Cryospheric Hazards and Risk Perceptions in the Mt. Everest Region, Nepal

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Abstract

Multiple studies have reported potential risks posed by a rapid expansion of glacial lakes in the Mt. Everest region of Nepal. People's perception of such cryospheric hazards can influence their actions, beliefs, and responses to those hazards and associated risks. This paper analyzes local people's perceptions of cryospheric hazards and risks using a social survey dataset of 138 households in the *Khumbu* and *Pharak* areas of the Mt. Everest region of Nepal. A statistical logit model of categorical household data showed a significant positive correlation with the perceptions of cryospheric risks to their livelihood sources, mainly tourism. Local people's GLOF risk perceptions are also influenced by their proximity to rapidly expanding glacial lakes and potential flood zones located in Dudhkoshi River basin. The emergency remediation work implemented in the *Imja* glacial lake by the Government of Nepal in 2016 has served as a cognitive fix, especially in the low lying settlements in Pharak. Uncertainties of cryosphere that exist in the region can be attributed to a disconnect between how scientific knowledge on GLOFs risks is communicated to the local communities and how government policies on climate change adaptation and mitigation have been limited only to awareness campaigns and emergency remediation works. 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.

Key words: 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, 2010; Bolch et al., 2012; Nie and Liu, 2013). GLOF risks have increased significantly in the recent decades with more rapid melting of glaciers, caused in large part by climate change (Kargel et al., 2011; NRC, 2012). In the Mt. Everest region of Nepal there have been three major GLOFs since the 1970s: Naare (1977), Dig-Tsho (1985), and Taam Pokhari (1998) along with several smaller englacial outburst floods that are occurring more frequently in recent years (Rounce et al. 2017). Despite the heightened sense of vulnerability to these glacial flood events and other cryospheric hazards among locals, there have been no systematic study to assess local people's perceptions of risk or what Grothmann and Pratt (2005) calls "risk appraisal" of GLOFs and other cryospheric hazards in the region. This research seeks to address two key research questions: 1) how do the local people perceive the risk of cryospheric hazards in comparison to other natural hazards in the region? and 2) What are the major factors that directly influence their risk perceptions? Answers to these questions are sought through an in-depth analysis of people's risk perceptions of GLOFs and other natural hazards and risks captured in a socio-economic dataset generated for a large research project funded by an NSF CNH research grant.

GLOFs pose a significant threat to society and infrastructures. Such hazards can discharge, with little warning, massive volumes of water in a highly destructive way, catching downstream communities off-guard and unprepared (Bajracharya et al., 2007; Mool et al., 2011; Carey et al., 2012). The biggest GLOF in the region, however, was the 1985 outbreak of Dig Tsho in the Bhotekoshi Valley, which discharged an estimated 6-10 million cubic meters of water and caused severe damage worth more than three million dollars (Mool et al., 2011). Supraglacial lakes, such as Imja Tsho or Imja Lake, have formed in the Himalayan region over the last five decades, and are now rapidly expanding to levels likely to trigger devastating GLOF events (Thakuri et al., 2016, Bolch et al., 2008; Bajracharya, Shrestha, & Rajbhandari, 2007) drawing the significant attention of media and the scientific community.

Risk perception research has long been a subject of hazards and risk analysis (Tobin and Montz 1997). Numerous climate variability studies have repeatedly shown influence of risk perception on people's knowledge, action, beliefs and response (Leiserowitz 2006, Etkin & Ho 2007, Patt & Schröter 2008, Fosu-Mensah et al. 2012, Halder et al. 2012). Although scientific knowledgebase on GLOF hazards and risks is fairly comprehensive for Nepal, a systematic study of risk perception to such hazards are scarce. In such conditions, understanding of risk perceptions to cryospheric hazards is essential to stimulate adaptive actions. The socio-cognitive Model of Private Proactive Adaptation to Climate Change (MPPACC), which was based on decades of research on risk perception, presents perception as a key variable influencing or being influenced by all the model's determinants of adaptive behavior (Gorthmann and Patt, 2005). Perceptions of the risk from hazards and impact are shaped more by direct personal experiences than by second hand information (Clayton et al., 2015) or information on physical and morphological changes in physical system (e.g. change in volumes of glacial lakes or retreat of glaciers) in case of this study. This research follows the socio-cognitive framework of Private Proactive Adaptation to Climate Change (MPPACC) by Gorthmann and Patt (2005) to understand how people appraise risks and to examine the factors affecting risk perception, which has a key role in influencing adaptation action and resilience.

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 (potentially dangerous) based on criteria related to factors such as, the size and rate of growth of the lake, and position in relation to moraines and associated glaciers (Khanal et al., 2015). Among these, Imja glacial lake located in the Mt. Everest region is considered to be of critical (Mool et al., 2001a & 2001b) to moderate risk (Rounce et al, 2016). Studies by Somos-Valenzuela and colleagues (2014; and 2012) 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 milliion m^3 from 35.8 ±0.7 million m^3 (Sakai et al., 2007). A flood model study conducted by Somos-Valenzuela (2015) recommended the lowering the lake at least by 3 m to minimize potential impact in the downstream communities, but also highlighted that significant reduction of risk could be achieved by lowering the lake by 20 m. A case study was conducted on Tsho Rolpa located in Dolakaha-an adjacent district highlighted diversity in people's perceptions of GLOF risks from the lake and their response to potential hazards. In another study, Khanal et al., (2015) highlighted the importance of conducting a comprehensive risk assessment of socioeconomic vulnerability to GLOFs, particularly to design appropriate risk reduction strategies in Nepal. However, none has used a system approach to understand both the social and natural systems associated with GLOF and other cryospheric hazards.

While studies on vulnerability and risk perception to cryospheric hazards are relatively new and scarce for the Himalaya, the literature on the Andes is comparatively more comprehensive. For instance, in Peru—particularly avalanches, glacial lake outburst floods and glacier recession—has been thoroughly examined through multi-disciplinary research (Haeberli and Whitman, 2015; Bury, 2010; Carey, 2005). 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.

In this study, a schematic diagram of vulnerability of social system to cryospheric hazards and risk and response of communities is developed to show cryospheric hazards are part of the region's complex natural-social systems (see Fig. 1). Understanding of risk by the communities and enhancement of preparedness to vulnerability and risk in the system can help increase the resilience of this complex natural and social system to eliminate vulnerability (Fig. 1).

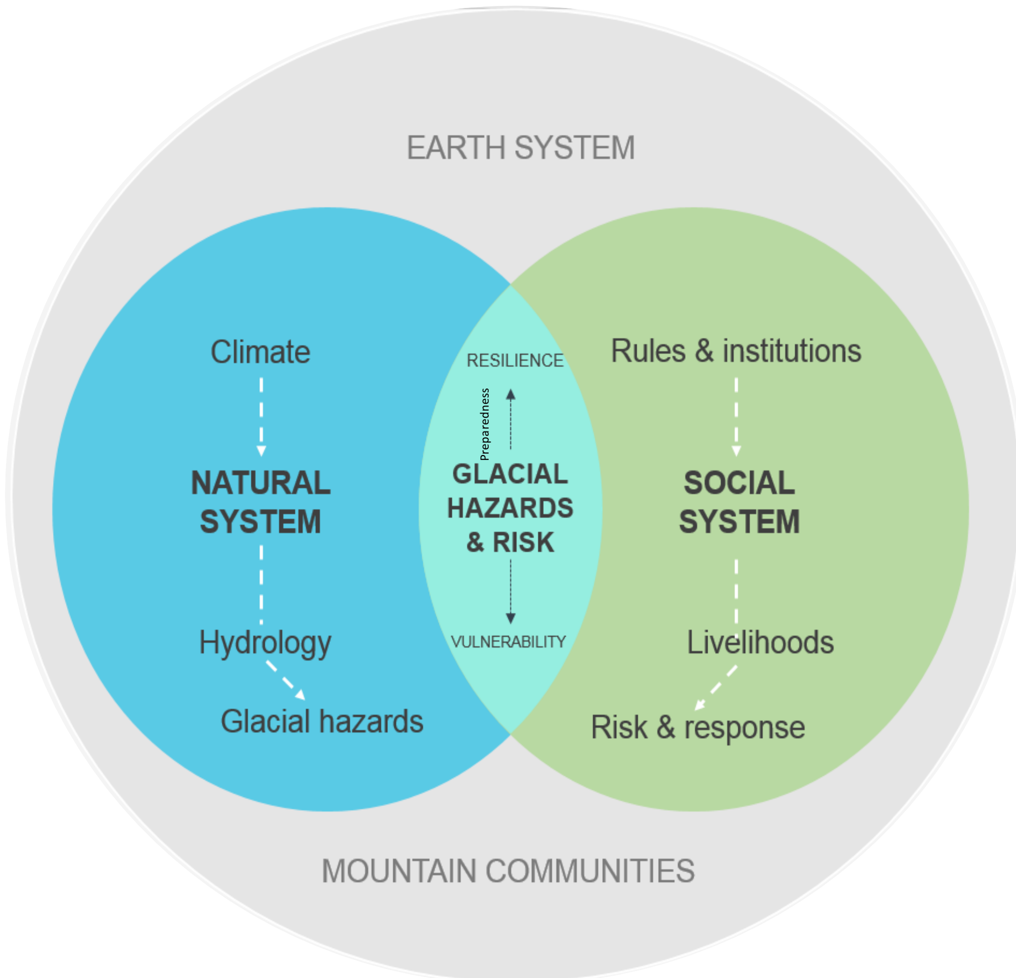

Fig.1. Complex natural-social system interaction in the mountain communities

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 & 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 socio-cultural 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

(Grorthmann 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., 2010). 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: i) person’s belief in his/her capacity for adaptive action or adaptation efficacy, and ii) 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 adaptive action. This study, therefore, adapted the Grothmann and Patt (2005) model to explain risk perception of cryospheric hazards in the Mt. Everest region, Nepal.

A comparison of cryospheric hazards with other natural hazards are made based on the various personal experience 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 that 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.

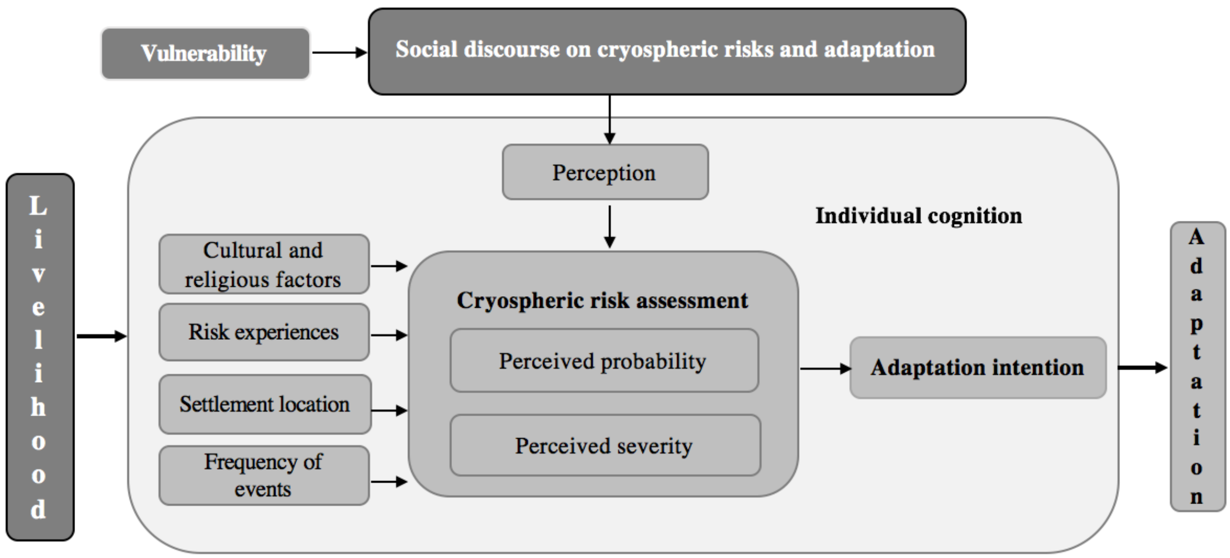

Fig. 2. Process model showing cryospheric risk appraisal and various influencing factors.

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 Sagarmatha National Park and Buffer Zone (SNPBZ), this region covers 124,400 hectares (1148 sq. km) (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 7,000 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 to 80% of the annual precipitation falling between June and September (Wagnon et al., 2013; Salerno et al., 2015). Winter months are normally cold and dry with few days above freezing and very little precipitation (Shea, 2015b). Dudhkoshi river is the main river system in the region. There are several villages and settlements along this river basin which are considered to be vulnerable to potential flood events.

The SNPBZ covers three major village development committees (VDCs): Khumjung and Namche VDCs and the northern part of Chaurikharka VDC (these VDCs are in the process of being merged into the proposed Pasang Lhamu Rural municipality). In the study area, there are 63 villages and settlements, which range in the elevation from Jorsalle at 2,805 m a.s.l. to

Gorakshep at 5170 m a.s.l. (Puschiasis, 2015). The Khumbu valley, consisted of Khumjung and Namche VDCs, cover much of the higher altitude villages, whereas the Pharak area—mostly in the uppder Chaurikharka VDC--is in the lower elevation areas with more diversified livelihood sources. This covers an area of 275 sq. kmto 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 (Klatzel, 2012: Part 1). 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, and potato the only major crop that can be grown widely, agriculture 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, 2007). Those involved in tourism businesses are often still partially involved in agriculture as a seasonal practice.

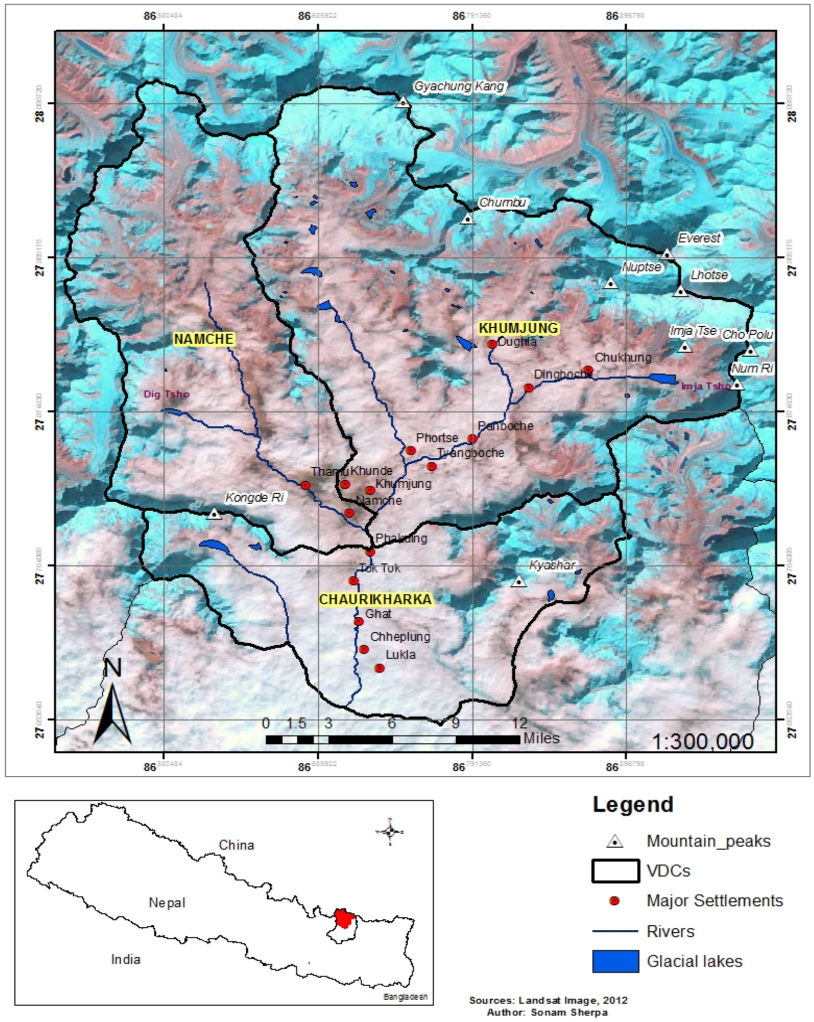

Fig.3. Study site.

4. Research Design

4.1 Data collection

This research draws upon the socio-economic 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 and qualitative understanding (Bernerd, 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 (Bernerd, 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 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.

4.1.1. 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 the Table 2. A simple logit model for binary data is shown in following equation (i). Here y_i^* designates the latent perception on glacial lake as threat or not.

$$y^* = \alpha + \beta X_i + \varepsilon_i \quad \text{(i)}$$

$$y_i = \begin{cases} 1 \; if \; y_i^* > t \\ 0 \; if \; y_i^* > t \end{cases}$$

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

4.1.2. 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 hazards in the Mt. Everest region of Nepal. These pairwise ranking data of major hazard and risk categories obtained from the focus group discussion was 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 hazards, 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 sub-problems that are easily comprehended and subjectively evaluated (Saaty, 1980).

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*

4.2.2 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 are 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) 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. 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 among138 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.

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

5.1. Understanding risk perception 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, 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.

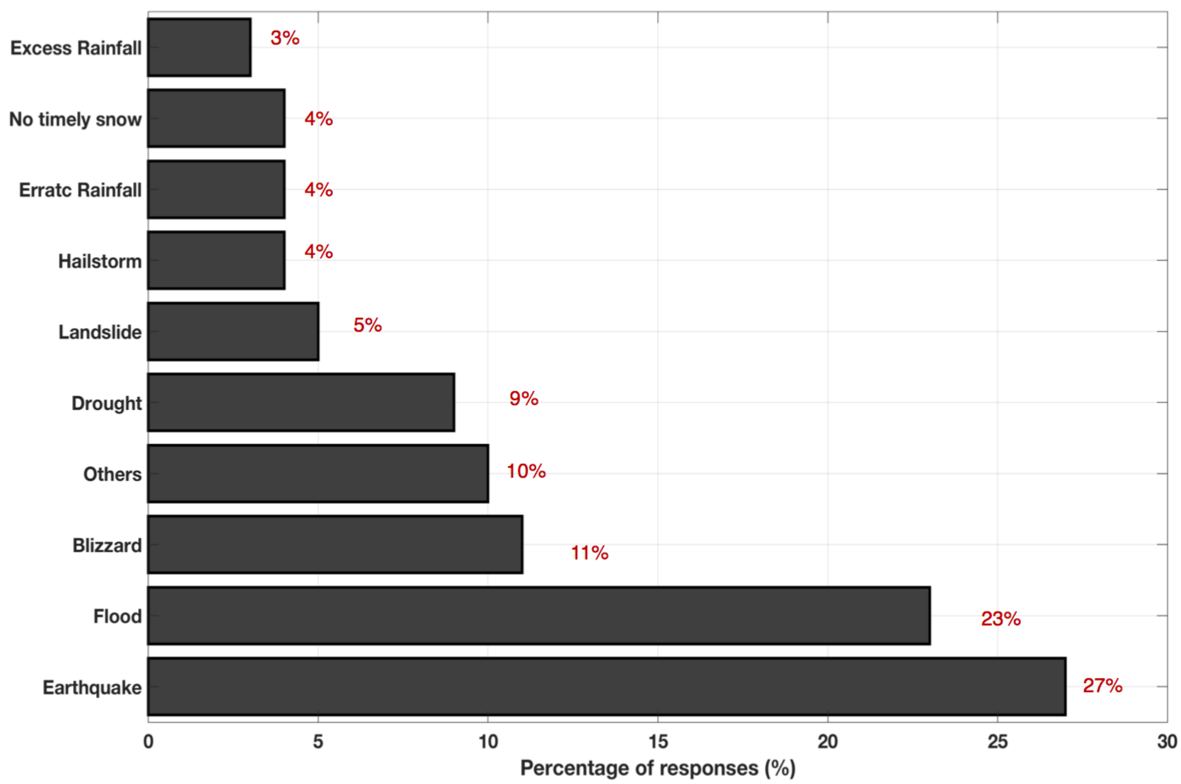

Fig.4. Percentages of the perceived natural hazardous event in the Everest region of overall respondents (n=138) based on multiple response ranking.

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 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%) have 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 ten years as shown in table 3. Torrential rains and hailstorm were cited by 21% and 8% of respondents respectively.

Table 3. Percentage response on climate hazards in last 10 years.

Climate Events experiences in last 10 Years.	**Yes (%)**	**No (%)**
Drought experience	27	73
Glacial Flooding experience	28	72
Heavy rain experience	21	79
Blizzard experience	31	69
Hailstorm experience	8.2	91.8

5.2. Risk perception 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 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.

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	Std. Err.
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

Note: * means that the corresponding parameters is different from zero at the 5% significance level.

5.4. 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 areas located in two different altitudinal zones. The pairwise ranking data from the focus group discussion two villages, which are at a higher elevation and lower elevation, Dingboche (4350 m a.s.l.) and Monjo (2835 m a.s.l.) villages, facilitated to better understand the perception of risk appraisal based on location. 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 5th place as opposed to Dingboche based on the likelihood and severity of damage.

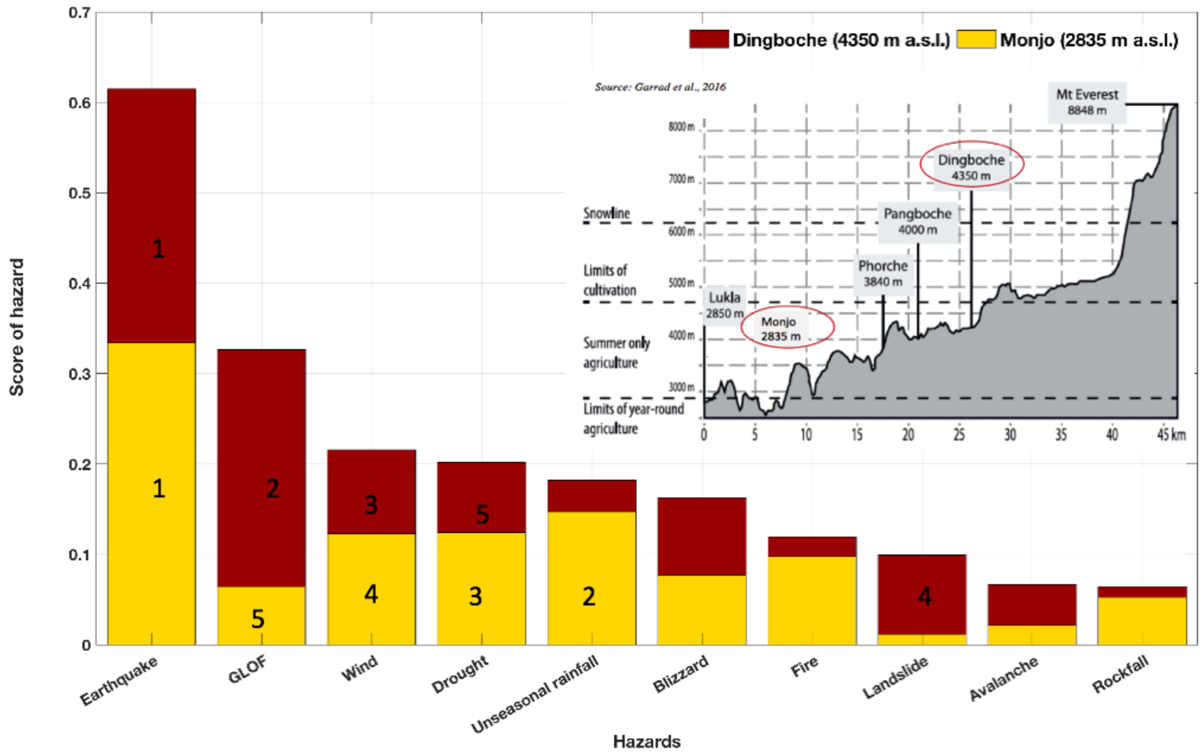

Fig. 5. Ranking of various natural hazards using pairwise ranking data obtained from focus group discussion for Dingboche (red) and Monjo (blue) settlement. An Analytical Hierarchy process of scoring is used in this data. 1-5 ranking in both settlements are shown in the figure.

5.5. Individual perception of risk 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 are 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 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 supraglacial lakes (Fig.6.). This mental model provided a background on different components are affecting tourism—one of the two key livelihood sources.

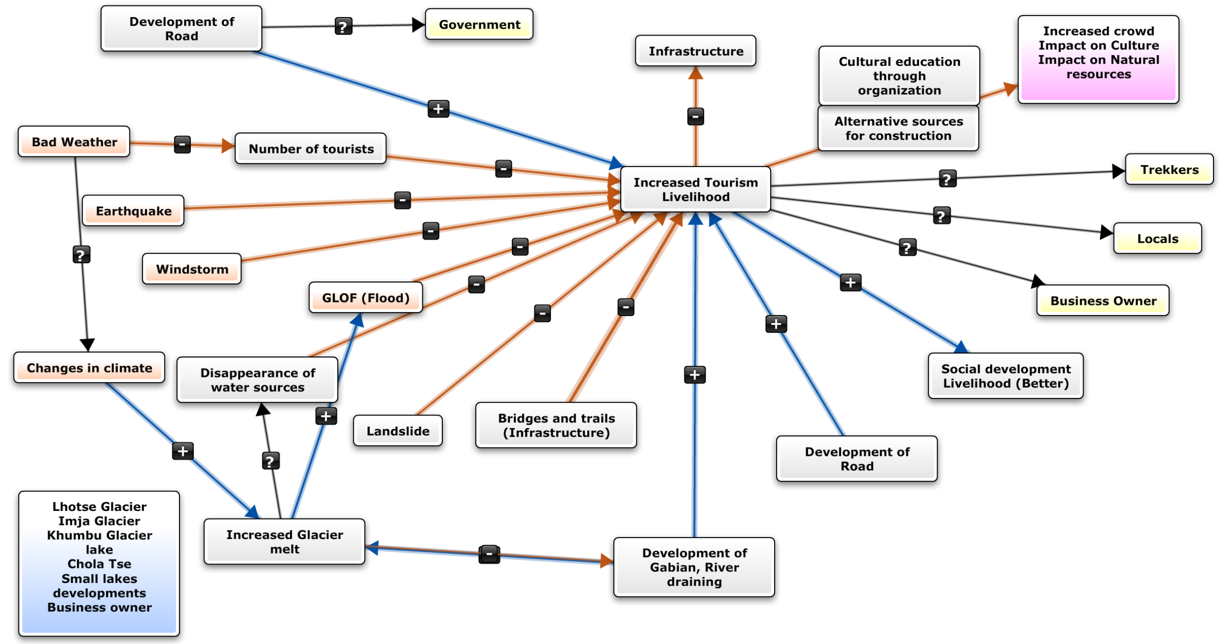

Fig.6. Mental model of a tourist entrepreneur from Mt. Everest region.

6. Discussion and Conclusion

Analyzing the perceptions of hazards and risks is increasingly being recognized in 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 on how a complex set of socio-economic, 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 on-set" 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 was 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 on-set" 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 on-set 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 compare to the younger generation (Hamilton, 2011). Livelihoods, specifically tourism, has a significant influence on the risk perceptions to cryospheric hazards, as it is currently the major source of income. 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-ecologcal 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 to 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, 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 3.5m. 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 (7^{th} 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 et al., 2015). This change could be explained by what some call a "cognitive fix" for the people influencing their behavior (Heberlein, 2014: 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 particular importance is the territorial control of the central government through the establishment of SNPBZ and how tourist revenues are shared and allocated in development projects; however, these are beyond the scope of this paper, and is hoped be addressed in the larger study. This is particularly important 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 approaches. This study hopes to provide information to climate adaptation policymakers about the current status of the system to develop better adaptive capacity. 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 local communities. In this region, many scientific studies have been conducted to assess the hazards and risks associated with GLOFs starting from the early 1980s. However, there are also, contrasting scientific findings communicated to the locals. The Imja glacial lake, for instance, was categorized as a potentially dangerous glacial lake (Ives and Messerili 1981; Vuichard and Zimmerman 1987; Hammond et al., 1988) in the 1980s, but some scientists found this be one of the most dangerous glacial lakes (Yamada and Sharma 1993; Watanabe 1994; Watanabe 1995); however, some other found the lake to be moderate to of no risk (Byers et al., 2013; Somos et al., 2014; Thakuri et al., 2016; Rounce et al., 2016). Although uncertainty is a reality in scientific studies, different scientific projects and confusions about the risk of Imja glacial lake have resulted in more confusions among the local people. Despite several years of effort, knowledge exchange and science communication by the experts and government agencies to the Sherpas of the Khumbu and Pharak valleys have been fruitful, and in turn, has increased a sense of fear and dread among them. In addition to this, the small englacial flood happened in June immediately after the earthquake of April 2015 created more fear and panic not only among the people in Khumbu and Pharak area but also the people living in along the riversides of Dudhkoshi Valley. 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

Acknowledgements

This material is based upon work supported by the National Science Foundation under the grant number CNH-1516912, *CNH-L: Science-Driven, Community-Based Approach to Reducing Glacier Lake Outburst Flood Risks,* which is a collaborative research project of

University of Texas, Austin (PI: Dr. Deane McKinney), Arizona State University (Co-PI: Dr. Milan Shrestha), and University of Colorado, Boulder (Co-PI: Dr. Alton Byers). Their guidance and support is gratefully acknowledged. Summer fieldwork of 2016 immensely benefitted from the research assistance received from Mr. Jagadish Parajuli (ASU, School of Sustainability) and Mr. Saroj Adhikary, Ms. Shanta Sharma, and Mr. Lalmani Wagle of Tribhuvan University, Nepal.

References

Bajracharya SR, Mool PK, Shrestha BR (2007) The Impact of Climate Change on Himalayan Glacier and Glacial Lakes. Kathmandu: International Centre for Integrated Mountain Development (ICIMOD).

Bolch T, Buchroithner MF, Peters J, Baessler M, Bajracharya S (2008) Identification of glacier motion and potentially dangerous glacial lakes in the Mt. Everest region / Nepal using spaceborne imagery. Nat Hazards Earth Syst Sci 8:1329–1340.

Bolch T, Kulkarni A, Kääb A, Huggel C, Paul F, Cogley JG, Frey H, Kargel JS, Fujita K, Scheel M, and Bajracharya S (2012) The state and fate of Himalayan glaciers. Sci 336(6079): 310-314

Bury J, Mark BG, McKenzie JM, French A, Baraer M, Huh KI, Zapata Luyo M, and GomezLopez. R (2011) Glacier recession and human vulnerability in the Yanamarey watershed of the Cordillera Blanca, Peru. Clim Change 105:179–206.

Byers AC, McKinney DC, Somos-Valenzuela M, Watanabe T, Lamsal D (2013) Glacial lakes of the Hinku and Hongu valleys, Makalu Barun National Park and Buffer Zone, Nepal. Nat Hazards 69:115–139. http://dx.doi.org/10.1007/s11069-013-0689-8

Carey M (2005) Living and Dying with Glaciers: People's Historical Vulnerability to Avalanches and Outburst Floods in Peru. Glob Planet Change 47:122–134.

Carey M (2010) In the Shadow of Melting Glaciers: Climate Change and Andean Society. Oxford University University Press, New York.

Carey M, Huggel C, Bury J, Portocarrero C, and Haeberli W (2012) An integrated socio-environmental framework for glacier hazard management and climate change adaptation: lessons from Lake 513, Cordillera Blanca, Peru. Clim Change, 112(3-4):733-767.

Crona B, Wutich A, Brewis A, and Gartin M (2013) Perceptions of climate change: Linking local and global perceptions through a cultural knowledge approach. Clim Change, 119(2):519–531. https://doi.org/10.1007/s10584-013-0708-5

Cutter SL, Boruff BJ, and Shirley WL (2003) Social vulnerability to environmental hazards. Social Science Quarterly, *84*(2):242–261. https://doi.org/10.1111/1540-6237.8402002

Dahal K R, and Hagelman R (2011) People's risk perception of glacial lake outburst flooding: a case of Tsho Rolpa Lake, Nepal. Env Hazards, 10(2):154–170. https://doi.org/10.1080/17477891.2011.582310

DNPWC (2006) Sagarmatha National Park Management and Tourism Plan 2006-2011.

Etkin D, & Ho E (2007) Climate Change: Perceptions and Discourses of Risk. J. Risk Res, 10(5), 623–641. https://doi.org/10.1080/13669870701281462

Fisher J F (1990) Sherpas: Reflections on change in Himalayan Nepal. Berkeley: University of California Press.

Frank E, Eakin H, and López-Carr D (2011) Social identity, perception and motivation in adaptation to climate risk in the coffee sector of Chiapas, Mexico. Global Environ Chang 21(1):66–76. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2010.11.001

Fosu-Mensah BY, Vlek PLG, & MacCarthy DS (2012) Farmers' perception and adaptation to climate change: a case study of Sekyedumase district in Ghana. Environ Dev Sustain 14(4):495–505. https://doi.org/10.1007/s10668-012-9339-7

Garrard R, Kohler T, Price MF, Byers AC, Sherpa AR, Maharjan GR (2016) Land Use and Land Cover Change in Sagarmatha National Park, a World Heritage Site in the Himalayas of Eastern Nepal Land Use and Land Cover Change in Sagarmatha National Park, a World Heritage Site in the Himalayas of Eastern Nepal. Mt Res Dev 36(3): 299–310. https://doi.org/10.1659/MRD-JOURNAL-D-15-00005.1

Green C (2004) The evaluation of vulnerability to flooding. Disaster Prevention and Management: An Int J 13(4):323-329.

Grothmann T, Patt A (2005) Adaptive capacity and human cognition: The process of individual adaptation to climate change. Glo Env Change, 15(3):199–213. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2005.01.002

Hammond JE (1988) Glacial lakes in the Khumbu region, Nepal: An assessment of the hazards. MA thesis, University of Colorado Department of Geography, Boulder, USA

Haeberli W, Whiteman C, (2015) Snow and Ice-Related Hazards, Risks, and Disasters. In: Snow and Ice-Related Hazards, Risks, and Disasters: A General Framework, pp 1-34 https://doi.org/10.1016/B978-0-12-394849-6.00001-9

Halder P, Sharma R, Alam A (2012) Local perceptions of and responses to climate change: experiences from the natural resource-dependent communities in India. Reg Environ Change, 12(4):665–673. https://doi.org/10.1007/s10113-012-0281-x

Heberlein T A (2014) Navigating environmental attitudes. Chapter 4.

Hegglin E, Huggel C (2008) An Integrated Assessment of Vulnerability to Glacial Hazards: A Case Study in the Cordillera Blanca, Peru. Mt Res Dev 28(3–4):299–309.

Helm P (1996) Integrated risk management for natural and technological disasters. Tephra, 15(1):4-13.

Huggel C, Kääb A, Haeberli W, Teysseire P, Paul F (2002) Remote sensing based assessment of hazards from glacier lake outbursts: a case study in the Swiss Alps. Can. Geotech. J 39:316–330.

Ives JD, Messerli B (1981) Mountain hazards mapping in Nepal: Introduction to an applied mountain research project. Mt Res Dev 1:223-230.

Jones NA, Ross H, Lynam T, Perez P, Leitch A (2011) Mental models: an interdisciplinary synthesis of theory and methods. Ecol Soc 16(1): 46. [online] URL: http://www.ecologyandsociety.org/vol16/iss1/art46/

Kargel JS, Cogley JG, Leonard GJ, Haritashya U, Byers A (2011) Himalayan glaciers: The big picture is a montage. Proceedings of the National Academy of Sciences, 108(36):14709-14710.

Khanal NR, Mool PK, Shrestha AB, Rasul G, Ghimire PK, Shrestha RB, Joshi SP (2015) A comprehensive approach and methods for glacial lake outburst flood risk assessment, with examples from Nepal and the transboundary area. Int J Water Resour D 31(2):219–237. https://doi.org/10.1080/0900627.2014.994116

Klatzel F (2012) The Sherpa people. Gaiety of spirit: The Sherpas of Everest region. Mera publication.

Leiserowitz A (2006) Climate Change Risk Perception and Policy Preferences: The Role of Affect, Imagery, and Values. Clim Change, 77(1):45–72. https://doi.org/10.1007/s10584-006-9059-9

Matias D (2017) Slow onset climate change impacts: Global trends and the role of science-policy partnerships. Discussion paper

Mool PK, Bajracharya SR, Joshi SP (2001a). Inventory of glaciers, glacial lakes, and glacial lake outburst floods: Monitoring and early warning systems in the Hindu Kush-Himalayan region – Nepal. Kathmandu: ICIMOD.

Mool PK, Wangda D, Bajracharya SR, Kunzang K, Gurung DR, Joshi SP (2001b) Inventory of glaciers, glacial lakes, and glacial lake outburst floods: Monitoring and early warning systems in the Hindu Kush-Himalayan region – Bhutan. Kathmandu: ICIMOD.

Mool PK, Maskey PR, Koirala A, Joshi SP, Wu L, Shrestha AB, Eriksson M, Gurung B, Pokharel B, Khanal NR, Panthi S, Adhikari T, Kayastha RB, Ghimire P, Thapa R, Shrestha, B, Shreshta S, Shrestha RB (2011) Glacial Lakes and Glacial Lake Outburst Floods in Nepal. Icimod, 1–109. https://doi.org/978 92 9115 193 6

National Research Council, & Committee on Population (2012) Himalayan glaciers: Climate change, water resources, and water security. National Academies Press.

Nie Y, Liu Q, Liu S (2013) Glacial Lake Expansion in the Central Himalayas by Landsat Images, 1990–2010. PLoS ONE, 8(12), e83973. http://doi.org/10.1371/journal.pone.0083973

Nirupama N (2012) Risk and vulnerability assessment: a comprehensive approach. Int J Dis Res Built Env 3(2):103-114.

Patt AG, Schröter D (2008) Perceptions of climate risk in Mozambique: Implications for the success of adaptation strategies. Glo Env Change 18(3):458–467. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2008.04.002

PEP (2004) Hazard, Risk, and Vulnerability Analysis Toolkit, Provincial Emergency Preparedness, British Columbia, p. 66.

Puschiasis O (2015) From global issues to local perception of climate change: practices and discourse regarding water resources among Sherpas in Khumbu (Everest region, Nepal). Dissertation, University of Paris West Nanterre La Défense

Rodriguez N, Eakin H, de Freitas Dewes C (2017) Perceptions of climate trends among Mexican maize farmers. Clim Res 72(3):183–195.

Rounce D, McKinney DC, Lala JM, Byers AC, Watson CS (2016) A New Remote Hazard and Risk Assessment Framework for Glacial Lakes in the Nepal Himalaya. Hydrol. Earth Syst. Sci Discussions 1–48. https://doi.org/10.5194/hess-2016-161

Rounce D, Byers AC, Byers EA, McKinney DC (2017) Brief Communications: Observations of a Glacier Outburst Flood from Lhotse Glacier, Everest Area, Nepal. The Cryosphere Discussions, (November) 1–10. https://doi.org/10.5194/tc-2016-239

Salerno F, Guyennon N, Thakuri S, Viviano G, Romano E, Vuillermoz E, Cristofanelli P, Stocchi P, Agrillo G, Ma Y, Tartari G (2015) Weak precipitation, warm winters and springs impact glaciers of south slopes of Mt. Everest (central Himalaya) in the last 2 decades (1994–2013). The Cryosphere 9:1229–1247. doi:10.5194/tc-9-1229-2015

Saaty TL (1980) The analytic hierarchy process. New York: McGraw-Hill.

Shea JM, Wagnon P, Immerzeel WW, Biron R, Brun F, Pellicciotti F (2015b) A comparative high-altitude meteorological analysis from three catchments in the Nepalese Himalaya. Int. J. Water Resour 31(2):174–200. https://doi.org/10.1080/07900627.2015.1020417

Siegrist MH, Gutscher (2006) Flooding risks: A comparison of lay people's perceptions and expert's assessments in Switzerland. Risk Anal 26(4):971-979.

Sjöberg L (2000) Factors in risk perception. Risk Anal 20(1):1-11.

Slovic P (2000) The perception of risk. Earthscan Publications, London

Smith K (2004) Environmental Hazards: Assessing Risk and Reducing Disaster, Routledge, New York, NY, p. 306.

Somos-Valenzuela MA, McKinney DC, Byers AC, Rounce DR, Portocarrero C, Lamsal D (2015) Assessing downstream flood impacts due to a potential GLOF from Imja Tsho in Nepal. Hydrol. Earth Syst. Sci 19(3):1401–1412. http://10.0.20.74/hess-19-1401-2015

Somos-Valenzuela MA, Mckinney DC, Byers AC, Rounce DR, Portocarrero C (2013) Modeling Mitigation Strategies for Risk Reduction at Imja Lake, Nepal. CRWR Online Report 2013-6. http://www.crwr.utexas.edu/reports/2013/rpt13-6.shtml

Somos-Valenzuela M, Mckinney DC, Byers AC, Voss K, Moss J, Mckinney JC (2012) Ground Penetrating Radar Survey for Risk Reduction at Imja Lake, Nepal. CRWR Online Report 2012-3. http://www.crwr.utexas.edu/reports/2012/rpt12-3.shtml

Sun Y and Ziqiang Han (2018) Climate Change Risk Perception in Taiwan: Correlation with Individual and Societal Factors. https://doi.org/10.3390/ijerph15010091

Thakuri S, Salerno F, Bolch T, Guyennon N, Tartari G (2016) Factors controlling the accelerated expansion of Imja Lake, Mount Everest region, Nepal. Ann Glaciol 57(71):245–257. https://doi.org/10.3189/2016AoG71A063

Thapa K, Shakya B (2008) Integrated Study on Hydrology and Meteorology of Khumbu Region with Climate Change Perspectives. WWF Nepal, Kathmandu.

Thieken AH, Kreibich H, Müller M, Merz B (2007) Coping with floods: Preparedness, response and recovery of flood-affected residents in Germany in 2002. Hydrolog Sci J 52(5):1016-1037.

Tobin GA, Montz BE (1997) Natural hazards: explanation and integration. Guilford Press, New York, NY, p 132–164

Tversky A, Kahneman D (1974) Judgment under Uncertainty: Heuristics and Biases. Sci 185(4157):1124-1131.

Vuichard D, Zimmermann M (1986) The Langmoche flashflood, Khumbu Himal, Nepal. Mt Res Dev 6(1): 90-93

Yamada T, Sharma CK (1993) Glacier lake and its outburst flood in Nepal Himalayas. Young, G.J. (ed.) Snow and Glacier Hydrology 319-330. Proceedings of International Symposium, Kathmandu, Nepal, 16-21 November 1992. IAHS-AISH Proceedings and Reports Publications 218. International Association of Hydrological Sciences, Wallingford.

Wagnon P, Vincent C, Arnaud Y, Berthier E, Vuillermoz E, Gruber S, Ménégoz M, Gilbert A, Dumont M, Shea JM, Stumm D, Pokhrel B K (2013) Seasonal and annual mass balances of Mera and Pokalde glaciers (Nepal Himalaya) since 2007. The Cryosphere 7:1769–1786, doi:10.5194/tc-7-1769- 2013

Watanabe T, Ives JD, Hammond JE (1994) Rapid growth of a glacial lake in Khumbu Himal, Nepal: Prospects for a catastrophic flood. Mt Res Dev 14 (4): 329-340.

Watanabe T, Kameyama S, Sato T (1995) Imja Glacier dead-ice melt rates and changes in a supra-glacial lake, 1989_1994, Khumbu Himal, Nepal: Danger of lake drainage. Mt Res Dev 15: 293-300.

Weber EU (2010) What shapes perceptions of climate change? 1(June), 332–342. https://doi.org/10.1002/wcc.41

Weinstein ND (1989) Effects of personal experience on self-protective behavior. Psychol. Bull *105*(1):31-50. http://dx.doi.org/10.1037/0033-2909.105.1.31

Whiteman CA (2011) Cold region Hazards and Risks. Wiley-Blackwell, 366 pp.

Wisner B, Blaikie P, Cannon T, Davis I (2004) At Risk: Natural Hazards, People's Vulnerability and Disasters, 2nd edition, Routledge, London, p. 471.

Zaalberg R, Midden C, Meijnders A, McCalley T (2009) Prevention, adaptation, and threat denial: Flooding experiences in the Netherlands. Risk Anal 29(12):1759-1778.

Zahedi F (1986) The Analytic Hierarchy Process—A Survey of the Method and its Applications. Interfaces 16(4):96–108. https://doi.org/10.1287/inte.16.4.96

Zimmermann M, Bichsel M, Kienholz H (1986) Mountain Hazards Mapping in the Khumbu Himal, Nepal. r6(1):29-40. doi:10.2307/3673338