A sustainable partnership of scientists, policymakers, and local communities is urgently needed to build a science-driven, community-based initiative that focuses not just in addressing a single GLOF threat but develops on a comprehensive cryospheric risk management plan and considers opportunities and challenges of tourism in the local climate adaptation policies.

Keywords Cryospheric hazards · GLOFs · Risk perception · Adaptation · Mt. Everest region · Nepal

1 Introduction

Glacial lake outburst floods (GLOFs) are among the most serious cryospheric hazards for mountain communities around the world (Huggel et al. 2002; Carey 2005, 2010; Ives et al. 2010). They pose a significant threat to human lives and infrastructures, as they can

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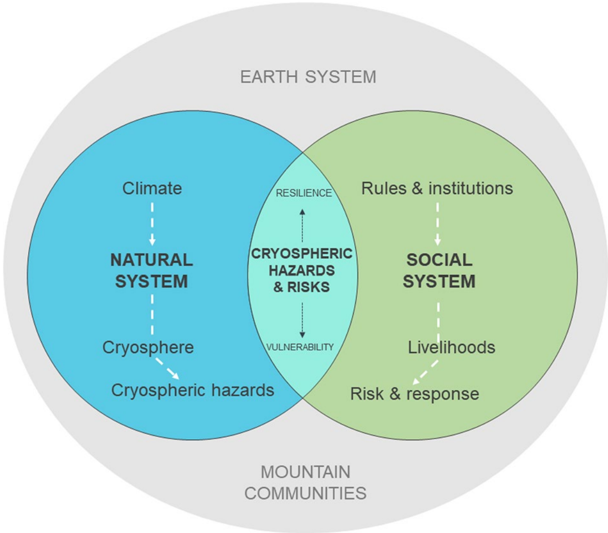
discharge—with little warning—massive volumes of water in a highly destructive way, catching nearby and downstream communities off-guard and unprepared (Mool et al. 2001; Carey et al. 2012; Westoby et al. 2014). GLOF risks in the Himalayan region have increased in recent decades with rapid melting of glaciers, caused in large part by climate change (Bolch et al. 2008, 2012; Kargel et al. 2011; NRC 2012). Multiple studies have predicted the potentially catastrophic outburst of glacial lakes in the Sagarmatha (Mt. Everest) National Park and Buffer Zone (SNPBZ, hereafter Mt. Everest region), primarily from the rapidly expanding *Imja Tsho*—a supra-glacial lake located in the northeastern corner (see Watanabe et al. 2009 for a historiography).

It is well recognized that people's perceptions can influence their actions, beliefs, and responses to natural hazards and associated risks (Leiserowitz 2006; Etkin and Ho 2007; Patt and Schröter 2008). This study provides a systematic approach that combines household survey (quantitative) data with ethnography (qualitative data) to analyze how Himalayan communities, particularly the Mt. Everest Region, perceive and rank GLOFs in comparison with other major natural hazards and risks common in the area such as drought, landslides, and fire. This approach identifies the socioeconomic and cultural factors influencing local people's perceptions and provides insights into the ways the local people respond to potential GLOF disaster risks. In doing so, the study builds upon the *High Mountains Adaptation Partnership* (*HiMAP*) project (2012–2015), which helped develop a Local Adaptation Plan of Action (LAPA) as part of its scientific, social, and institutional capacity building activities (Byers et al. 2015; Byers and Thakali 2016).

The SNPBZ of Nepal, which covers the Khumbu Valley to the north and the Pharak Valley to the south, has experienced two major GLOFs: Naare (1977) and Dig Tsho (1985)[1] as well as at least six smaller "englacial conduit outburst floods" in the last ten years (Rounce et al. 2017b). The 1985 Dig Tsho flood discharged an estimated 6–10 million m^3 of water down the Dudhkoshi River, completely damaging a newly built hydropower plant worth more than three million dollars, 14 bridges, about 30 houses, trail networks, and several hectares of cultivated lands (Vuichard and Zimmermann 1986). This valley was completely cut off from the rest of Nepal for several days. Following this event, the fear of GLOFs increased for local people. This fear was further intensified after news coverage of a potential threat of a GLOF emanating from Tsho Rolpa glacial lake, located in nearby Rolwaling Valley, in the mid-1990s and comparisons were drawn between Tsho Rolpa and Imja Tsho in terms of their similar potential for flooding, exacerbating fears among local people in the Khumbu while facilitating the categorization of Imja Tsho as "one of the three potentially dangerous glacial lakes in Nepal" [ICIMOD (2007, 2011) but see Budhathoki et al. (2011), Rounce et al. (2017a) and Lala et al. (2018) for a new assessment that categorizes Imja Tsho as a moderate threat]. Fears were exacerbated by the fact that Imja Tsho was no more than a small pond in the 1960s, increasing to 1.03 km^2 by 2007, mainly in the eastern edge connected with the glacier surface (Watanabe et al. 2009: 259) and 1.26 km^2 by 2015 (Rounce et al. 2017a). Interestingly, although Imja Tsho is one of the most extensively studied glacial lakes in the Himalaya, few of its copious studies have contained a social science element. In view of this, a science-driven, community-based approach to

[1] Although these two are the most significant GLOFs in the SNPBZ, several smaller events have been reported in the SNPBZ and the adjacent valleys, including two smaller GLOFs in Dig Tsho that have occurred since the major GLOF of 1985. There are also Tama or Taam Pokhari (Hongu Valley) GLOF of 1998 (see Byers et al 2013; Lamsal et al. 2016) and Langmale (Barun Valley) of 2017 (see Byers et al forthcoming in *Landslides*).

Fig. 1 Complex natural–social system interaction in the mountain communities



reducing GLOF risks in the SNPBZ was proposed in 2012 as part of a USAID-funded project (https://www.highmountains.org) (Byers et al. 2014; Watanabe et al. 2016), and this study seeks to contribute toward that noble goal. The present study seek to build upon these earlier works while introducing a number of social science tools that show promise of enhancing our understading of people's perceptions of risks and hazards in the high mountain environment.

Our research follows the socio-cognitive *Model of Private Proactive Adaptation to Climate Change* (MPPACC) developed by Grothmann and Patt (2005) to understand how people appraise risks and to examine the factors affecting risk perception, as these can define their adaptation action and resilience. In the Himalaya, while the literature on mountain hazards started to build as early as the 1980s (Ives and Messerli 1981; Zimmermann et al. 1986), only in recent years have the social and humanistic perspectives on GLOFs emerged (Byers et al. 2014; Sherry and Curtis 2017). A systematic and interdisciplinary approach, hence, is needed to fully capture the complex natural–social system interactions of cryospheric hazards in the Himalaya (see Fig. 1). This approach helps identify local priorities and place-based narratives and enable local people make appropriate changes in their LAPA. The underlying principle of this approach is that people risk perceptions are shaped by direct personal experiences as much as by second-hand information (Clayton et al. 2015), which in our case is the scientific information on the physical and morphological changes in physical system (e.g., change in volumes of glacial lakes or retreat of glaciers).

2 Theoretical foundations and gaps

2.1 Overview of cryospheric hazards and vulnerability in Nepal

In Nepal, among 1466 glacial lakes covering a total of 64.8 km^2, 21 glacial lakes have been identified as critical or potentially dangerous based on the size and rate of growth of the lake and position in relation to moraines and associated glaciers (ICIMOD 2011; Khanal et al. 2015; Thakuri et al. 2016).[2] Imja Tsho was initially considered to be in the critical condition (Hammond 1988; Watanabe et al. 1994, 1995; Mool et al. 2001; Bajracharya et al. 2007; ICIMOD 2007); however, several new studies categorized Imja Tsho as moderate risk (Watanabe et al. 2009; Budhathoki et al. 2011; Rounce et al. 2016, 2017a). Despite the differences on whether or not Imja Lake posed an immediate threat, results of these scientific studies provided the strong foundation for further research on people's perceptions of GLOF risks and vulnerability. For instance, studies by Somos-Valenzuela et al. (2013) focused on a bathymetry survey, a ground-penetrating radar survey, hydrodynamic modeling, and remote observations of the Imja glacial lake showed a rapid growth in area and volume to 61.7 ± 3.7 million m^3 from 35.8 ± 0.7 million m^3. A flood model study conducted by Somos-Valenzuela et al. (2015) recommended the lowering the lake at least by 3 m to minimize potential impact in the downstream communities, although lowering 20 m would be more desirable to significantly reduce the GLOF risks. These reports from the HiMAP team at University of Texas Austin and University of Colorado were followed by several new publications from the same team (Rounce et al. 2016, 2017a; Lala et al. 2018) that are based on integration of remote sensing with field survey to quantify and characterize the expansion rate of Imja and other glacial lakes in the Himalaya and to develop a comprehensive classification system to categorize and characterize GLOF risks in the region.

Byers and Thakali (2016) was one of the first attempts to consider socioeconomic factors into climate change adaptation plans in the Khumbu Valley. The major focus of this study was to help local communities develop the LAPA, which was completed and published in Nepali and English by the HiMAP project in 2015 after 2 years of community consultations concurrent with detailed measurements and evaluations of Imja glacial lake. Similarly, the Government of Nepal, with the help of the Global Environment Fund and the United Nations Development Programme, also implemented in 2016 an emergency remediation work in Imja Lake to lower the lake by 3.5 m (UNDP 2016). Although it is early to discuss the full results of this remediation effort, it was clear during our fieldwork that the local communities have a mixed response to this project (see Sects. 5.3 and 6). In a field study conducted in the Rolwaling Valley of neighboring Dolakha district, Dahal and Hagelman (2011) reported a low risk perception among residents living in the downstream communities and the main factors were "the cry wolf effect of the 1997 evacuation that followed an inaccurate prediction of a Tsho Rolpa outburst" and "a false sense of security among those at risk" because the Government of Nepal built a remediation structure—the first of its kind in Nepal—that included the lowering of the lake by 3 m by building a dam in terminal moraine with a "rudimentary" early warning system. Sherry and Curtis (2017), which focused on the same Tsho Rolpa, found that local community's religious belief system influences how they interpret and respond to this glacial lake's hazards and risks; however, religious aspects such as rituals and prayers could contribute toward social cohesion and capacity to cope with fear and uncertainty that swept through the valley.

In comparison with the Himalaya, the GLOF hazard and risk literature on the Andes are comparatively more comprehensive. For instance, in Peru, particularly avalanches, glacial lake outburst floods, and glacier recession have been thoroughly examined through

[2] Rounce et al (2017a) reported 131 glacial lakes in Nepal in 2015 that are greater than 0.1 km^2. Among them, 11 lakes were reported as very high risks and 31 as high risk. Imja Tsho was identified as moderate hazard, mainly due to the lack of avalanche trajectories that could trigger overflow from the lake; however, the sheer volume of water in the lake remains a cause of concern.

multi-disciplinary research (Haeberli and Whiteman 2015; Bury et al. 2011). An integrated assessment of the vulnerability of cryospheric hazards conducted by Hegglin and Huggel (2008) in the Cordillera Blanca, Peru, including both the physical–technical and the socio-economic approaches, showed a strong need for vulnerability research integrating physical and social sciences and related theoretical frameworks to be readily applied in practice. Similarly, study conducted in Peru, focused mainly on Carhuaz's Lake 513, used an integrated socio-environmental framework for glacier hazard management. It concluded that there was an increased need for scientific communication among locals and policymakers (Carey et al. 2012) for better adaptive capacity and resilient society. Carey (2005, 2010) provide an in-depth and insightful humanistic perspective at the social complexities related to GLOF disaster and post-disaster recovery.

In this study, a schematic diagram (see Fig. 1) developed to show how cryospheric hazards and people's perceptions of those hazards (and their risks) are reflective of the complex natural–social system interactions in the region. Understanding the interconnected and complex relations between the cryosphere and society is an essential part of assessing community priorities, their preparedness, and vulnerability (Fig. 1).

2.2 Risk perception appraisal

Within climate change science, risk perceptions of hazards and disasters are widely recognized. This draws heavily on the long tradition of environmental perception research in hazards geography and risk analysis (Tobin and Montz 1997; Cutter et al. 2003; Wisner et al. 2004). Several studies have highlighted the importance of people's perceptions of climate variability and adaptation, incorporating the way public understand, recognize, and respond to risks brought by changing climate based on various sociocultural and economic aspects (Crona et al. 2013).

Studies have shown that understanding of the accurate perception of climatic variability and change can facilitate individuals to take effective measures to protect their livelihood against threats from changing the environment and help policy maker in developing diverse strategies (Grothmann and Patt 2005; Rodriguez et al. 2017). The Grothmann and Patt model explains two perpetual processes of risk perception and perceived adaptive capacity: "risk appraisal" and "adaptation appraisal." This model was applied in the case of Mexico to examine the risk perceptions on drought exclusively among farmers, primarily to analyze why individual farmers adapt differently to risks brought by climate change (Rodriguez et al. 2017). The cognitive process of risk appraisal affects risk perception and is instrumental in developing climate change adaptation policy initiatives and policies because of their ability to influence how people respond to public communication, risk, and people's behavior in face of risk (Frank et al. 2011).

Perceived probability and perceived severity of a hazard are defined as a person's expectancy of being exposed to threats and how harmful the consequences of the threat would be if it were to actually occur, respectively. For example, person's perceived probability implies individual's expectancy of being exposed to a glacial flood and perceived severity indicates the judgement of harm to property and home. Adaptation appraisal which comes after a process of risk perception includes two factors: (1) person's belief in his/her capacity for adaptive action or adaptation efficacy and (2) the person's perceived ability to perform or carry out adaptive responses or perceived self-efficacy (Grothmann and Patt 2005: 203). This model is useful in explaining how the local people of the Mt. Everest region of Nepal appraise risk to cryospheric hazards, which is an essential component influencing

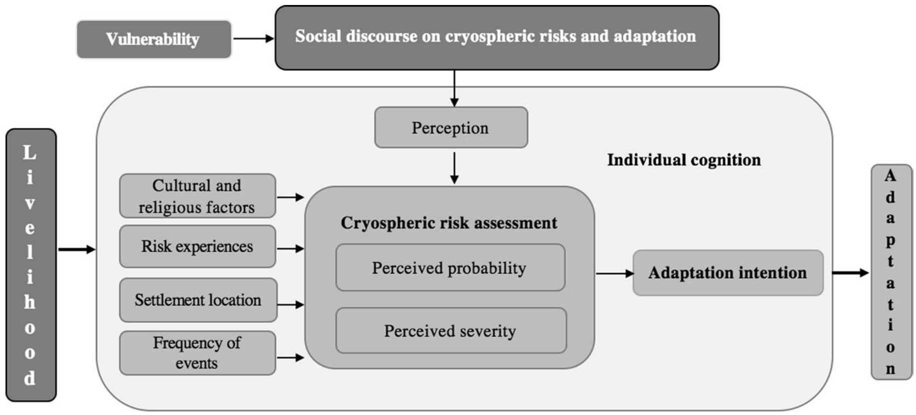


Fig. 2 Process model showing cryospheric risk appraisal and various influencing factors

adaptive action. This study, therefore, adapted the Grothmann and Patt (2005) model to explain risk perception of cryospheric hazards in the Mt. Everest region.

A comparison of cryospheric hazards with other natural hazards is made based on the various personal experiences of the environmental changes, which enhances the level of risk one perceives (Weber 2010). For example, personal experience with extreme events (e.g., avalanche, glacial flooding), and whether the respondent suffered from financial and physical damage, in a personal level as well as community level (e.g., destruction of infrastructure), can profoundly influence person's risk perception and affect the subsequent actions. Figure 2 shows the different variables that influence the people's perception of risk and how this is essential to develop the motivation to adapt and adaptation intention. A framework (Fig. 2) adapted after the model of Grothmann and Patt (2005) model focuses only on the perception of risk appraisal in this paper.

3 Research site

This research focuses on the Mt. Everest region of Nepal, mostly known as the *Khumbu* and *Pharak* areas as shown in Fig. 3. Situated at the base of the world's highest peak Mt. Everest (8848 m a.s.l.) within the SNPBZ, this region covers 124,400 ha (1148 km^2) (DNPWC 2006). Geographically, the region is largely composed of the rugged terrain and gorges of the Himalayas, with steep gradients that define both the vegetation and the settlement of people. An exceptional area with dramatic mountains, glaciers, deep valleys, and seven peaks over 7000 m, Mt. Everest (called *Chomolungma* by the locals and *Sagarmatha* in Nepali) is the Khumbu region's major attraction. The region has a monsoon-dominated climate, with 70–80% of the annual precipitation falling between June and September (Wagnon et al. 2013). Winter months are normally cold and dry with few days above freezing and very little precipitation (Shea et al. 2015). Dudhkoshi River is the main river system in the region. There are several villages and settlements along this river basin which are vulnerable to potential flood events.

The SNPBZ is located within the Khumbu Pasang Lhamu Rural Municipality. In the study area, there are 63 villages and settlements, which range in the elevation from Jorsalle at 2805 m a.s.l. to Gorakshep at 5170 m a.s.l. (Puschiasis 2015). The Khumbu Valley

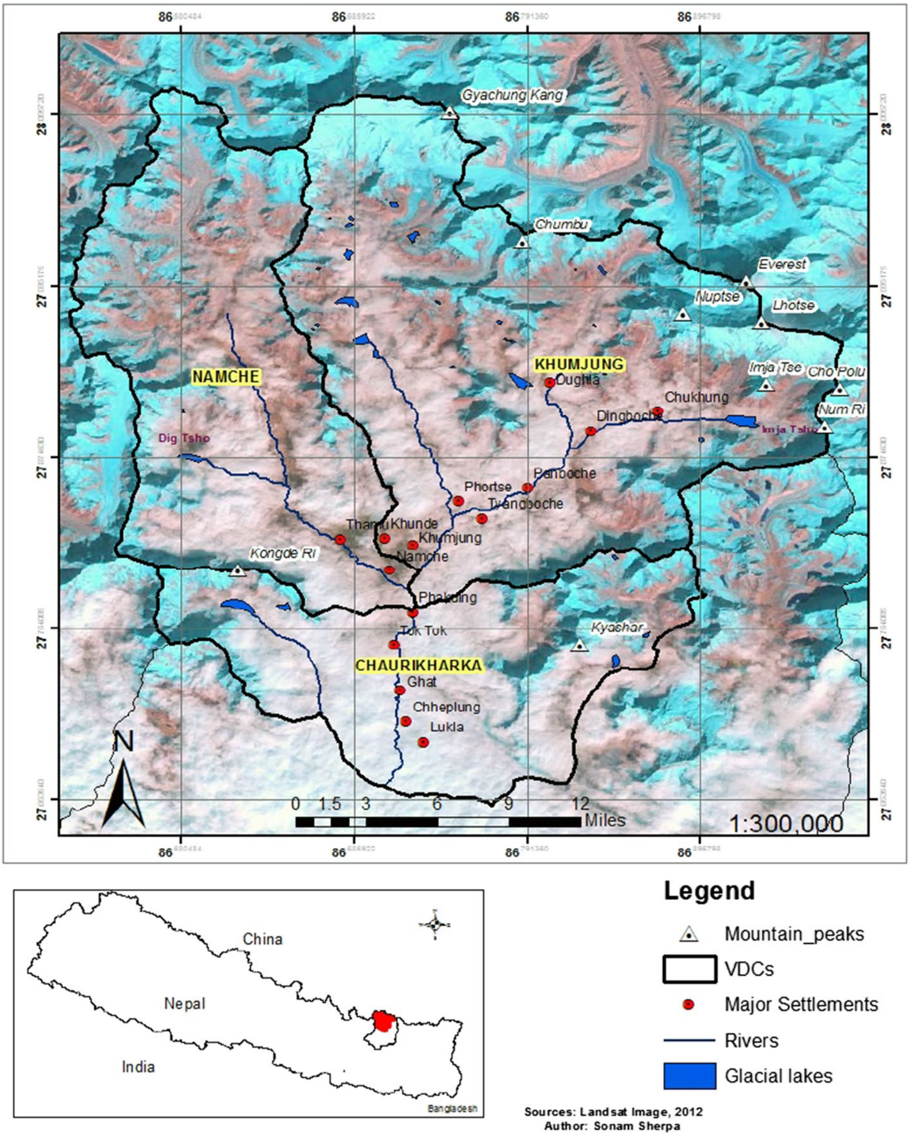


Fig. 3 Study site

covers much of the higher altitude villages where tourism is now the most dominant livelihood source, whereas the Pharak Valley is in the lower elevation with more diversified livelihood sources with a mix of agriculture and tourism. Pharak covers an area of 275 km^2 to the south of the park and was declared a buffer zone in 2002. Sherpas are the main indigenous ethnic group in this park. The Sherpa people have practiced subsistent agriculture since they settled in the area over 400 years ago (Stevens 1996). Over the last 50 years, however, with the opening of Khumbu region to tourism in 1950s and with the development of Lukla airport, schools, wellness facilities, and the national park, this has become a major tourist destination. This has led to a major transformation in the livelihoods of the Sherpas, from being experts in high mountain farming to experts in the tourism business (Fisher 1990). With less than 10% of the land being cultivable, agriculture dominated by potato farming (and more recently hay farming) is supplemented with tourism as the significant economic activity in the region. However, for economically marginalized households, agriculture and animal husbandry continue to remain a significant livelihood option (DNPWC 2006). Those involved in tourism businesses are often still partially involved in agriculture as a seasonal practice.

4 Research design

4.1 Data collection

This research draws upon the socioeconomic dataset generated for a large research project conducted in this region in which this author participated, mainly the 138 household survey data and two focus groups discussions following the protocols of established ethnographic methods. Since there are no comprehensive social data available in the region to analyze people's perceptions of natural hazards and disasters, this dataset was generated with a mixed social scientific method, which combines a household social survey with ethnographic techniques to generate both quantitative understanding and qualitative understanding (Bernard 2006). The data collection was completed by a team of researchers from Arizona State University, USA, and students from Tribhuvan University, Nepal, in Summer (May–June) of 2016 and June of 2017 following the institutional review board (IRB) human subject protocol. The household survey used a stratified random sampling method to select 150 sample households from nine villages spread across both the Khumbu and Pharak; 138 respondents completed the survey conducted in 2016. The survey instrument elicited self-reported data on household demography, income and livelihood sources, and people's perceptions of climate change, glaciers, experience on climate hazards experienced in last 10 years, and an open question about natural hazards experienced in the region by Sherpas.

To develop a comprehensive risk index, the perception of probability and severity risk data of climate hazards were also collected from a sample size of 18 in 2017 as a pilot study. Twenty-four in-depth semi-structured interviews were conducted in the major settlements that are located near flood-prone areas to obtain a cognitive apprehension of risk. In this process, a chain referral or network sampling method (snowball technique) is used where you use key informants and or/documents locate one or two people in the population and then ask those people to list others in the population and recommend someone for an interview (Bernard 2006). Here semi-structured interviews are not entirely used for analysis but are used to understand the background information of the natural–social systems of cryospheric hazards.

To get more in-depth insight as well as to compliment and cross-verify individual responses, this study also made use of two focus group discussions which were conducted in with 12 participants Dingboche (4350 m a.s.l.) village in Khumbu area and 11 participants in Monjo (2835 m a.s.l) village in Pharak area. These two locations were purposely selected to incorporate the thoughts and perception of residents from both Khumbu and Pharak valleys (Fig. 3). These focus group discussions mainly concentrated on the pairwise ranking of various hazards that were identified in the household survey to validate the information obtained from the household survey.

4.2 Data analysis

Survey data were prepared and analyzed in the Statistical Package for the Social Sciences (SPSS) and statistics and data (STATA) software. The key parameters obtained from household surveys were encoded in SPSS in the form of dummy variables (0 = No and 1 = Yes). These were further imported and analyzed in STATA for multiple response analysis for socio-demographic characteristics of the 138 respondents. The major variables are age, gender, income (farming or tourism), and risk experiences. First, the percent of people experiencing climate hazards (e.g., drought, glacial floods, heavy rain, blizzards, and hailstorm) in the past 10 years was analyzed and compared, as a proxy for personal risk experience appraisal that motivates people to take certain action including adaptive action (Weinstein 1989; Grothmann and Patt 2005). An open question was asked to locals to rank different natural hazards that they have experienced locally helped categorize and analyze these based on multiple response ranking. The answers to this question helped us understand the relative significance of cryospheric hazards in relation to other and risks that are not necessarily identified as climate risks. In-depth semi-structured interviews provided insights and local contexts of the cultural and religious background of the Sherpas and their understanding of risk and its relation to various natural hazards. Those were also useful in analyzing local people's risk perceptions in relation to changes in livelihood, particularly from subsistence agriculture to tourism and their perspectives on the changing climatic condition and flood events they have experienced.

4.2.1 Relationship between risk perceptions and social factors

This study employed a logit model utilizing variables recorded as a binary data (yes/no) to analyze the influence of various social factors such as age, gender, livelihood sources (e.g., tourism, farming), and past flood experiences on the risk perceptions of cryospheric hazards. Logistic regression is widely used in various studies to understand the climate change risk perceptions (Sun and Han 2018; Rodriguez et al. 2017). The perception on "*glacial lake as threat*" is taken as a dependent variable, whereas age, livelihood sources, tourism and farming, experience of GLOFs, and gender are taken as explanatory variables. Details of variables and their meanings based on household survey are presented in Table 4. A simple logit model for binary data is shown in the following Eq. (1). Here y_i^* designates the latent perception on glacial lake as threat or not.

$$
\begin{gathered}
y^* = \alpha + \beta X_i + \varepsilon_i \\
y_i = \begin{cases} 1 \text{ if } y_i^* > t \\ 0 \text{ if } y_i^* > t \end{cases}
\end{gathered}
\tag{1}
$$

where t is the threshold and ε denotes the error term.

4.2.2 Ratio scale prioritization of natural hazards from focus groups

Two focus groups conducted in Dingboche (4350 m a.s.l.) in the Khumbu and one in Monjo (2835 m a.s.l) in Pharak generated the pairwise ranking of the various natural

Table 1 Scoring approach of AHP for focus group discussions conducted in two villages

Intensity of value	Interpretation
1	Requirement *i* and *j* are of equal value
3	Requirement *i* has a slightly higher value than *j*
5	Requirement *i* has a strongly higher value than *j*
7	Requirement *i* has a very strongly higher value than *j*
9	Requirement *i* has an absolutely higher value than *j*
2, 4, 6, 8	These are intermediate scales between two adjacent judgements
Reciprocals	If requirement *i* has a lower value than *j*

hazards in the Mt. Everest region of Nepal. These pairwise ranking data of major hazard and risk categories obtained from the focus group discussion were analyzed using ratio scale prioritization method of Analytical Hierarchy Process (AHP) (Saaty 1980; Zahedi 1986). The result obtained from AHP focus group discussion is cross-validated with the results of the household survey as a part of data triangulation in this study.

In this method, various natural hazards were given values based on their probability and severity as shown in Table 1. This method generated ratio data and values for each natural hazard, which were further normalized and ranked. These scores are interpreted based on the scores where higher values indicate that the particular natural hazard is perceived as high risk based on their capability of damage and frequency, as compared to others and vice versa. Here, sum of all the normalized values is 1. This analytic hierarchy method provides a means of decomposing the problems into a rank of subproblems that are easily comprehended and subjectively evaluated (Saaty 1980).

4.2.3 Mental model

During the fieldwork of 2017, this study also made use of a mental modeling tool, which is widely used in natural resource management and hazard risk management to elicit the perceptions and worldviews of stakeholders (Jones et al. 2011). Mental modeling can capture the plurality of stakeholder perceptions, values, and goals under changing environmental condition. The mental model of a tourism entrepreneur from Dingboche village is included in this research, mainly to understand how and where the cryospheric hazard lies in individual's web of livelihood and risk perceptions. This provides a basic background of the livelihood pattern and risk perception.

5 Results

A summary of descriptive statistics for socio-demographic characteristics including age, gender, livelihood, and perception to cryospheric factors of the 138 respondents is reported in Table 2. In this study, 47% of the respondents were female, which might be because of the head of the family (typically male) who were the ones who came forward to respond to the survey. In the study area, all respondents reported Sherpa language as their main language and English and Nepali languages as secondary languages. Some of the respondents were Rais and Tamangs who migrated from the lower hill region of Solukhumbu district.

Table 2 Descriptive statistics for socio-demographic characteristics of the 138 respondents in the empirical analysis and risk experiences

Variables (Type)	Definition	Mean	SD
Age (C)	Age of the respondent Share of age (%) Age < 18 ≤ 30 = 67.21 Age < 30 ≤ 60 = 27.87 Age < 60 ≤ 80 = 4.92	41.00 (min = 18, max = 80, median = 39)	14.39
		Percentage (%)	
Female (c)	Female participants in the survey	47	–
Farming (c)	Participants involved in farming	79	–
Tourism (c)	Participants involved in tourism	50	–
Glacial flooding event remembers (c)	Participants who remembers GLOF event	48	–
Glacial lake poses a threat? (c)	Perception on glacial lake as a threat	45	–
Has any idea about glacial lake? (c)	Information on glacial lake	93	–

Type: C = continuous; c = categorical

SD standard deviation

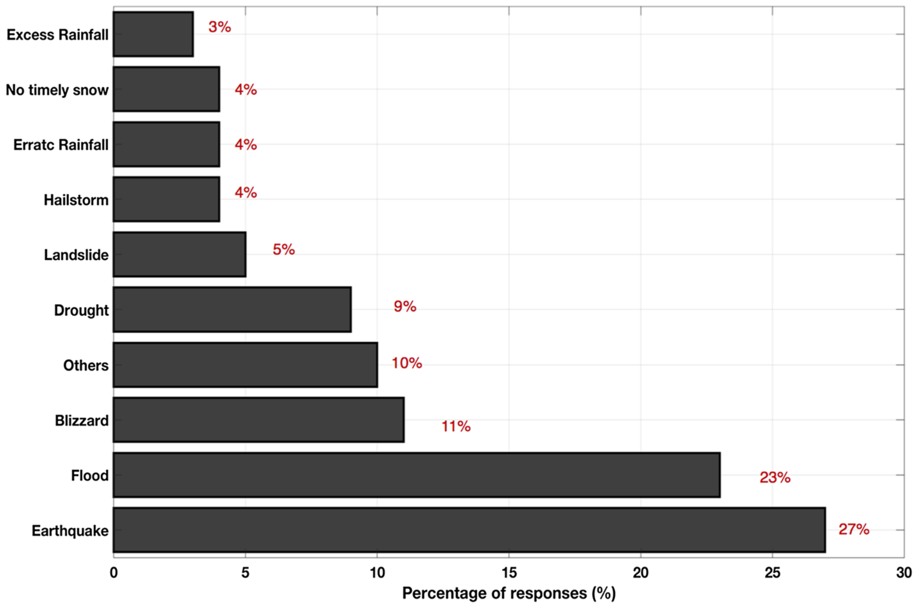


Fig. 4 Percentages of the perceived natural hazardous event in the Everest region of overall respondents ($n=138$) based on multiple response ranking

Respondents age varied from minimum 18 to maximum 80, with a mean of age 41, and the highest percentage of respondents were from age below 30 and above 18 (67%), as presented in Table 2. Within the region, 79% of the sample size were involved in farming, whereas 50% were in tourism business. The household survey showed among 138 respondents, 48% recalled flooding events that had occurred in the region, and among the 93% of respondents who have knowledge about glacial lakes, 45% perceive them as threat.

5.1 Analyzing risk perceptions from household survey data

An open question asked on various natural hazards allowed the locals to rank natural hazards based on their likelihood and potential to damage. In this survey, the highest portion of people, 27%, ranked earthquake as a most hazardous and risky as shown in Fig. 4. Since the survey was conducted a year after the Gorkha Earthquake of Nepal in April 2015 (7.4 magnitude), most respondents ranked earthquake as most hazardous, as recent or common events are more cognitively available. This multiple response ranking also showed 23% of respondents perceived glacial flood as a critical hazard in the region. Blizzards, drought, and landslide are perceived as hazardous by 11%, 9%, and 5% of the respondents, respectively, whereas hailstorms and the lack of timely snow are perceived as hazardous by 4% of respondents each, followed by excess or erratic rainfall by 3% respondents, and less than 1% respondents identified other different hazard categories. A comparison of cryospheric hazards with other natural hazards allowed the study to better understand where the cryospheric hazard lies in people's cognition.

Since experience of risk influences people's perception and ultimately changes people's behavior and motivation, this study tried to understand the percentage of people who have

Table 3 Percentage response on climate hazards in last 10 years

	Yes (%)	No (%)
Climate events experiences in last 10 years		
Drought experience	27	73
Glacial flooding experience	28	72
Heavy rain experience	21	79
Blizzard experience	31	69
Hailstorm experience	8.2	91.8

Table 4 Estimates in a logit model with dependent variables: perception on glacial lake as threat with different independent variables, age, livelihood: farming and tourism, gender and people who have experienced GLOFs as explanatory variables

Explanatory variables	Model 1	
	Coefficient	SE
Age	−0.03*	0.01
Involved in farming	−0.90*	0.53
Involved in tourism	0.74*	0.42
Gender (female)	−0.65*	0.38
Experienced of GLOFs	0.86*	0.43

*Means that the corresponding parameters are different from zero at the 5% significance level

experienced various climate hazards. Response of experiences of climate hazards in the last ten years obtained from the household survey showed that the highest number of respondents (31%) has responded experiencing blizzard in the Everest region of Nepal. 28% of the respondent have mentioned glacial flooding, and 27% cited droughts as climate hazard experienced in last 10 years as shown in Table 3. Torrential rains and hailstorm were cited by 21% and 8% of respondents, respectively.

5.2 Risk perceptions and influencing factors

A simple binary logit model used on categorical variables showed a significant positive correlation between who have experienced GLOFs with perceiving glacial lakes as threat. A negative correlation is observed with age and perception of glacial lake as a threat, indicating that older generation do not perceive glacial lakes as threat. Furthermore, a significant negative correlation between people involved in farming and female population with perception on glacial lake as threat showed that people of these two categories do not perceive glacial lake as threat (Table 4). However, population involved in tourism seem to perceive glacial lake as threat as shown in Table 4.

5.3 Risk perception based on settlements

To further disaggregate the findings of household survey data, this study relied on focus group discussion for a cross-validation, which would compare the results Khumbu and Pharak valleys located in two different altitudinal zones. The pairwise ranking data from the focus group discussion two villages: Dingboche (4350 m a.s.l.) and Monjo (2835 m

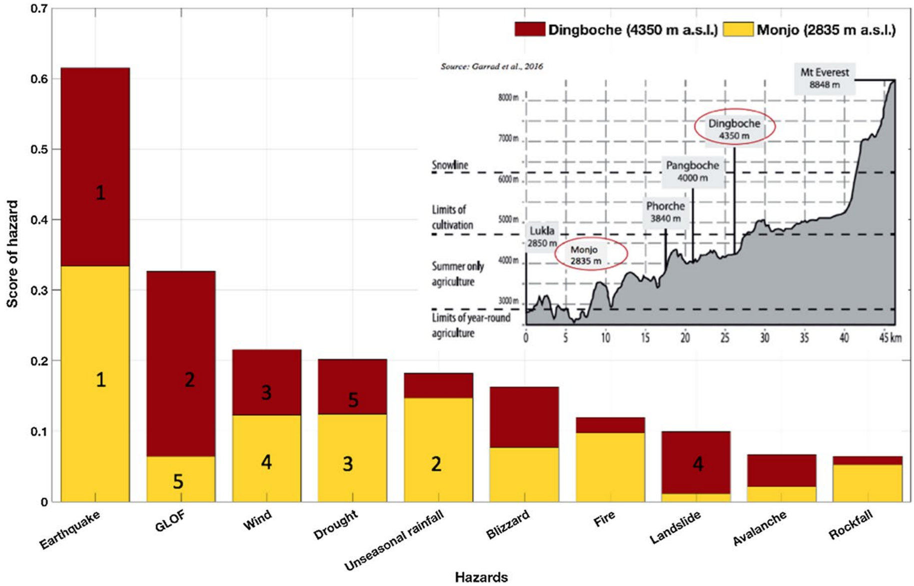


Fig. 5 Ranking of various natural hazards using pairwise ranking data obtained from focus group discussion for Dingboche (red) and Monjo (blue) settlement. An analytical hierarchy process of scoring is used in these data. 1–5 ranking in both settlements are shown in the figure

a.s.l.) facilitated to better understand the perception of risk appraisal based on spatial variations. In both settlements, the earthquake is ranked at number one, which aligns with the outcome of household survey data obtained in 2016. However, they differed on the second most critical hazards in their area. The GLOF was ranked in the second position in Dingboche village (Khumbu valley), whereas unseasonable rainfall was ranked in second in the Monjo village, which is located in lower altitude Pharak Valley (see Fig. 5). In Monjo, GLOF was ranked in fifth place as opposed to Dingboche based on the likelihood and severity of damage. The spatial variations seen between these two villages are mainly due to two major factors: (1) Dingboche located in the upper Khumbu Valley relies heavily on tourism compared to Monjo, where agriculture remains a significant source of income to complement their income from tourism, and (2) Dingboche is closer to Imja Lake and the locals are generally aware and more knowledgeable of GLOFs and the emergency remediation project implemented by the Government of Nepal in 2016. Several respondents in Monjo also did not differentiate between the glacial floods and normal flooding events caused by heavy rainfall.

5.4 Individual perceptions of risks and social background

A mental model (Jones et al. 2011) of one of the locals from the study site illustrates the perceptions and worldviews of sample respondents, toward the changing cryospheric system and changing scenarios of climate. This mental model of the tourism entrepreneur (Fig. 6) shows that the livelihood (tourism) of people is highly impacted by any change in the climate such as bad weather, increasing flash floods, and more importantly disappearance of the drinking water source due to melting of the glaciers (tracks colored in orange

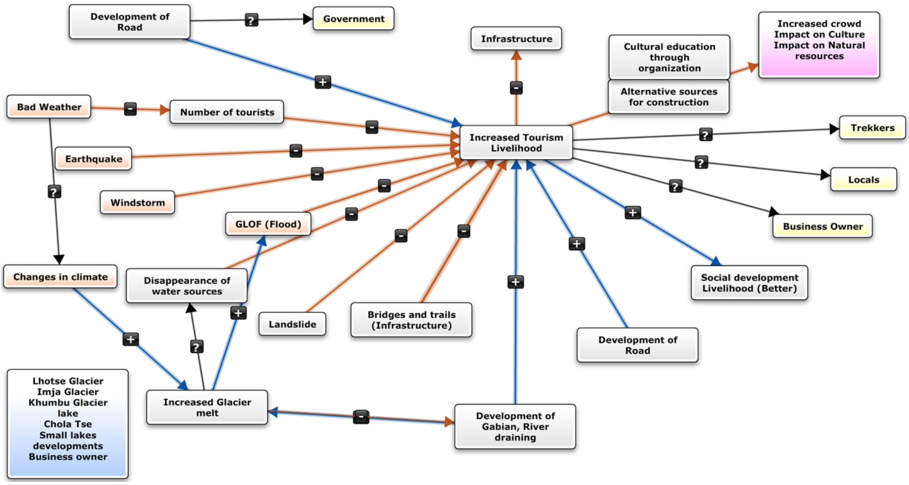


Fig. 6 Mental model of a tourist entrepreneur from Mt. Everest region

color in the mental model in Fig. 6). Changes in the cryosphere system such as the retreat of glaciers, Khumbu, Imja Tse, Lhotse glacier are observed with the formation of the small supra-glacial lakes (Fig. 6). This mental model provided a background on different components which are affecting tourism—one of the two key livelihood sources.

6 Discussion and conclusion

Analyzing the perceptions of hazards and risks is increasingly being recognized in the climate change literature as an effective tool to understand how local risk perceptions can influence their adaptation and mitigation measures. This type of study is particularly important for mountain regions facing the impacts of climate change, where empirical studies on these topics are rare, but could of enormous value to understand local adaptation strategies and processes. In this study, local people's risk perceptions of GLOF and other cryospheric hazards were comprehensively captured and analyzed for the Mt. Everest region of Nepal. The results of this study provide insights into how a complex set of socioeconomic, cultural, and ecological factors influence local people's perceptions and how those could help climate adaptation and mitigation policies in the region and the Himalayan region.

The household survey and focus groups discussion results clearly showed that local people consistently ranked "rapid onset" hazards with potentially catastrophic impacts such as earthquake, much higher than any other hazards alongside with glacial floods. The earthquake being ranked the first place in all instances suggests that its catastrophic impacts in the 2015 earthquake were still fresh in local's memories and have influenced the way people perceive the hazard risks. This is consistent with the finding of Tversky and Kahneman (1974) that human cognition of hazard is influenced by recent or common events that are more cognitively available. On the other hand, although ranked much lower (Table 3), "slow onset" climate change impacts (Matias 2017) such as loss of water sources (dryness) and frequent change in the weather are two major factors that are influencing the livelihood of people besides the changes in the cryospheric system and experience of various climate events (Table 3). This shows the tendency among the local people to be more fearful of "rapid onset risks" (or dread risks) that are infrequent but are deadly in impacts. GLOF is one of those two most critical hazards among 11 different natural hazards identified in the region.

There were, however, variations in how different individuals and communities perceive those hazards and risks. Local perceptions of cryospheric hazard are found to be influenced significantly by sources of livelihood, age factors, prior experiences of hazardous events, and geography. The socioeconomic data using a logit model showed that the young people perceive glacial lakes as a major threat than the older generation. This correlation might be due to the fact that the younger generation has more exposure to the media and various sources of information about changes in the glacial system brought about by climate change. In addition to this, the outcome of the study is also comparable to study that showed a lower concern among older people on the climate change and its adverse consequences because of shorter personal horizon compared to the younger generation (Hamilton 2011). Livelihoods, specifically tourism, is also found to be a major factor in determining risk perceptions to cryospheric hazards. Since the tourism is one of the major sources of income, most lodges are located in low-lying settlements connected with trails and those in tourism are likely to be more aware of the information related to GLOF risks. The ranking order obtained in both villages, Dingboche (earthquake, GLOF, Wind) and Monjo (earthquake, unseasonal rainfall, drought), showed a variation in the ways these two communities located in different altitude and socio-ecological settings perceive natural hazards and risks. It is important to note here that Dingboche is still a temporary and new settlement, which once was a pasture before tourism started to grow in the 1970s and it only become a major stop for those tourists traveling to the Everest Base Camps and other trekking peaks. In contrast, Monjo is a permanent settlement in Pharak areas, where farming is equally important as tourism, and the cyrospheric risk is perceived differently. This link with the significant relationship that was observed between the people involved in tourism and perceiving glacial lake as a threat. This adds livelihood diversification and geographic variations—two important features of mountains—as an important contributing factor for the Gorthmann and Patt model described earlier.

Another important factor that influenced people's perceptions was whether or not the individuals and communities had prior experiences with particular hazards. There is a direct correlation of the experiences of GLOFs (28% population) to risk perceptions of the glacial lake as a threat. It supports the outcome of previous studies showing the direct influence of risk experiences on the perception of climate change (Dai et al. 2015; Zaalberg et al. 2009). Furthermore, although both villages are situated in the flood-prone area, unlike Monjo village, people in Dingboche village consider GLOF as a high risk. Since Dingboche is located just below the Imja lake as compared to Monjo village (Fig. 3), the proximity factor to Imja and other glacial lakes seems to have played roles in determining their risk perception, which as it is reported elsewhere that respondents who live nearby riverbank tend to fear flooding more than those living further away (Siegrist and Gutscher 2006). However, their ranking of GLOF as a critical risk did not change, even after the 2016 emergency remediation work, which lowered the Imja Lake by 3.5 m. However, the result was different in Monjo village when a follow-up survey 2017 (Fig. 4) showed a change in how this community ranked GLOF after the completion of the project. In 2016, it was ranked third, but in 2017, it was ranked much lower (seventh place). The reason cited by the focus group participant was that the Imja Lake was already dammed by the government, and thus, the risk of flood was lower, even though some scientists believe the lake should be lowered by 20 meters to eliminate the flood impact in the nearest village, Dingboche (Somos-Valenzuela et al. 2015). This change could be explained by what some call a “cognitive fix” for the people influencing their behavior (Heberlein 2012: 588) and ranked hazards as less threat.

The social factors influencing local people’s risk perceptions are also strongly conditioned by the larger institutional and political factors associated with the central government’s relationships with Sherpa communities. Of importance is the territorial control of the central government through the establishment of SNPBZ and how tourist revenues are shared and allocated in local development projects; however, these are beyond the scope of this paper and are hoped to be addressed in the larger study. This is particularly significant for developing a Local Adaptation Plan of Action that could address cryospheric hazards as part of a more comprehensive plan for this region.

It was clear during the study that government-level climate adaptation policies need to go beyond providing only climate awareness, and locals should be involved in decision-making processes to develop a resilient society and to have a sustainable risk reduction approach. This study hopes to inform the policymakers develop adaptive capacity to deal with GLOF and other cryospheric hazards in the region. Among other factors influencing how individual perceive cryopsheric hazards, it is important to note how scientific and policy information regarding those hazards is communicated to the local communities. In this region, where Imja Lake has been one of the most studied lakes since the early 1980s, only in recent years significant efforts have been made to include social and humanistic perspectives to cover the complex social systems. This would help build the bridge between scientific knowledge base on GLOF and local communities, which are often confused with the contrasting—and at times contradictory—scientific findings, and this in turn has led to a sense of fear and dread among the locals. For instance, a small englacial flood that occurred immediately after the April 2015 earthquake resulted in fear and panic among the people not only the low-lying settlement but also among those in the higher elevation and the downstream villages along the Dudhkoshi River basin. There was no timely and appropriate early warning system in place, and there was no other alternative than to run uphill to a safe height. It, therefore, a sustainable partnership of scientists, policymakers, and local communities is urgently needed to build a science-driven, community-based initiative that focuses not just in addressing a single GLOF threat (e.g., Imja) but develops on a comprehensive cryospheric risk management plan and considers opportunities and challenges of tourism in the local climate adaptation policies.

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