The Human Dimensions of Climate Change in the Khumbu Region of Nepal: Implications of Hydrological Modification

By

Graham McDowell

A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of B.A. Honours in Geography

Department of Geography
McGill University
Montréal (Québec) Canada

April 2011

ACKNOWLEDGMENTS

It is with great appreciation that I thank my advisor Dr. James D. Ford. His contributions to this thesis—and my development as a scholar generally—have been beyond the call of duty. I am grateful for his mentorship and the many opportunities he has provided me. Thanks to Dr. Bernhard Lehner who, as a teacher enhanced my interest in water issues, and as the reader of this thesis improved its hydrology-related content considerably. I am appreciative of Dr. Lea Berrang-Ford's assistance with the quantitative aspects of this study as well as the Department of Geography and the Faculty of Science for funding which made this study possible.

I wish to acknowledge Bijan Garung (WWF Nepal) for his efforts during the complicated permitting of this project; the Government of Nepal for their interest and support of the study; ICIMOD for perspective, recommendations, and research facilities; the Department of Parks and Wildlife Conservation for productive feedback and practical assistance; and the many individuals in Kathmandu who informed the early stages of my fieldwork. My sincerest gratitude is extended to my interpreter and friend Ang Dawa Sherpa (of Namche). His knowledge and dedication greatly improved the content of this thesis. Special thanks are due to the residents of Khumbu, whose hospitality and willingness to share information about their lives was extremely generous.

I am thankful for my grandfather Dr. John R. Hendrick's early and enduring lessons in right action. Indeed, the moral compass inherited from him has guided this thesis and my scholarly efforts generally. My most heartfelt gratitude is expressed to my mother Christa Hendrick, whose unwavering love and trust have been companion to my many adventures—academics being no exception. Finally, I am grateful for the immeasurable support of Vanessa Kiss. Her encouragement and kindness are credited with the completion of these pages.

I dedicate this thesis to Jeff Petty, my early mentor and enduring friend.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF MAPS

LIST OF TABLES

Chapter 1: Introduction

Evidence is mounting that climate change is having perceptible and often adverse effects on human communities, especially where settlements coincide with climatically sensitive physical conditions and socio-economic/political constraints (IPCC, 2007b; World Bank, 2010b). Despite a growing body of scholarship illuminating such outcomes (e.g. Ford et al., 2008; O'Brien et al., 2004; Pouliotte et al., 2009), the production of knowledge examining links between climate change and human well-being in mountain regions, especially in least developed countries (LDCs), is lagging (Xu et al., 2009). Notwithstanding, there is increasing agreement that, because of climate change induced hydrological modifications, and given the often-marginalized nature of mountain populations, human communities in these regions may be some of the most vulnerable on the planet (Beniston, 2003; Huddleston et al., 2003; Viviroli et al., 2010; Xu et al., 2009). This study uses the 'vulnerability approach' to examine the relationship between climate change, hydrology, and human well-being in the mountainous Khumbu region of Eastern Nepal.

The sensitivity of mountain hydrology to climate change is increasingly recognized (Barnett et al., 2005; Messerli et al., 2004; UNEP, 2007; Viviroli et al., 2011). In a number of ranges (e.g. Himalayas, Andes, Alps), glaciers and snowfields comprise significant storage components of the water balance (Viviroli et al., 2007). Meltwater from these stores augments dry season river discharge, allowing communities to persist in otherwise water stressed regions (absolutely or seasonally) (Nesje and Dahl, 2000; Viviroli et al., 2011). However, globally observed reductions in glacier and snow cover—which are "strongly correlated with a significant rising trend in atmospheric temperatures"—are impacting this important function (Mark et al., 2010, p 795; UNEP, 2007). The viability of frozen stores is also related to the amount, state (solid or liquid), and spatial/temporal distribution of precipitation inputs (Singh and Singh, 2001).

While uncertainty about the localized effects of climate change on precipitation regimes exists (especially in mountain regions) (Beniston, 2003; Buytaert et al., 2010), there is agreement that the above-mentioned variables are likely to deviate from their historical trends this century (IPCC, 2007a). In addition to impacting glaciers and snowfields, precipitation changes modify hydrological processes at lower (i.e. inhabited) elevations where soil moisture, runoff, and stream flow (i.e. discharge) formation are related to rain and snowfall characteristics (P. Mool, personal communication, June 28, 2010).

Dependence on changing hydrological systems is not necessarily sufficient to impinge on human well-being. Where sensitivity to changes is minimal and/or the capacity to adapt to changing conditions is sufficient, human vulnerability to change is attenuated (Ford et al., 2006). However, given that 59% of the planet's mountain areas and 88% of mountain residents are found within LDCs (with their attendant socio-economic/political constraints), it is likely that these preconditions are not satisfied in a number of mountain communities (Huddleston et al., 2003). Nepal is illustrative of this general phenomenon.

Located between China and India on the southern flank of the Himalaya, the mountain nation of Nepal (81% mountainous) has been beset by political turmoil, persistent economic underdevelopment, and high levels of socio-economic inequality (Huddleston et al., 2003; Luitel, 2010; Macours, 2010); it ranks 138 of 169 countries on the 2010 United Nations Human Development Index (HDI = 0.516) (UNDP, 2010). Home to over twenty-nine million residents from 103 distinct castes and ethnic groups, the country is the poorest in South Asia and the twelfth poorest globally (2010 per capita income = $1,118 PPP) (Government of Nepal, 2001; Huddleston et al., 2003; World Bank, 2006, 2010a). Agricultural and pastoral livelihood activities support the majority of Nepal's economically active population with a corresponding 82% of the population living in rural/remote locations (World Bank, 2010a).

Despite a trend of modest economic growth, Nepal's weak government institutions, social stratification, and poorly developed/non-extensive infrastructure have precluded the equitable distribution of economic gains, leaving more than 50% of the population below the international poverty line (poverty headcount ratio at $1.25 per day (PPP)) (CIA, 2009; Sharma, 2009; World Bank, 2010a). Consistent with the situation observed in other mountainous LDCs (see Huddleston et al., 2003), a spatial correlation between the highest incidence and intensities of poverty and isolated mountain areas is evident (Hunzai et al., 2010). Providing some relief, however, mountain tourism has increased cash incomes in a few remote communities (Godde et al., 2000). Still, basic health, education, and sanitation facilities are absent or in short supply in many remote mountain areas (where 35% of Nepal's population reside) (Huddleston et al., 2003; Hunzai et al., 2010). Given Nepal's climatically sensitive mountain terrain and socio-economic/political conditions, it is likely that climate change will introduce stresses that exacerbate the country's already urgent human well-being challenges (Xu et al., 2009).

The mountainous Khumbu region of eastern Nepal is a distinct cultural and administrative unit within the rural Solukhumbu District. Accessible only by foot, the region is characterized by extremely mountainous terrain and its exceptional elevation range (2800m - 8848m) (Sherpa and Bajracharya, 2009). Within this dramatic landscape, ~3500 residents pursue a mix of agricultural, pastoral, and, more recently, tourism-based livelihoods (*ibid*.). The region enjoys international acclaim due to its iconic Sherpa culture and high altitude peaks—including Mount Everest. Still, most residents continue to subsist on minimal cash incomes and limited government services. Like residents of many remote mountain regions, Khumbu's population is expected to be adversely affected by climate change induced hydrological modifications (Beniston, 2003). However, empirical research explaining the nature of vulnerability and the pathways through which impacts manifest has been a consequential omission to date (Xu et al., 2009).

This study is based on two months of field research in Nepal (June 27 – August 22). Its objective is to identify and characterize for whom, in what ways, and for what reasons climate change induced hydrological modifications (might) pose a threat to human well-being in Khumbu. This aim is comprised of several specific targets:

- To employ place-based, mixed method (quantitative/qualitative) techniques—emphasizing stakeholder involvement—to identify locally relevant hydrological changes (exposure), subsequent effects (sensitivity), and responses (adaptive capacity)
- To use information obtained in four community level surveys to identifying region-wide vulnerabilities
- To generate results that are meaningful for decision-makers working at multiple scales

More broadly, the study seeks to advance understanding of climate change vulnerability and its determinants in mountainous contexts. To the authors' knowledge, this is the first systematic, region-wide assessment of human vulnerability to Khumbu's changing water resource dynamics.

This thesis is comprised of seven chapters. Following the Introduction, Chapter 2 presents the human dimensions of climate change research paradigm and discusses the 'vulnerability approach', which provides the theoretical framework of this study. Chapter 3 describes the physiographic, hydrological, climatic and socio-economic/political characteristics of Khumbu and the study communities sampled within. Chapter 4 details the methods used while Chapter 5 summarizes results. Chapter 6 provides a comprehensive discussion of the study's findings. A final chapter concludes.

Chapter 2: The vulnerability approach

This study is guided by the vulnerability approach of Ford and Smit (2004) and Ford et al. (2006), which comprises a specific conceptual and analytical approach within the human dimensions of climate change (HDCC) research paradigm. HDCC research is concerned with the human causes of climate change, the consequences of changes for individuals and societal groups, as well as the ways in which humans respond to changes. The field emerged in the late 1980's as a logical extension of early scientific congruence about the actuality of climatic changes (Ford et al., 2010). Today, findings illuminated by HDCC scholars provide essential commentary on the state of human well-being vis-à-vis observed and projected climatic changes (e.g. IPCC Working Group II).

2.1 Vulnerability assessment

Interdisciplinary by nature, HDCC research organizes around the concept of 'vulnerability' with vulnerability assessments accounting for a large share of literature to date (Ford et al., 2010; Janssen et al., 2006; Polsky et al., 2007). In the broadest sense, vulnerability assessments seek to understand how human well-being is affected by climatically driven biophysical changes (Eakin and Luers, 2006; Kelly and Adger, 2000). However, conceptions of vulnerability and the means of assessing it have evolved considerably since initial studies (Adger, 2006; Fussel and Klein, 2006). Whereas early 'first generation' assessments conceptualized vulnerability as a direct *outcome* of biophysical changes, more recent 'second generation' work posits that vulnerability is a *state,* which exists due to complex and dynamic socio-economic/political realities (i.e. non-climatic drivers); biophysical changes are mediated through these conditions (Ford et al., 2007; Fussel and Klein, 2006; O'Brien and Leichenko, 2000). To be sure, studies with leanings to the former persist (e.g. NAPAs), but a general trend toward

emphasis on social determinants of vulnerability is apparent (e.g. IPCC Working Group II) (Ford et al., 2010).

The changing nature of vulnerability assessments can be attributed to two parallel factors: the advancement of conceptual thinking within the disciplinary fields utilized by vulnerability scholars (e.g. geography, political economy, human ecology) and the evolving nature of extra-academy information needs (e.g. climate change policy development) (Patt et al., 2009). First generation research—drawing heavily on earlier natural hazards scholarship—has been termed 'top down' and 'impacts driven' because of its focus on modeling (and quantifying) the effects of projected biophysical changes *on* human communities (Ford et al., 2009). This work tends to be driven by the information needs of government bodies or other sizable institutions seeking large-scale appraisals of future impacts (e.g. US Country Studies) (Smith and Lazo, 2001). In these studies, vulnerability is an outcome related to the occupancy characteristics of communities with respect to the magnitude, frequency, onset attributes, and spatial extent of future biophysical changes (Ford and Smit, 2004); technical and engineering solutions are advocated (e.g. sea walls to protect low-lying communities). First generation assessments dominated the HDCC literature through the 1990's and clarified some of the ways future climate change might affect humans.

Despite important contributions, first generation studies have been criticized as too reliant on future projections of biophysical impacts in light of modeling uncertainties; as advancing *a priori* definitions of relevant biophysical risks at the expense of stakeholder relevance; and as excluding local residents from problem identification and solution development (see Burton et al., 2002; Ford and Smit, 2004; Smit and Wandel, 2006). As well, they have been described as overly focused on technical and engineering responses; as paying scant attention to the socio-economic/political elements of vulnerability; and—by conceptualizing vulnerability as an outcome of biophysical changes independent of the aforementioned elements—as failing to link

assessment methods and outcomes with actual decision-making processes (see Adger, 2006; Burton et al., 2002; Eakin and Luers, 2006; Ford and Smit, 2004; Fussel and Klein, 2006; Smit and Wandel, 2006). Attempts to address these issues by critically reconsidering the nature of vulnerability as well as the means of identifying and addressing it mark the entrance of second generation scholarship. The vulnerability approach of Ford and Smit (2004) and Ford et al. (2006)—which shares similarities with the work of Turner et al. (2003), Eriksen et al. (2005), Belliveau et al. (2006), and Smit and Wandel (2006)—is one influential model to emerge from this effort.

2.2 The vulnerability approach: conceptual framework

The vulnerability approach conceptualizes human vulnerability as a function of *exposure* to biophysical changes, *sensitivity* to exposure, and *adaptive capacity* relative to exposure-sensitivity (Ford et al., 2006). This conception indicates that the susceptibility of individuals, societal groups, and communities to harm will be differentiated based on their relationship to the socio-economic/political factors that reduce sensitivity and/or increase adaptive capacity (Ford and Smit, 2004). Here, vulnerability is not an outcome of direct biophysical changes but rather a context specific state that emerges as a result of the interplay between biophysical changes and existing social conditions (*ibid*.). Importantly, this nexus is "conditioned by social, economic, cultural, political, and climatic conditions and processes operating at multiple scales over space and time" (Ford et al., 2008). Additionally, and important in terms of policy relevance, this conception and terminology is consistent with that of the UNFCCC and IPCC.

Exposure is a characterization of a community's location relative to climatic stimuli: it defines whether biophysical changes intersect with inhabited areas and evaluates the nature (e.g. magnitude, frequency) of relevant stimuli (Ford and Smit, 2004). Exposure is also related to livelihood characteristics within the community, which can manifest as identifiable socio-

economic settlement arrangements (Ford et al., 2006). For example, land that is especially susceptible to biophysical disturbance (e.g. flood-prone) may be inexpensive, leading to a concentration of low-income residents in such areas. Differential exposure can result from dissimilar climate stimuli; however, non-climatic stressors (e.g. marginalization, inequality, poverty) have been shown to be the dominant factor in a number of community level studies (e.g. Ford et al., 2006; Pouliotte et al., 2009). Notwithstanding, at larger scales of analysis (e.g. Khumbu) the variability of climatic stimuli can be a salient issue (see Chapter 5).

Sensitivity is closely related to exposure and is an expression of the susceptibility of an exposure unit (e.g. community) to be harmed by biophysical changes (Ford et al., 2006; Smit and Wandel, 2006). The concept clarifies whether exposure is of consequence to the system in question. For example, in a community that is exposed to local water shortages but is relatively close to another reliable water source, able-bodied residents will be less sensitive given their ability to walk to the alternate water source; however, elderly residents may be highly sensitive to the exposure if they cannot access the source. Of relevance to this study, there is a generally recognized relationship between direct dependence on natural resources and an increased likelihood of exposure-sensitivity (IPCC, 2007b). Where exposure-sensitivity exists, coping with present challenges and/or planning for future threats becomes necessary (Ford et al., 2006).

Adaptive capacity is a measure of the degree to which a system is able to cope with or plan for the exposure(s) to which it is exposed and sensitive (Ford and Smit, 2004). Adaptations can be autonomous (i.e. occur without intervention) or planned (i.e. require informed and strategic action) (IPCC, 2007b). Effective adaptation (i.e. sufficient, comprehensive, and implemented) can ameliorate the otherwise negative impacts of climate change (and in some cases foster net gains) (McSweeney and Coomes, 2011; Smit and Wandel, 2006). For example, the vulnerability of a farmer who has high exposure-sensitivity to decreasing precipitation inputs

is attenuated if he or she has the capacity to access drought resistant seeds. While adaptation is a common response to exposure (Adger et al., 2009), research to date has shown that adaptive capacity is uneven within and between communities, households, etc. (due to factors such as age, sex, health, economic means, social status, social networks, access to decision makers, and risk perception) (e.g. Ford et al., 2008; IPCC, 2007b; O'Brien et al., 2008; O'Brien and Leichenko, 2003; Paavola and Adger, 2006). When adaptation is insufficient, vulnerability to exposure-sensitivities emerge (Ford and Smit, 2004). As such, identifying the adaptive capacity of exposure-sensitive populations is central to understanding the ways in which climate change vulnerabilities manifest in human communities (Smit and Wandel, 2006) (Figure 2.1).

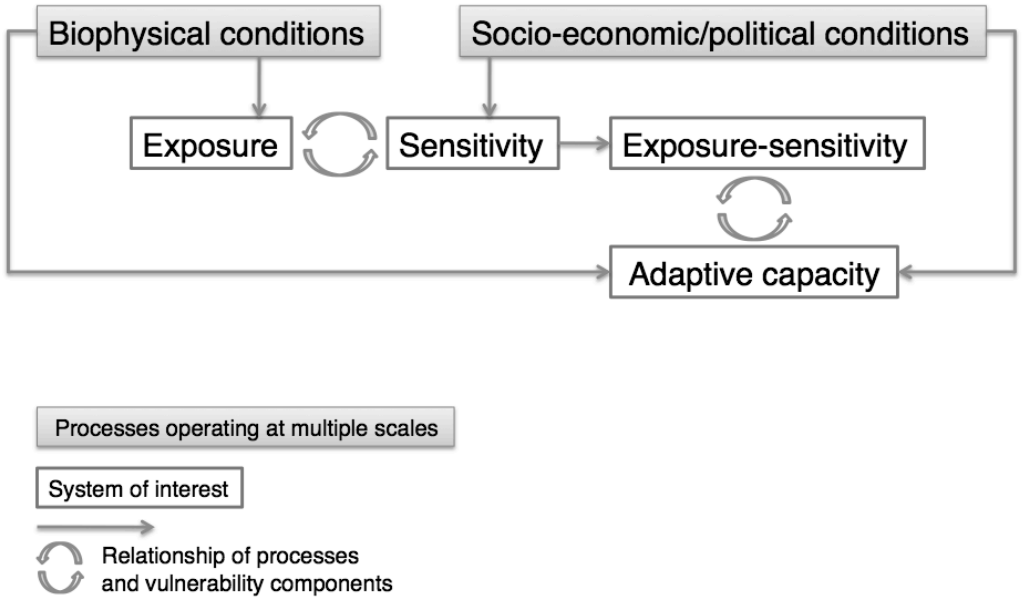


Figure 2.1: Conceptual Framework of the Vulnerability Approach

Overall goals of the vulnerability approach are to identify and characterize who and what are vulnerable to climatic exposures and why, to describe adaptive capacity and its determinants, and to identify current and future vulnerability and ways of redressing it (Ford et al., 2010). Meeting these aims requires grounding the model's conceptual components in an actionable framework.

2.3 The vulnerability approach: analytical framework

The analytical framework of the vulnerability approach is premised on the idea that the climatic and socio-economic/political factors affecting exposure, sensitivity, and adaptive capacity today will be similar in kind to those of import in the future (note: this is not to say that these factors will not change but rather that there is a greater likelihood that these factors will matter more than factors not currently relevant to the community) (Ford et al., 2006; Glantz, 1996; McLeman and Hunter, 2010). Assessments, then, seek to gain contextualized information about past and current responses to climatic stimuli as an empirically based means of identifying current and future vulnerabilities as well as opportunities to reduce vulnerability—a method known as temporal analogue (Ford et al., 2010; Glantz, 1996). Analytically, vulnerability assessments in this model can be broken into two stages.

During the first stage, efforts are made to identify the climate stimuli to which community members are exposed and sensitive, to characterize how community members experience and manage these exposure-sensitivities, and to identify the factors that influence exposure-sensitivity and evaluate the efficacy of past and present adaptations (Ford et al., 2008). Given the place specific nature of these aims, assessments typically focus on local-scales (i.e. households, communities, and regions) and stakeholder collaboration (Ford and Smit, 2004; Pearce et al., 2009; Smit and Wandel, 2006; Tremblay et al., 2008).

Local stakeholders possess otherwise unattainable insights about the dynamic equilibrium of socio-economic/political realities and local environmental conditions (Ford and Smit, 2004; Smit and Wandel, 2006); where scientific assessments of environmental change are minimal, of short duration, or absent, the importance of stakeholder knowledge is redoubled (e.g. Khumbu). Because the relationship of the above factors constrain or support adaptive capacity, local observations are critically important for understanding the conditions from which vulnerabilities

emerge (Ford and Smit, 2004; Furgal, 2005; Smit and Wandel, 2006). As well, involving residents brings stakeholders into the process of knowledge production, which will ultimately represent their experience of climatic changes. For these reasons, working with local stakeholders is essential for meeting stage one objectives.

The second analytical stage assesses future vulnerability by evaluating directional changes of exposure-sensitivity as well as the factors that influence adaptive capacity (Ford and Smit, 2004). In practice, system relevant factors are examined in relation to projections of future climate change (e.g. based on GCMs) and/or theoretical models of socio-economic/political change (Ford et al., 2008). While the vulnerability approach cannot remove the inevitable uncertainties of future projections (Patt et al., 2005), it is significant that the variables examined will at the minimum be relevant to the system considered. Similarly, that information about adaptive capacity is based on system relevant options and limitations makes identifying viable capacity building opportunities more realistic. In combination, the two stages provide an actionable means of identifying and characterizing who and what are vulnerable climatic exposures and why (first stage), of describing adaptive capacity and its determinants (first stage), and of identifying future vulnerability and opportunities for its amelioration (second stage). Critical to the last point, the ownership and recognized relevance of research outcomes achieved by involving stakeholders in vulnerability assessments greatly enhances the efficacy of resultant capacity building efforts (Ford et al., 2007; Tremblay et al., 2008).

The first stage of the analytical framework provides critical base-line information; logically it must precede the second stage. The point is particularly relevant to this study. While some vulnerability assessments have been conducted in Khumbu, almost all have focused on vulnerability to glacial lake outburst floods (GLOFs) (Bajracharya and Mool, 2009; Birendra et al., 2007). Because such work has typically relied on top down methods based on biophysical

modeling, GLOF research has contributed only modestly to the understanding of the exposure-sensitivity and adaptive capacity of Khumbu residents, and only in relation to low frequency, high magnitude flood events. That there have been no peer-reviewed studies explicitly examining the relationship between changing water resource dynamics and human well-being is consequential in regard to this study's analytical structure. Given the paucity of base-line information it follows that a vulnerability assessment of the region must prioritize the aims of the first analytical stage. As such (given time and resource constraints), the study does not explicitly examine future scenarios; however, empirically based and literature-supported hypotheses about future exposure-sensitivity and adaptive capacity are discussed in Chapter 6.

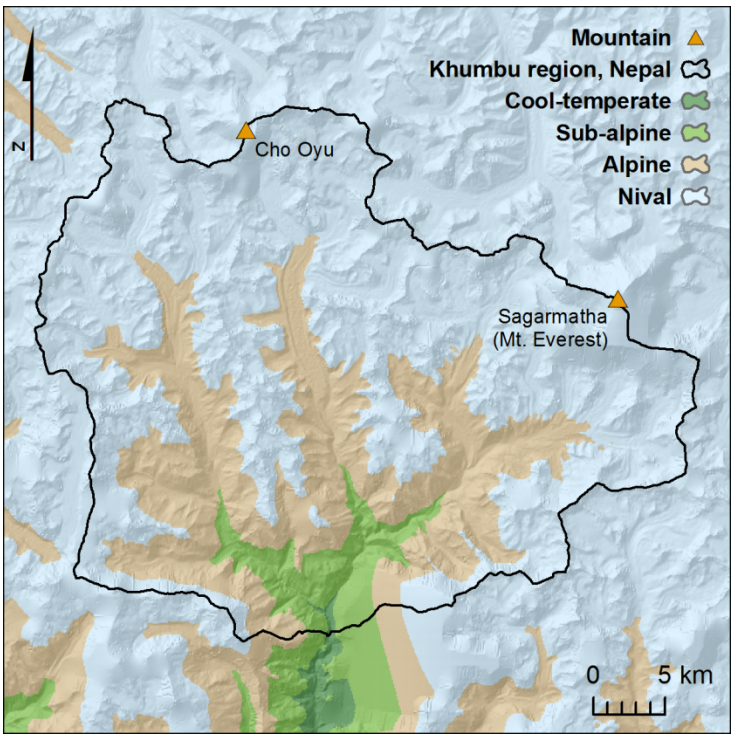
HDCC research has played a crucial role in elucidating the multifaceted relationships between climate change and human well-being. And in focusing on the concept of vulnerability, the field has helped recast impacts in human terms. Vulnerability assessments have been the harbinger of this transformation; however, as shown assessment methods have evolved considerably since the field emerged in the late 1980's. Though the vulnerability approach benefited from earlier conceptual and analytical advancements, its prioritization of depth of understanding (including dynamic, multi-scale processes and conditions), local stakeholder involvement, and nuanced responses to harmful impacts marks a notable departure from earlier assessment approaches. Moreover, that the vulnerability approach leads to information that is contextually relevant yet commensurate with the terminology and objectives of the principal climate change institutions (e.g. UNFCCC, IPCC) enhances its relevance. Considering these advantages, and given the objectives of this study, it is concluded that the vulnerability approach provides a robust theoretical foundation for examining the human dimensions of climate change in the Khumbu region of Nepal.

Chapter 3: Khumbu in context

The effects of global climate change on human systems are the result of its dynamic interaction with specific geographic and social contexts. Understanding the implications of this nexus requires place-based research (Ford et al., 2009). Localized assessments are especially important for remote mountain regions like Khumbu where the hydrological effects of climate change and the socio-economic/political conditions through which they manifest are poorly understood.

3.1 Khumbu: geography, hydrology, and climate change

The Khumbu region (~28˚6' N, 86˚42' E) is located in northeast Nepal approximately 140 km from the capital city of Kathmandu. The region occupies 1,100 km^2 of extremely mountainous terrain with a rugged topography and climate that has precluded extensive infrastructure and settlement development (Stevens, 1993). Still, since their migration from Tibet some 500 years ago, Sherpa residents have adapted to, and survived in, Khumbu's demanding environment (Sherpa and Bajracharya, 2009). To the north, the region is bound by the Khumbu-Himal and the towering summits of Mount Everest (8848m) and Cho Oyu (8201m), to the south by the Numbur-Kantega range, and to the east and west by jagged ridgelines linking the two. Khumbu's physiography represents the most dramatic elevation gradient on the planet, rising 6048m from south to north in less than 40km (*ibid*.). This towering landscape is incised by three major river valleys, which drain the region of glacier and snow melt as well as liquid precipitation inputs. These valley's and their respective perennial rivers are the Bhote Kosi, the Dudh Kosi, and the Imja Khola. The confluence of these rivers at Larstsa Doban (2,800m) marks the southern limit of the region (Map 3.1).



Map 3.1: Major Geographic Features and Bioclimatic Zones of Khumbu

Khumbu can be divided into four major bioclimatic divisions: a cool-temperate zone, a sub-alpine zone, an alpine zone, and a nival zone (Sherpa and Bajracharya, 2009). These zones are delineated as a function of elevation and to a lesser extent, slope aspect (Thapa and Shakya, 2008). The cool-temperate zone (2,800 – 3,000m) comprises a very small proportion of the region (~2%) but boasts the highest flora and fauna diversity due to mild temperatures and moist conditions. The conditions are also conducive to diversified agriculture; however, steeply inclined V-shaped valleys at lower elevations limit such activity. The sub-alpine zone (3,000 – 4,000m) comprises a narrow band that traces the region's major valleys; it accounts for ~ 8% of Khumbu's land area and is home to most of its residents. Here natural sub-alpine forests of rhododendron, pine, fir, and birch are interspersed with settlements, cultivated plots, and rangeland. The zone is subject to < 0˚C winter temperatures and resultant snow cover. About 31% of Khumbu is characterized as an alpine zone (4,000 – 5,000m). The zone's cold, dry, and

windy climatic conditions produce a treeless landscape covered in stunted vegetation; precipitation falls as snow in winter and during cold spells in summer. The zone plays a crucial role in livestock grazing, and, increasingly, tourism-based activities/livelihoods (e.g. high altitude trekking). The nival zone (>5,000m) covers ~ 58% of Khumbu and is characterized by bare soil, rock, and snow as well as copious reserves of glacial ice (Sherpa and Bajracharya, 2009).

Khumbu's hydrology is dominated by the Indian Monsoon and the temporal redistribution effects of glacier and snow melt (Thapa and Shakya, 2008). Precipitation inputs to Khumbu are concentrated in the summer months (June-September) when the northward shift of the Intertropical Convergence Zone (ITCZ) pulls heavy monsoon rain and snowstorms into the area (*ibid*.). Monsoonal inputs comprise a large proportion of Khumbu's annual precipitation (~75 – 85%). Winter precipitation (January - March) occurs due to orographic forcing of mid-latitude westerlies; the snow water equivalent of winter snowfall is comparably small (Lang and Barros, 2004). Annual precipitation in Khumbu ranges from over 2500mm in the cool-temperate zone to less that 500mm in the alpine and nival zones (Thapa and Shakya, 2008). Though inter-regional precipitation patterns vary as a function of elevation and topography (and inter-annual inputs differ markedly), the region as a whole is considered relatively moist (Salerno et al., 2008).

Both snow and glaciers function as fresh water reserves which redistribute precipitation inputs across a range of temporal scales (Jansson et al., 2002). This aspect of Khumbu's hydrology is critical given the dependence of communities on meltwater to augment dry season (April - May, October - December) water needs (Stevens, 1993). As of 2001, Khumbu had 278 glaciers, which covered 482km^2 (~44% of the region) and represented 51km^3 of ice (Mool et al., 2001). Maximum glacial accumulation (i.e. snowfall) occurs in the nival zone during the summer, however, because temperature peaks coincide with monsoon inputs, these 'summer accumulation type' glaciers undergo peak ablation and accumulation within the same season

(Ageta and Higuchi, 1984). Snow cover is seasonally variable but can extend below 3,000m (Thapa and Shakya, 2008). While the volumetric contribution of glacier and snow melt to discharge is greatest in summer, the relative contribution of melt is much greater during the dry seasons (Thayyen and Gergan, 2010). In all seasons, the meltwater proportion of discharge is greater at higher elevations where accumulated rainfall and groundwater inputs are relatively small (Mark and Seltzer, 2003; Sharma et al., 2009). Annual discharge data is only available for the Imja Khola river, which has an average discharge of ~ 3500 l/s (Thapa and Shakya, 2008 citing Nepal Department of Hydrology and Meteorology statistics). The river's peak flow occurs in August (~ 8700 l/s) while its minimum flow occurs in February (~1020 l/s) (*ibid*.). Assuming that discharge from the Bhote Kosi and Dudh Kosi is similar (which seems reasonable given the comparable catchments and morphology of each), average discharge from Khumbu is ~10500 l/s.

The localized effects of climate change on Khumbu hydrology are poorly understood (Sharma et al., 2009). Research to date has frequently aggregated Khumbu with other eastern Himalayan regions to assess the effects of Himalayan glacial change on extra-regional waterways and residents (e.g. Babel and Wahid, 2008; Immerzeel et al., 2010; Lal, 2005). The work has commonly relied on hydrological models based on GCMs and assumptions that may not reflect the actual influence of climate change on Khumbu's unique glacial environment (Thayyen and Gergan, 2010). The few regionally specific and empirically grounded studies that have been completed tend to focus on glacial coverage change (not the implications of spatial/volumetric changes on discharge regimes) and the formation of potentially dangerous glacial lakes. Indicative of Nepal's limited financial capacity and Khumbu's complex mountain terrain, the region's meteorological and hydrological observation network lacks the temporal scope and spatial density needed to derive definitive precipitation, temperature, and discharge change conclusions (Fujita et al., 2006; Sharma et al., 2009). Insufficient instrumental capacity remains a

major obstacle in understanding and quantifying the effects of climate change on Khumbu's hydrology (Hannah et al., 2005).

Despite limited meteorological and discharge data, glacial change can be used as a secular proxy for climate change: temperature and precipitation are key determinants of mass balance as well as variables affected by climate change (M. Baraer, personal communication, September 15, 2010). Viewed as such, and given the rapid retreat and down wasting of many Khumbu glaciers, it is well documented that Khumbu's climate is changing (Xu et al., 2009). Bajracharya and Mool (2009) examined the spatio-temporal change of Khumbu's glacial coverage by comparing topographic maps (1960s) and satellite images (i.e. Landsat Multispectral scanner, Landsat TM, Landsat Enhanced TM Plus, and Advanced Land Observing Satellite); they found recession rates of 10 - 59 m/yr for most of the region's glaciers since the 1960s. The rate of retreat has accelerated since 2000 (up to 74 m/yr) suggesting an amplified temperature increase and/or precipitation decrease (*ibid*.). Since the 1960s, glacial retreat has led to the formation of 24 glacial lakes: 12 potentially dangerous (*ibid*.). Though field-based termini position and mass-balance studies are few (Bolch et al., 2010), in-situ studies have confirmed Bajracharya and Mool's observations (e.g. Byers, 2008; Kadota et al., 1997; Kadota et al., 2000). Glacial recession and shrinkage as well as glacial lake formation are conspicuous indicators of climate change; however, emphasis on these aspects of change may be overshadowing other hydrological modifications (e.g. snow cover change) of importance for Khumbu's population.

3.2 Khumbu: socio-economic/political characteristics

In many regards, socio-economic/political data about Khumbu is limited (Korner, 2009). Accordingly, the remainder of this chapter synthesizes information from published sources and information obtained from stakeholders in Khumbu and Kathmandu.

Khumbu is home to approximately 3,500 residents; 90% are Sherpa while the remaining 10% are migrants from the Rai, Tamang, Brahmin, and Chherti ethnic groups (Sherpa and Bajracharya, 2009; Stevens, 1993). Over 95% of the population is Buddhist and 'geomantism' (e.g. deification of mountains) is a foundational component of peoples' identity and sense of place (Sherpa and Bajracharya, 2009; Spoon, 2009; Stevens, 1993). The sex ratio for the region is roughly equal, but a marginally higher proportion of women is suspected by residents and supported by the findings of a 2001 Solukhumbu district census (i.e. + 2.44%) (ICIMOD/CBS, 2003). Community leaders noted that 'middle-aged' (20 - 45) residents comprise a slight majority (but the out-migration of youth probably shapes this age structure). For the period 1991 - 2001, the population growth rate was 10%, however, since this value is inclusive of in- and out-migration, birth rate trends remain uncertain (Sherpa and Bajracharya, 2009). Average household size is approximately five persons.

Khumbu has 63 settlements spanning elevations from 2,805m (Jorasalle) to 5,170m (Gorak Shep) (Sherpa and Bajracharya, 2009). Of these, only seven are considered major year-round villages: Namche, Thame/tang, Thamo, Khumjung, Khunde, Phortse, and Pangboche (Stevens, 1993). Khumbu's settlements are defined by their bioclimatic location (*ibid*.). Permanently occupied mid-elevation settlements (those listed above) are referred to as 'Yul'. These largest of Khumbu settlements are comprised of approximately 80 - 170 households. Smaller seasonal settlements are referred to as 'Yersa' (high-elevation summer place) and 'Gunsa' (low-elevation winter place), respectively (*ibid*.). Yul are located in the sub-alpine zone on alluvial terraces above the region's major rivers; Yersa are dispersed at higher elevations in the expansive alpine and lower nival zones; and Gunsa are found on pieces of terraceable land in the deep valleys of Khumbu's cool-temperate and lower sub-alpine zones (*ibid*.). As livelihood

opportunities change (i.e. tourism), some Yersa and Gunsa are becoming year-round communities (e.g. Pheriche) (Sherpa and Bajracharya, 2009).

Livelihoods in Khumbu are based on three activities: agriculture, pastoralism, and/or tourism (Sherpa and Bajracharya, 2009). The former follow an agropastoral system characterized by multi-elevational, seasonally determined cropping and grazing patterns (Stevens, 1993). The system is adapted to the inherent limitations and fragility of Khumbu's mountain environment and accounts for the establishment of Yersa and Gunsa settlements (*ibid*.).

Agriculturalists grow a limited number of hardy crops capable of surviving Khumbu's harsh environment: potatoes, buckwheat, and barley are ubiquitous subsistence staples (Sherpa and Bajracharya, 2009). Maize and wheat are grown in Gunsa whereas hay production is concentrated in Yersa (Stevens, 1993). Fields for these crops are non-irrigated and reliance on precipitation is absolute (Shrestha and Aryal, 2011). For agriculturalists, crops have two critical roles: providing household sustenance and generating cash income. Whereas most households in Khumbu (including those involved in other livelihood activities) grow the majority of the food they consume, for agriculturalists, selling excess yield provides access to cash income for goods not produced by the family (e.g. shoes). The influx of tourists, their preference for dietary variety, and their ability to pay, has compelled some agriculturalists to plant non-traditional, water intensive crops, which have higher cash returns. Small-scale irrigation is required for many of these poorly adapted varieties.

Pastoralists engage in transhumance practices with yak (male) and nak (female), cattle, and yak/cow hybrids (Sherpa and Kayastha, 2009). In the summer, livestock are grazed in highland pastures; they are brought to lower elevations once winter snowfall covers alpine and nival zone rangeland (Stevens, 1993). Pastoralists and their livestock provide a number of income generating goods and services. Goods include dairy products and wool (for clothing, etc.); naks

are preferred for these items (Sherpa and Bajracharya, 2009). Yaks (and other male livestock) play an important role in transporting goods, with income generation from expedition support services being an important activity (Sherpa and Kayastha, 2009).

In 1953 Tenzing Norgay and Sir Edmund Hillary made the first ascent of the world's tallest peak: Mount Everest. Their feat, and Hillary's subsequent praise of the region's culture and landscape, created considerable international interest in Khumbu (Sherpa and Bajracharya, 2009). Today, approximately 30,000 foreigners visit the region each year (*ibid*.). As a result, many households are directly or indirectly involved with tourism. Common activities include lodge ownership, the operation of guide services, and the management of small tourist-focused shops; expedition climbing and trekking support services (e.g. climbing guide, porter, cook) are common income generating activities for many male residents. The influx of tourism dollars is also a clear pull factor for migrant workers. Despite income generating opportunities, history has shown that the stability of tourism-based livelihoods is highly sensitive to extra-regional economic and political factors (*ibid*.)

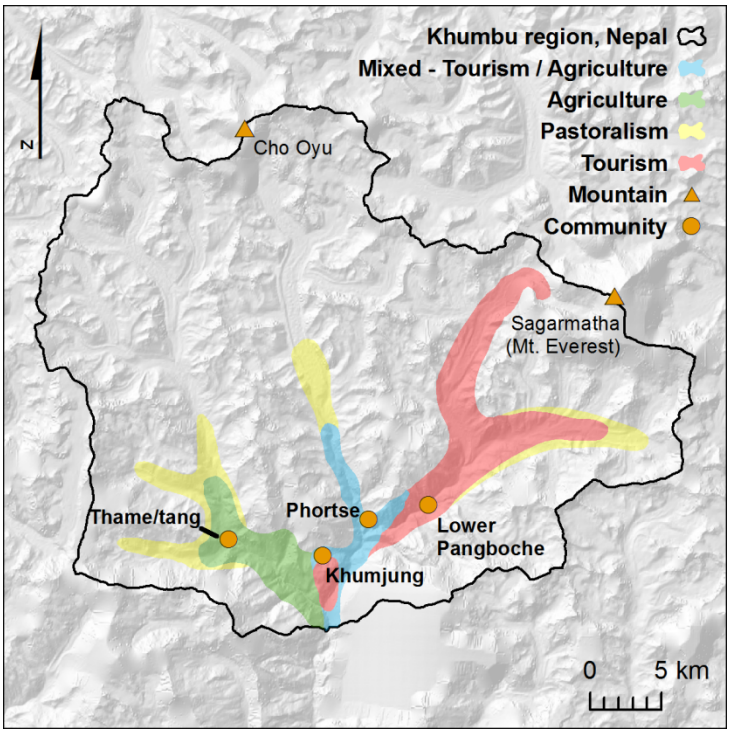
In 1960, Sir Edmund Hillary established the Himalayan Trust to bring education, health facilities, and infrastructure development to Khumbu (Himalayan Trust, 2008). The organized efforts of the Trust have been accompanied by many sporadic aid projects, no doubt conceived through the interaction of residents and tourists (and necessitated by the failure of the central government to provide development assistance) (see Luitel, 2010 for contextual discussion). The Trust, the influx of tourism, and the ability of residents to attract foreign aid have enabled many communities to gain a degree of development (e.g. increased health outcomes, larger incomes, and access to education) not seen in other mountain settlements of the eastern Himalaya (P. Mool, personal communication, June 28, 2010). Notwithstanding, these benefits have not been accrued evenly across Khumbu; communities along the popular trekking routes (i.e. trail to

Everest base camp) have seen the most opportunity and resultant social change (HKKH, 2009; Sherpa and Bajracharya, 2009). As a consequence of foreign influence, an inter-regional pattern of dominant livelihood activities is evident with resultant socio-economic inequality significant and growing (Stevens, 1993). In this regard, the proclaimed 'success' of Khumbu's development is preemptive (e.g. Sacareau, 2009); visitors seldom travel to non tourism-based areas (e.g. Bhote Kosi valley), precluding their awareness of concurrent poverty.

Khumbu has a nested management structure that merges institutional and traditional approaches. In 1976, the region was designated as Sagarmatha National Park by the government of Nepal; the park is primarily concerned with conservation issues (see DNPWC, 2006). Given this focus, policies have at times conflicted with local customs (e.g. fuel wood harvesting). A 'Buffer Zone' system was initiated in 2002 to address this discord by ensuring the "long term protection and maintenance of biological diversity, while providing…a sustainable flow of natural products and services to meet community needs" (Spoon, 2009). The buffer zone encompasses all inhabited areas, wherein communities are permitted to follow traditional decision-making and land management practices (*ibid*.). It also gives residents a voice in regional planning and provides access to funds for community development projects (50% of park entrance fees) (B. K. Dhakal, personal communication, July 19, 2010). The system has been well received and is regarded as an effective way for residents to interact with the National Park. In spite of this, the central government is not considered an accessible decision-making body and the lack of state funding/support is a source of tension. Adding an international, though mostly symbolic, element to Khumbu's management, Sagarmatha National Park was inscribed as a World Heritage Site in 1979 in recognition of its "superlative natural phenomena [and] unique cultural traditions" (UNESCO, 2007).

3.3 Study communities

This project uses place-based methods to identify region-wide vulnerabilities with respect to climate change induced hydrological modifications. As such, working in settlements that were identified by stakeholders as significant at the regional scale but also representative of the unique socio-economic/political dynamics of their location within Khumbu was essential. Interviews were conducted in four Yul settlements to assess the exposure, sensitivity, and adaptive capacity of residents living therein. Communities are described geographically from West to East, which, with the exception of Khumjung, coincides with a pattern of less to more tourism-based livelihood activity (Map 3.2).



Map 3.2: Study Communities and Livelihood Zones

3.3.1 Thame/tang

The twin settlements of Thame (lower) and Thametang (upper) are located at ~3,880 and ~3,840m, respectively. They are situated in the seldom-visited Bhote Kosi valley and are divided

by a large lateral moraine. Thame is situated at an off-camber bend of the relatively small Thame Khola River; Thametang is positioned high above the main channel of the Bhote Kosi. Thame has a slightly larger population (~245 vs. ~240 persons). Despite these differences, the settlements are considered culturally and administratively synonymous; approximately 90 households are in evidence.

The Bhote Kosi valley was formerly an important salt trading route with Tibet (via Nangpa La pass). However, with the subsequent decline of the salt trade (1960s) and the longtime closure of the valley to foreigners (border security concerns), trade-based livelihoods have vanished and tourism-based activity has been limited (Sherpa and Bajracharya, 2009). Agricultural and pastoral livelihoods dominate economic activity though a limited number of small tourist lodges are present (Figure 3.1).

Figure 3.1: Thame (left) and Thametang (right)

3.3.2 Khumjung

Khumjung is located on a high saddle (~ 3,790m) well above the confluence of the Bhote Kosi and Imja Khola valleys; it is the most populated settlement in Khumbu (~816 persons, ~170 households). The most significant Hillary Trust development projects have been concentrated in Khumjung (e.g. the Khumjung School and Khunde Hospital) and countless visitors pass through

the community each year. Together, these factors have given residents the human capital and access to visitors needed to pursue tourism-based livelihoods. However, the economic gains of this coincidence are producing a complex social mosaic whereby a hierarchical class structure between the local residents and temporary workers (which wealthier residents sometimes hire to carry out menial tasks) is emerging. Along with the in-migration of temporary workers, wealthier residents often choose to migrate out of the settlement during the 'off-seasons' (winter and summer). As a backdrop to Khumjung's socio/economic development, agriculture remains an important livelihood activity for many residents. The educational and health services found in the Khumjung are important resources for the entire region (though they are less accessible to distant communities) and help secure the settlement's place as an important regional center (B. K. Dhakal, personal communication, July 19, 2010) (Figure 3.2).

Figure 3.2: Khumjung

3.3.3 Phortse

Phortse is located on a high terrace (3840 m) above the Dudh Kosi and Imja Khola rivers. It has a population of ~ 416 persons (~80 households) and is the main settlement in the Dudh

Kosi valley. Despite being proximal to the Everest trekking route, tourism has lagged because access requires a steep ascent up non-serviced trails. The Khumbu Climbing School—which trains men (predominantly) from throughout Khumbu in expedition climbing skills—is located in Phortse. Thus, while agriculture is the most discernible livelihood activity (i.e. lack of tourist lodges), there is a relatively high concentration of mountaineering and trekking guides in the community. Phortse is illustrative of the socio-economic characteristics that emerge when 'traditional' and 'modern' livelihood strategies are of similar importance (Figure 3.3).

Figure 3.3: Phortse

3.3.4 Lower Pangboche

Lower Pangboche (3,890m) is located 5km northeast of Phortse on a small plateau above the Imja Khola River. Approximately 150 residents fill about 28 households. The settlement is located directly on the trail to Everest; consequently, livelihoods are highly tourism dependent with perhaps three-quarters of all buildings having tourism related components (e.g. lodge, tea shop, etc.). However, residents without tourism related infrastructure are still involved in the industry. Examples include, trekking guides, those selling agricultural goods to lodges, and

pastoralists who provide transportation services to expeditions. Like Khumjung, migrant workers are attracted to Lower Pangboche because of economic opportunity. Overall, Lower Pangboche is indicative of the dramatic socio-economic transformations brought about by heavy dependence on tourism-based livelihoods (Figure 3.4).

Figure 3.4: Lower Pangboche

This chapter presented the unique geographic, hydrological, and/or socio-economic/political characteristics of Khumbu and the study communities contained therein. It is apparent from the paucity of available information, that characterizing the effects of hydrological change on human well-being is not possible from afar. Place-based research incorporating the local/traditional knowledge of residents provides a more tenable means of explicating this socio-ecological relationship. Actualizing the benefits of place-based research, however, requires the application of a systematic yet contextually sensitive assessment method.

Chapter 4: Methods

To procure information about the contextually specific nature of climate change vulnerability in Khumbu, a mixed method approach utilizing quantitative and qualitative techniques was developed and applied. Stakeholder input was central and informed the creation of a questionnaire to identify locally relevant water issues as well as the physical characteristics and social effects of current hydrological changes. Stakeholders also informed aspects of the project's study design and application, ensuring that both were cognizant of important social mores. Coupled with systematic procedures, involving stakeholders in the questionnaire and study design process as well as research activities improved researcher/participant relations and the quality of subsequently obtained information regarding exposure, sensitivity, and adaptive capacity.

4.1 Questionnaire content and development

The results of this study are based largely on information obtained through the application of a standardized questionnaire. Closed-choice and semi-structured, open-ended questions were included to glean the benefits of quantitative and qualitative assessment methods (and to minimize the disadvantages of relying on either alone); questions were informed by the vulnerability approach outlined in section 2.2. Closed-choice questions permitted large amounts of information to be gathered in a timely manner, the quantification of basic participant information and observations, and the ability to infer community findings to the regional scale. Open-ended questions provided follow up information to close-ended question responses, allowed the inclusion of enquiries where *a priori* assumptions of possible answers were not appropriate, and encouraged participants to add depth and detail to the questionnaire's foci. Questions were coded with numerical and alphabetical characters for later analysis (Tables 4.1 and 4.2).

Table 4.1: Closed-Choice and Open-Ended Question Example

In general, are there times when there is too little water available to meet your needs?

0. No
1. Yes
    a. **When (select all that apply)?**
        1. All year
        2. Spring
        3. Summer
        4. Fall
        5. Winter
    A. **Please briefly explain how you are affected in times of too little water**

    B. **Please briefly explain what you do to make it through times of too little water**

* *See Appendix A for complete questionnaire*

Table 4.2: Components of Vulnerability as Assessed Through Questions

Component of vulnerability	**Sample question**
Exposure	Where does the water that you use come from?
Sensitivity	Have current hydrological changes affected you?
Adaptive capacity	What do you do to make it through times of too little water?

Questionnaire development drew on information from multiple sources. Its foundation was an extensive literature review, which provided familiarity with the vulnerability approach as well as eastern Himalaya vulnerability research to date; it helped identify human vulnerability to changing water resource dynamics in Khumbu as an important knowledge gap in both research domains. Subsequent e-mail correspondence with Nepal-based researchers and consultation with Dr. James Ford initiated tentative question generation. A review of conventional and critical questionnaire development literature was completed with special attention paid to considerations for LDC assessments (e.g. Boynton et al., 2004; UN DESA, 2005). Specific questionnaire development began in Nepal where direct stakeholder consultation was possible. However, due to practical limitations of accessing Khumbu prior to initiating the study (time, money, weather), it

was necessary to complete the questionnaire in Kathmandu. Available options were pursued to minimize the introduction of bias resulting from this situation (see below).

In Kathmandu, a number of formal meetings were carried out with researchers, government officials, and Khumbu residents (residing in Kathmandu). Researchers with experience working in Himalayan communities gave feedback on tentative questions, suggestions for content inclusion and/or exclusion, and practical advice for the questionnaire's structure. Government officials indicated information needs with regards to climate change vulnerability, which informed question inclusion and enhanced the questionnaire's (potential) policy relevance. In addition, Khumbu residents played a central role in identifying and addressing bias and confirming that questions were relevant, understandable, and culturally appropriate. The questionnaire was piloted with two Sherpa and one Solukhumbu resident in Kathmandu.

4.2 Sample design

To administer the questionnaire, a Khumbu-specific sample design was developed, which prioritized obtaining a representative and non-biased survey from the sampled area/population; its basic elements are summarized below (Table 4.3):

Table 4.3: Basic Elements of Sample Design

Study element	Designation
Target area	Inhabited areas of Khumbu
Study area	Inhabited areas of Khumbu
Sample area	Four sample communities within inhabited areas of Khumbu (stratified non-random selection)
Target Population	All residents of Khumbu
Study Population	Four sample communities
Sample Population	One adult (18 and over) from every n^{th} house in sample communities (stratified random selection)
Objective	80 interviews (20 from each study community)

Given the variability of Khumbu's settlement characteristics, a stratified non-random selection criteria was used to achieve a representative *sample area/study population*. Through review of Steven's (1993) seminal *Claiming the High Ground: Sherpas, Subsistence, and Environmental Change in the Highest Himalaya* and meetings with stakeholders in Kathmandu and Khumbu, the geographic location (i.e. three main Khumbu valleys and one regional center), population size (i.e. Yul), and livelihood attributes (e.g. primarily tourism) of settlements were identified as important stratification criteria. Within this specification, multiple stakeholders selected/confirmed Thame/tang, Khumjung, Phortse, and Lower Pangboche as communities which together represent the unique geographic and socio-economic characteristics of Khumbu. A stratified (age and sex) random *sample population* strategy was chosen for selecting study participants to ensure representative age/sex balance and impartiality in the study's dataset; stratification and randomization procedures are described in the following section. An objective of twenty interviews per community was selected to assure sufficient statistical power and qualitative information for subsequent analysis.

4.3 Procedures

Fieldwork was undertaken in Khumbu from July 17th - August 11th inclusive (28 days). Because residents speak Sherpa and/or Nepali, identifying a competent interpreter was critical. Regional leaders recommended Ang Dawa Sherpa (of Namche, 3,440m): a college graduate fluent in the requisite languages (among others). Dawa's capabilities were confirmed during pre-study interviews (which clarified the study's objectives and methods) and subsequent procedural trainings (e.g. ensuring impartiality). Hiring an interpreter from Khumbu—but not from a study community—allowed the utilization of the interpreter's local knowledge and credibility while limiting the potential effect of response bias due to unforeseen interviewer/respondent conflicts of interest.

The same systematic procedures were followed in each sample community. Upon arrival, community leaders (e.g. mayor) were identified and contacted. Meetings were arranged to inform of the study's activities and to gather baseline information about the community's population and household numbers as well as sex and age ratios. Time was spent confirming information through community observation (e.g. walk-throughs); if deviations were observed (rare), additional community members were consulted until reported and observed values were reconciled. Household numbers were always double counted, as this value was central to the study's sampling method.

Because Khumbu settlements do not have standardized road/address housing configurations, a contextually appropriate randomization procedure had to be developed. A simple equation was devised to identify which households would be sampled:

$$s = H/20 + h$$

Where *s* is the household sampling interval, *H* is the total households and *20 + h* is the interviews required plus a subjective non-response/adequate spatial coverage variable. The subjective nature of *h* did not affect randomization; rather it addressed the fact that interviews would not be obtained at every household and that a spatially concentrated sample may result without the variable. Given relatively small settlement sizes, *h* value flexibility was limited (i.e. must result in a whole *s* value), however, it is believed that the values used were appropriate and effective (Table 4.4). Once the community specific *s* value was calculated, the interpreter was asked to 'randomly' select a house in the community. Concurrently, the researcher thought of a number between 1 and 5. From the interpreter-selected house, a house *n* places away (i.e. researcher's pre-selected number) was located; this house marked the beginning of the sample.

Table 4.4: Household Selection Statistics

Settlement	Number of houses	h	s
Thame	~ 50 houses	2.5	every 4th house
Thametang	~ 40 houses	3.3	every 3rd house
Khumjung	~ 170 houses	1.25	every 8th house
Phortse	~ 80 houses	6.6	every 3rd house
Pangboche	~ 28 houses	8	every house

* Thame and Thametang household sample values calculated independently

With representative sex and age proportions known, stratification objectives were delineated for each community (e.g. 3 men 18-25, 5 men 26-45, 2 men ≥ 46). Thereafter, interviews were attempted with the individual that opened the door at every n^{th} house (note: typical inter-household LDC selection methods (e.g. birthday closest to interview date) were not appropriate (e.g. birthdays not known)). This procedure was followed until stratification objectives began to saturate. Selective interviewing was then initiated to ensure stratification aims. Initially, the same sampling procedure was followed but only when an individual fitting the needed criteria opened the door was an interview attempted. Once this strategy became redundant (i.e. encountering the same house twice), a second strategy was pursued. Individuals who opened the door (who did not fit the needed stratification criteria) were asked if individuals meeting the stratification criteria were available to speak (e.g. male individual between 18 and 25). If multiple suitable individuals were available, and none volunteered to speak, the interpreter would 'randomly' invite one to participate. In the context of cultural sensitivity regarding direct request for participation (especially for women), this approach helped remove bias from stratified participant selection (note: female participation was not in itself considered culturally problematic). Interviews were attempted at all acceptable times of the day to avoid temporal occupancy bias. If the n^{th} house was not occupied or the interview was refused, efforts were

shifted to the nearest house; the household sampling interval (e.g. every 4th house) was resumed once an interview was obtained. This highly adapted sampling procedure effectively balanced impartiality, systematic methods, and cultural sensitivity.

The study was explained to every potential interviewee in his or her chosen language. If consent was obtained, the interpreter proceeded with the interview. Each question was read verbatim from the questionnaire (translated into the respondents chosen language); respondent answers were translated to English and documented (notebook) after each question. To minimize non-sampling data error, written notes were entered into an Excel spreadsheet (quantitative) and Word document (qualitative) each night; entries followed the questionnaire code structure exactly.

4.4 Additional contextual information

In addition to formal interviews, a number of non-standardized activities added contextual information not otherwise available; for example, meetings with locally assigned government officials (e.g. the Chief Warden of Sagarmatha National Park) and visits to climatically sensitive sites (e.g. micro-hydro stations). These activities also provided a means of crosschecking interview-derived information.

4.5 Data analysis

Quantitative data obtained through the questionnaire was analyzed using Stata Intercooled version 11.1. Descriptive and basic inferential statistics were preformed to identify and summarize socio-economic information as well as exposure, sensitivity, and adaption trends. Chi-squared analyses or Fisher's exact tests (as appropriate) were used to test associations at the 95% confidence level. Statistical analysis was performed on the region-wide sample (four community aggregate) as well as individual community samples (to explore the specificities of associations). Qualitative questionnaire responses were grouped according to their respective questionnaire

codes then itemized based on their relationship to vulnerability (i.e. exposure, sensitivity, and adaptive capacity). Response type frequency counts (non-automated) were also conducted to determine the relative prominence of specific content. Once quantitative and qualitative analyses were completed, an exhaustive review of results was conducted based on the vulnerability framework outlined in section 2.2.

Chapter 5: Results

The study's sample size and stratification objectives were achieved. Eighty interviews were conducted in four regionally characteristic sample communities with representative age and sex ratios for each community and the region attained. The sample is generally considered a good proxy for Khumbu's population (note: pastoralists are somewhat underrepresented given their migration to higher elevations in summer). Basic socio-economic statistics from the aggregate sample are summarized below (Table 5.1):

Table 5.1: Khumbu Socio-Economic Summary Statistics

Variable			**Frequency (%)**
Interviews per settlement			**80 (100)**
Thame/tang			20 (25)
Khumjung			20 (25)
Phortse			20 (25)
Lower Pangboche			20 (25)
Sex of respondents			**80 (100)**
M			40 (50)
F			40 (50)
Age of respondents			
Age 18-25			21
Age 26-45			36
Age ≥ 46			23
	Mean	**Min.**	**Max.**
Age	39.6	18	87
Household size	**Mean**	**Min.**	**Max.**
Number of persons	5.1	2	11
Time lived in Khumbu			**80 (100)**
Whole life			68 (85)
Most of life			0 (0)
Recently moved to Khumbu			10 (13)
Temporary resident			2 (3)
Livelihoods pursued			**Non-Cumulative**
Agriculture			71 (89)
Pastoralism			13 (16)
Tourism			49 (61)
Other wage labour			7 (9)
Importance of agriculture for livelihood			**71 (100)**
**% based on responses to 'Livelihoods pursued'*			
Low			1 (1)
Medium			29 (41)
High			40 (56)

Table continued on next page

Importance of livestock for livelihood	**13 (100)**
**% based on responses to 'Livelihoods pursued'*	
Low	0 (0)
Medium	10 (77)
High	3 (23)
Importance of tourism for livelihood	**49 (100)**
**% based on responses to 'Livelihoods pursued'*	
Low	2 (4)
Medium	18 (37)
High	29 (59)
Importance of other waged labour for livelihood	**7 (100)**
**% based on responses to 'Livelihoods pursued'*	
Low	0 (0)
Medium	3 (42)
High	4 (57)
Own means of livelihood (e.g. land, livestock, lodge)	**80 (100)**
Yes	67 (84)
No	13 (16)
Level of cash income	**80 (100)**
No cash income	0 (0)
Low income	15 (19)
Neither low nor high	64 (80)
High	1 (1)
Education received	**80 (100)**
Informal	33 (41)
Primary school	28 (35)
High school	15 (19)
College/University	4 (5)
Adult education	0 (0)
Gompa (Monk training)	0 (0)

**Non-Cumulative = category totals are non-cumulative since any given article may be classified into multiple non-exclusive categories.*

These findings are consistent with existing socio-economic information for Khumbu (pointing up the validity of the sample) but also add missing quantitative information for a number of variables. In particular, specific information about the proportion of residents involved in agriculture (89%), pastoralism (16%), tourism (61%), and/or other waged labour (9%) as well as the importance of these activities for local livelihoods.

5.1 Exposure-sensitivity

Exposure and sensitivity to climate-related hydrological risks are conditioned by the nature of hydrological modifications and the specificities of human/hydrology relationships. When asked about climate change effects, 78% of respondents indicated that anomalous

biophysical changes were occurring in the region. However, most respondents were unfamiliar with 'anthropogenic climate change' (94%) and thus did not attribute their observations to human induced climate change, *per se*. Changing precipitation regimes (within living memory) were most commonly cited (76%); decreasing winter snowfall—which is not being replaced by equivalent rainfall (i.e. solid to liquid phase shift)—was an almost ubiquitous observation (73%). Respondents noted that decreased snowfall translated into reduced winter and spring discharge volumes in small streams (consistent with findings by Thayyen (2010) in India's high elevation Din Gad catchment). Changing summer rainfall patterns were also noted, but the nature of these changes was less definitive. Some interviewees (14%) mentioned more rainfall but a larger number (30%) suggested greater rainfall intensity and variability. Overall, there is a strong sense that winters are becoming drier (with attendant effects on stream flow) and that summer precipitation is less consistent (findings consistent with recent work by Manandhar et al. (2010) in the mountainous Mustang district of Nepal). A few—primarily involved in tourism related activities—noted receding glaciers and cloudier conditions.

Despite the general persistence of exposure characteristics among the sample, differential exposures, driven by geography, were apparent. Fewer residents in Lower Pangboche had observed changes in snowfall and stream flow, potentially a result of the settlement's high elevation (highest of sample communities), which may be delaying the localized effects of climate warming (e.g. warming not sufficient to disrupt higher elevation precipitation patterns). As well, because of Thame's proximity to the Thame Khola River, more intense and variable summer rainfall is increasing the settlement's exposure to flooding, a unique exposure related to the community's riverside location. Notwithstanding, the hydrological changes outlined above accurately characterize the climatic stimuli to which most Khumbu residents are exposed and sensitive.

All respondents indicated that—for safety and water quality reasons—small streams originating above settlements are their primary source of water. Large rivers have unstable moraine banks and immense discharge volumes that make water extraction extremely hazardous and, moreover, the high silt concentration of river water makes it unsuitable for consumption and cleaning. No respondents reported accessing water from large rivers, a finding that challenges—at least for Khumbu—the prevailing assumptions that discharge variation in major rivers is the key climatic exposure-sensitivity faced by Himalayan peoples. All streams used for water access originated in small snow dominated catchments with little or no glacerized area, indicating that glacial retreat is not a direct exposure-sensitivity for most Khumbu residents (though some involved in tourism suggest that glacial change (and cloudier days) can affect the regional aesthetics upon which their livelihoods partly rely). Eighty-nine percent of respondents (and all agriculturalists) stated that direct precipitation is an additional source relied upon to meet water needs (Table 5.2).

Table 5.2: Sources of Water and their Importance

Variable	**Frequency (%)**
Sources of water	**Non-Cumulative**
Main river channel	0 (0)
Small streams	80 (100)
Direct rainfall	71 (89)
Another source	0 (0)
Importance of smaller streams	**80 (100)**
**% based on response to 'Sources of water'*	
Not very important	1 (1)
No distinct importance	5 (6)
Very important	74 (93)
Importance of direct rainfall	**71 (100)**
**% based on response to 'Sources of water'*	
Not very important	2 (3)
No distinct importance	5 (7)
Very important	64 (90)

**Non-Cumulative = category totals are non-cumulative since any given article may be classified into multiple non-exclusive categories*

Because of their close dependence on local hydrology and the nature of climatic exposures, many (63%) Khumbu residents are currently sensitive to changing hydrological regimes. Throughout the region, water for household uses (e.g. drinking water, cooking, personal hygiene) is diverted from nearby streams, through small diameter plastic pipes (often in ill-repair), to community access points. Water is rarely available in homes (lack of income to build infrastructure), thus residents are required to carry water from each community's few pipe outlets to their homes. While lower winter stream flow—which reduces water availability at access points—was said to be a long-standing challenge (because colder winter temperatures produce less melt water), almost all exposed and sensitive residents mentioned that recent discharge reductions are more significant and of longer duration than historical trends (Table 5.3). Exacerbating this situation, the influence of western ideas was said to be manifesting as more water intensive cultural norms (e.g. additional water extraction to meet enhanced expectations of personal cleanliness).

Table 5.3: Water Stress

Variable	Frequency (%)
In general, are there times of too little water?	**80 (100)**
Yes	43 (54)
No	37 (46)
When is there too little water	**Non-Cumulative, 43 (100)**
**% based on responses to 'times of too little water' (yes)*	
All year	0 (0)
Spring	13 (30)
Summer	1 (2)
Fall	2 (5)
Winter	43 (100)

**Non-Cumulative = category totals are non-cumulative since any given article may be classified into multiple non-exclusive categories.*

Because household water use is similar across Khumbu, sensitivity to reduced stream flow is a common challenge faced by exposed residents. However, concurrent, livelihood specific exposure-sensitivities emerge when occupational activities are considered (differential intra-

occupation response capacities are discussed in section 5.2). For agriculturalists, there is a statistically significant association between their livelihood activity and current exposure-sensitivity (Fisher's exact, $p < 0.01$). A component of this sensitivity is related to increased demand for irrigated crops in the context of declining stream flow. More critical, though, is the relationship between precipitation characteristics and crop yields. Agriculturalists noted that snow and rainfall modifications are having negative effects on the few subsistence crops capable of surviving in Khumbu. The most serious and widely cited effect (45%) was a causal relationship between declining winter snowfall, decreasing soil moisture content (i.e. plant available water), and lower soil fertility. Nearly one-third of agriculturalists added that more intense summer rainfall damages seedlings while atypical late summer rains (typically dry) cause potato rot. Agriculturalists cite that crop yields have already begun to decline as a consequence of precipitation change.

The exposure-sensitivity of pastoralists was found to be less clear. Decreased winter snowfall/lower soil fertility was said to negatively affect grass productivity in Khumbu's rangelands; however, less snow cover was associated with improved grass accessibility. In addition, reduced stream flow was cited as a challenge for watering livestock, but longer periods of liquid water at higher elevations were considered beneficial (i.e. streams not frozen). The pastoralists interviewed were unable to conclude whether the net effect of current exposures was negative (i.e. less grass available) or positive (i.e. more grass/fresh water accessible in winter).

Aesthetic change is a concern for those reliant on tourism-based activities for their livelihood. Despite observations of current change, those involved in tourism indicated that aesthetic impacts have not yet affected the influx of tourists. Indicative of the emergence of tourist specific lodge facilities (e.g. showers and flushing toilets), however, there is a statistically significant relationship between increasing water use and tourism-based livelihoods (X^2, $p <$

0.05). Proprietors cited declining winter and spring stream flow as limiting their ability to meet tourists' water availability expectations. Those working in the expedition climbing sector, noted that glacial and snow cover change as well as cloudier conditions were making climbing routes less predictable, thereby increasing the hazards associated with their work.

A final exposure-sensitivity faced by Khumbu residents is the effect of changing stream flow dynamics on the region's micro-hydroelectric capacity. A number of small micro-hydro stations have been built in Khumbu to address the underlying causes of regional deforestation: fuel wood harvesting for heating and cooking (Ives, 2004). The largest of these, the Khumbu Bijuli Company station on the Thame Khola River, serves 20 communities (including Thame/tang and Khumjung); meetings with the station's manager and chief technical adviser indicated that this generator is not sensitive to current stream flow changes. However, many settlements rely on less sophisticated generators, which, in Phortse and Lower Pangboche, were cited as now generating too little electricity for winter heating and cooking needs as well as sustaining damage during intense summer rain/flood events.

5.2 Adaptive capacity

Consistent with the existence of general *and* livelihood specific exposure-sensitivities, current adaptations in Khumbu take on both common and distinctive characteristics. The most ubiquitous adaptations in Khumbu relate to decreased winter and spring stream flow. All exposed and sensitive residents (63%) noted that water rationing—limiting water consumption to drinking and cooking requirements—was a common coping mechanism. However, because rationing limits water availability for personal hygiene, livestock watering, etc., this strategy was considered by all to reduce well-being. To attenuate the ills of rationing, respondents cited a need to retrieve water from alternate sources. In all settlements, respondents knew of area streams with higher discharge volumes, however, such streams were always further away (at least an

additional hour) and typically required traversing more complicated terrain to access. A common sentiment was that retrieving water from alternate streams was more physically demanding (carrying water longer distances) and risky (steep snow and ice covered terrain). Despite the current viability of alternate water sources, the ability to benefit from their existence was found to vary markedly.

At the household level, those most successful in adapting to reduced winter and spring stream flow were healthy, multi-member households and/or financially-capable residents. Physical vitality is a necessary but not sufficient component of accessing water form alternate sources; sufficiency requires that families are also capable of managing the responsibilities of absent members (e.g. child care). Two alternate coping strategies were documented among financially-capable residents: hiring assistants to help with water retrieval activities and basic roof water collection systems. Many respondents pursued these adaptive strategies (especially the former), however, 22% of exposed respondents indicated that there were limits to their ability to cope with hydrological change. For example, households that lacked physical health (e.g. elderly) and/or family support (e.g. single-headed households)—which tend to coincide with limited financial-capability—were not able to effectively cope with reduced stream flow. In addition, some temporary workers noted that they faced access discrimination in times of water scarcity (e.g. expected to forego their place in line at alternate sources when locals arrive). Even among those with higher adaptive capacity, access to alternate water sources was said to fall short of attenuating water stress and consequent rationing.

Agriculturalists did not have adaptation strategies for coping with precipitation changes. Whereas precipitation changes in other parts of the world have prompted actions to adopt more suitable crop types, etc. (Burke and Lobell, 2010), Howden et al. (2007) point out that "there are fewer and less-effective options for significantly ameliorating risks when [environmental]

conditions become more limiting" (a reality echoed by local agriculturalists) (p. 19693). Khumbu's environmentally limiting growing conditions, then, help explain why no direct adaptations to precipitation change are currently occurring. Reciprocity based crop sharing programs are an existing risk management strategy for coping with sub-subsistence level crop yields. However, agriculturalists worry that current precipitation changes will lead to more frequent yield declines, which deplete the necessary net yield surplus of communities wishing to provide assistance to needy households. This concern is consistent with the IPCC's prediction (high confidence) that South Asian "subsistence farmers…will suffer complex, localized impacts of climate change", which are expected to translate into crop yield decreases of 2.5 - 10% in the 2020s (medium confidence) (Aggarwal and Sivakumar, 2011; IPCC, 2007b, p 413). A few relatively more financially-capable agriculturalists in tourism-dependent communities have installed basic roof water collection systems for their non-traditional, water intensive crops.

Given that many pastoralists were not available for interviews during this study, the nature of exposure-sensitivity and adaptation among them remains indefinite. Still, those interviewed mentioned specific responses to current hydrological changes: grazing livestock at Yul rangelands into early winter due to reduced snow cover and liquid water availability or, conversely, purchasing excess hay to compensate for reduced rangeland grass productivity.

Those involved in tourism did not mention current adaptations to aesthetic change or new mountaineering hazards; however, responses to decreased stream flow were commonly cited and observed. Given declines in winter and spring water availability, new water demands, and financial-capability, many involved in tourism (lodge owners especially) have installed large roof water collection systems. Respondents clarified that roof water systems were needed for increased water demand *and* as a response to hydrological change. Because Lower Pangboche is

relatively less exposed to hydrological change, fewer roof water systems were in evidence; a point that clarifies the role of stream flow change as a component driver of this coping strategy. Another strategy employed by those in the tourism sector is equivalent to that described above: hiring assistants to fetch additional water from alternate water sources. The most financially-capable lodge owners in Khumjung said that they leave the region in the winter off-season, with seasonal water stress as one motivating factor.

In communities affected by times of insufficient micro-hydroelectric output, residents cited the need to again gather fuel wood for heating and cooking. Respondents added that visitors to Khumbu have heating expectations exceeding Sherpa standards. Collecting fuel wood to satisfy household *and* tourist heating demand was acknowledged as a necessary but unsustainable coping strategy.

The aforementioned adaptations clarify the household and livelihood level climate change responses currently occurring in Khumbu. However, it was observed that adaptation is also being embedded at the community level through foreign aid and Buffer Zone funding requests. In all sample communities, locals (as organized through community-wide decision making boards) were seeking external funds they believed would enable community-wide sensitivity reducing projects to be developed (e.g. more advanced water piping infrastructure and/or robust hydro-electric generators). In the most tourism-dependent areas, there was an *expectation* of international donor assistance, which had the contemporaneous effect of superseding individuals' adaptation initiative. Though all respondents indicated that access to external funding was insufficient and unreliable, during this study the residents of Thame were able to secure Buffer Zone funding for a small flood protection project.

5.3 Region-wide vulnerabilities

Despite evidence of adaptation to changing hydrological conditions, 90% of those who had observed climate-related hydrological changes (78%) indicated that modifications were currently having a negative impact on their ability to support themselves and their families (Table 5.4). Findings indicate that—because of variable exposure-sensitivity and adaptive capacity—a complex mosaic of vulnerability exists within Khumbu; however, four key region-wide vulnerabilities emerge from the aggregate sample (the theme which this thesis examines). General indicators of these vulnerabilities include livelihood type, lack of livelihood diversity, low income (in the context of Khumbu's increasingly cash-based economy), and/or marginal social status. This section elucidates *current* region-wide vulnerabilities, which were identified because of their role in adversely affecting at least 50% of the sample population (or a smaller subset of Khumbu's population for whom vulnerability is directly linked to at least one-half of the total population (i.e. vulnerability of lodge owners)). Vulnerability complexities, determinants, and trends are examined in Chapter 6.

Table 5.4: Vulnerability to Current Climatic Changes

Variable	Frequency (%)
Current climate-related changes are having a…	**50 (100)**
**% based on responses to 'observed any climate-related changes' (yes = 50)*	
Negative impact	45 (90)
No noticeable impact	4 (8)
Beneficial impact	1 (2)

Vulnerability to changing water availability for household uses is a region-wide challenge. Sixty-three percent of respondents indicated that water rationing is now required due to winter and spring stream flow reductions. Seasonal household water use reductions were said to decrease ones quality of life, especially with regard to health (i.e. reduced hygiene and hydration capability). This vulnerability is most acute among those with severe limits on their

capacity to augment household water supply with water from alternate sources (as described in section in section 5.2). Namely, temporary workers and those who lack household level support (e.g. single-headed households); a challenge redoubled if physical faculties are diminished (e.g. elderly). Because water availability among the aforementioned actors may be significantly reduced, the extent of rationing can pose a pernicious threat to well-being (especially among dependent children and the elderly).

Over one-half of Khumbu's agriculturalists are experiencing, or acutely concerned about, declining yields due to precipitation changes. In view of limited adaptation options, this suggests that the region's food system is quite vulnerable to changing precipitation regimes. At present, however, yield declines are not sufficient to affect overall food security and vulnerability is largely restricted to agriculturalists with otherwise limited livelihood diversity (Fisher's exact, $p < 0.01$). For these agriculturalists, cash generating opportunities are diminished as a function of reduced crop productivity (recall that surplus yield is sold to tourist lodges), an outcome that is aggravating the already serious economic poverty of many agriculturalists. Agriculture is Khumbu's most widespread livelihood activity (89%), one upon which 56% of residents are highly dependent. Because of its regional importance and the current lack of adequate adaptation options, vulnerability in this sector is perhaps the single most important climate-related challenge in Khumbu today.

Those involved in tourism (61%) are Khumbu's most financially-capable sub-population. While this capability does help ameliorate some vulnerabilities, it does not supersede general expectations of equitable behavior *within* Sherpa culture. Specifically, it is not appropriate for lodge owners to meet the higher water demands of their clientele simple because they can hire help to retrieve what would be sufficient amounts; in the context of reduced stream flow—which requires rationing among many residents—lodge owners are not entitled to higher water

extraction (note: a number of non-lodge owning respondents suggested that water extraction for lodges is often excessive and transgresses this norm). As mentioned, roof water collection systems are a strategy which does moderate water shortage challenges, but collection systems are limited by the same precipitation changes producing shortage in the first place. Consequently, lodge owners remain vulnerable to reduced winter and spring stream flow (despite some excess extraction). For many, this is a threat to the maintenance (and expansion) of their livelihood since it imposes an inability to meet tourists demand for shower and flushing toilet facilities, etc. Spring is high tourist season in Khumbu, thus water shortage presents the greatest challenge during this period. Fewer than 50% of the sample population own tourist lodges, however, the reverberations of this vulnerability through the region's interdependent tourism-based economy suggest indirect, but widespread implications.

Finally, vulnerability to reduced winter hydro-electric capacity is common among communities not serviced by the Khumbu Bijuli Company generator (at least among those sampled or visited). This vulnerability is again necessitating the collection of fuel wood for heating and cooking while also inhibiting the development/decreasing the functioning of facilities, which attract amenity-seeking tourists. Unreliable access to hydroelectricity is a driver of unsustainable landscape change and may be one factor leading to the polarization of communities 'benefiting'/not 'benefiting' from tourism-based economic development.

The results of this study point up the significant variability—but also persistence—of exposure-sensitivity, adaptive capacity, and ultimately vulnerability within and across Khumbu. Because of the close involvement of stakeholders in project development and execution, the findings detailed in this chapter are considered to closely reflect local views on climate related hydrological challenges. To summarize, from the array of current water related issues examined, four persistent and consequential region-wide vulnerabilities emerged:

- Vulnerability to reduced water access for household uses as a result of exposure-sensitivity and insufficient adaptive capacity to declining winter and spring stream flow, especially among marginalized sub-populations
- Vulnerability to declining crop yields as a function of exposure-sensitivity and lack of adaptive capacity to reduced winter snowfall and more intense and variable summer rainfall, especially among those highly dependent on agricultural livelihoods
- Vulnerability to reduced water access for meeting the high water demands of tourists as an outcome of exposure-sensitivity and adaptation constraints to reduced winter and spring water availability, especially among tourist lodge owners
- Vulnerability to reduced hydro-electricity production as a consequence of exposure-sensitivity and limited/mal-adaptation to lower winter stream flow, especially among those living in communities not serviced by the Khumbu Bijuli Company generator

The following chapter looks critically at the complexities, determinants, and trends of these region-wide vulnerabilities before investigating possible responses and orienting findings within the broader HDCC scholarship.

Chapter 6: Discussion

Climate related hydrological vulnerabilities in Khumbu have implications both apparent and unseen, are driven by a host of dynamic processes, and will require nuanced responses to attenuate. These issues, and their significance for HDCC scholarship in mountain regions, are expanded upon in this chapter.

6.1 Region-wide vulnerability complexities

The current region-wide vulnerabilities in Khumbu are not discrete challenges; they have interrelated consequences and secondary effects. For example, declining crop yields lead to reduced food availability for tourist lodges, which in turn increases the challenge of meeting tourists' food expectations (i.e. large quantities and diversities of food). However, in the context of the agriculture sector's relative economic poverty, and lodge owners financial capability, economic incentives for agriculturalists to continue selling irrigated crops (which take water away from household uses) and ever-greater relative proportions of their yield (which compromises household subsistence) are emerging; incentives that ostensibly shift lodge owners' burden onto poorer residents. Likewise, the struggle of lodge owners to meet tourists' water demand has made water services (e.g. showers) relatively scarce, and thus valuable. In response, some households have built water intensive facilities to attract tourist dollars (e.g. makeshift shower stalls). While such facilities may bring revenue, they do so at the expense of significant time and effort among household members, and often impose sacrifices in household water use.

Time reallocated to retrieving water for household uses is lost from other activities and may have particularly harmful secondary effects on human capital acquisition. Notably, time lost from formal education and subsistence skills expansion and refinement, losses that are likely to have lasting impacts in terms of regional development. Interrelated consequences and secondary

effects indicate that region-wide vulnerabilities cast a net of pernicious feedbacks and impacts far beyond their most apparent challenges.

6.2 Determinants of region-wide vulnerabilities

Khumbu's region-wide vulnerabilities are indicative of pervasive constraints on adaption to exposure-sensitivities. Barriers to adaptation can be conceptualized at various, interdependent scales: the household, community, region, and national/global. At the household level, it is clear that low livelihood diversity, poverty, and/or marginalization are key drivers of vulnerability. As the results show, livelihood types are correlated with specific vulnerabilities. Heavy dependence on a single livelihood activity reduces households' ability to manage risks by shifting activities among various livelihood options (e.g. working more as a trekking guide when yields are poor). Low livelihood diversity is an emerging phenomenon, which is returned to in section 6.3. The inability to afford cash-based adaptations is another major barrier to adaptation among poor households. For example, roof water collection systems and hiring water-fetching assistants are adaptations that moderate the intensity of water access challenges, but are out of reach for low-income households. Low income also drives vulnerability indirectly as described in section 6.1. Finally, marginalization is a major driver of vulnerability, especially with regard to water access for household uses. For temporary workers in Khumbu, scarcity induced water access discrimination is a determinant of their vulnerability to reduced water availability. Other residents are marginalized as a function of limited household level family support and practical constraints to mobility (e.g. elderly). In both cases, reductions in water access initiate positive feedbacks that deepen initial marginalization. The above determinants help explain the household level experience of region-wide vulnerabilities. The various degrees, and co-occurrence, of these determinants clarify additional irregularity in patterns of vulnerability among households.

At the community scale, vulnerability is determined largely as a function of location. Specifically, location determines the nature of biophysical exposure, dominant livelihood activity, access to international aid, and intra-regional political influence; factors that define the type and scope of needed adaptations and relative access to the socio-economic and political means used to facilitate social adjustment. The characteristics of exposure within Khumbu vary in relation to community specific physical geography and climate related hydrological changes. Because local scale biophysical changes are the immediate conditions to which human systems respond (i.e. the local expression of larger phenomenon), location ultimately determines the place-specific hydrological challenges faced within the region. Dominant livelihood types are also correlated with community location. It has been shown that the ability to engage (or not) in tourism-based livelihoods (and by extension, other wage-based employment) is closely tied to whether or not communities are located along popular trekking routes. As such, the concentration of livelihood-based region-wide vulnerabilities is largely determined by community locations within Khumbu. As well, communities proximal to popular trekking areas have greater access to visitors, which ultimately translates to relatively more international aid in these areas. International aid is perceived by residents as reducing exposure sensitivity and enhancing adaptive capacity, although potential problems of aid are assessed below. A final determinate of community level vulnerability is relative political influence. As described in Chapter 3, Buffer Zone funding is the main source of government assistance to Khumbu. Because relatively more tourism dependent/aid benefiting communities are lauded for bringing money into the region, leaders from these communities (who also have access to better education which improves their communication skills) may have more political influence at regional Buffer Zone fund allocation meetings. Insofar as this is true, the benefits of scarce government assistance are being directed to already economically advantaged communities.

From the foregoing discussion, it should be clear that region-wide vulnerabilities do not connate a spatially homogeneous pattern of impacts. Rather, these vulnerabilities are widespread among the population but arranged spatially as a function of biophysical exposure, livelihood opportunities, access to international aid, and influence in regional politics.

Determinants of vulnerability operating at the regional scale are perhaps the most germane to this study's results. A significant challenge for adapting to hydrological change in Khumbu is the region's isolation. For example, moderating household water shortage or crop failures with imports is not a viable option given the absence of road/rail access and the small, weight limited loads that porters and livestock can transport into the region. Due to its isolation many adaptations must occur within Khumbu, however, its marginal high elevation environment imposes a major barrier; the potential inability to substitute crops and the lack of water access alternatives (e.g. groundwater) are two of many issues. A large component of region-wide vulnerabilities can be attributed to the growth of tourism, the influence of western ideals on Sherpa culture, and the resulting transition to a cash-based economic system. These changes can also, however, be credited with marked increases in education, health, etc. Notwithstanding, this transition is at the root of increasing demands on water resources, current issues of economic inequality, and the loss of regional autonomy (i.e. more dependence on foreign actors). The degree to which residents have embraced these changes is proportional to the inefficacy of the Nepalese government in meeting community/regional needs. More explicitly, the paucity of government resources and intervention have—through their absence—enabled many of the vulnerability determinants within Khumbu to emerge. A major issue is the now heavy dependence on international aid to meet development goals. Whereas residents rightly view donor assistance as the most accessible source of development funding, the adverse aggregate effect of uncoordinated aid projects is also apparent: spatially concentrated benefits, project

degradation (i.e. lack of long-term funding), and missed opportunities for development synergies. As a product of structural failures and as a component of vulnerability enhancing cultural change, it is mistaken to conclude that international aid, in its current ad hoc form, is a desirable exposure-sensitivity reducing/capacity building option. It is the immediacy of regional hardships that masks this reality.

Regional change in Khumbu has made residents increasingly dependent on processes operating beyond their influence. For example, the limited role of the state in Khumbu is symptomatic of economic and political challenges at the national level (which play out 140 km away in Kathmandu); challenges related to international patterns of structural inequality. Nepal's governance challenges have, in turn, led to an increasingly cash-based economy, an enhanced reliance on tourism, and a heavy dependence on international aid. While this westernization has brought benefits few in Khumbu would relinquish (e.g. provision of basic needs), it has come at the expense of regional autonomy and the subjection of local well-being to fickle extra-regional economic and political conditions. Specifically, tourism and international aid are sensitive to economic slowdown/recession and political instability (e.g. Nepal's Maoist uprising) among other common national to global phenomena (Papatheodorou et al., 2010; Pappas, 2010). Given the degree to which extra-regional dependence conditions the sensitivity and adaptive capacity of Khumbu residents, it must be acknowledged as an overarching determinant of current region-wide vulnerabilities.

6.3 Vulnerability trends

As the product of changing biophysical and social processes, vulnerability is a dynamic condition. While great uncertainty about the nature of future hydrological modification in Khumbu is undeniable, climatic changes that have occurred—and which the results of this study suggest are already affecting local hydrology—are projected to intensify in the coming decades

(IPCC, 2007a). At the same time, after eighty interviews and numerous stakeholder meetings, it appears that the trajectory of social change in Khumbu is one of deepening dependence on international actors. If the results outlined in Chapter 5 are any guide, these parallel trends are likely to enhance regional climate change vulnerability. Examples of this include reduced livelihood diversity as a greater number of residents commit to relatively more lucrative tourism-based livelihood activities (which reduces adaptation options); an increasing proportion of specialty crops being grown for tourists (which increases water consumption and increases the dependence of agriculturalists on extra-regional conditions); and worsening social and economic stratification as water scarcity increases and Sherpa culture westernizes (which suggests a greater polarization of 'winners' and 'losers' (see O'Brien, 2003)). Perhaps the greatest concern for future vulnerability, however, is that of regional food security. Should precipitation changes require, it is not clear that Khumbu's agriculturally limiting environment would permit viable crop substitutions. Clearly, this eventuality would impose significant challenges for the maintenance of human well-being. Notwithstanding these issues, climate change could also alleviate some existing hydrological challenges. One oversight in many internationally funded community water projects is the use of small diameter pipes that freeze in the winter and therefore stop the flow of water to community access points. Climate warming may reduce this occurrence, though the benefit would only accrue if stream flow remained viable. Ultimately, the exact nature of biophysical changes and social responses (regional and extra-regional) will shape the character of future climate change vulnerability (and benefits?) in Khumbu.

6.4 Responding to vulnerability

Khumbu residents have little influence on large-scale economic and political process or the mitigation of climate change; however, community- and regional-scale adaptations can attenuate adverse climate change impacts and enhance local resilience to future hydrological

changes. Because the large-scale determinates of vulnerability are relatively inflexible to small-scale actors, and given Nepal's limited financial resources, decision makers working at smaller scales might achieve the most efficient and equitable outcomes by pursuing planned adaptations targeting the region-wide vulnerabilities identified in this study (autonomous adaptation will proceed independent of planned action).

The establishment of specific responses to climate change vulnerability in Khumbu should only proceed after further stakeholder consultation and follow up studies; however, three initial recommendations are offered here. First and foremost, adaptation responses should be mainstreamed into a regional sustainable development strategy. Though it will entail the type of forethought often absent from development projects in Khumbu, a tenable sustainable development approach (informed by science and local knowledge) would promote synergistic approaches to adaptation, address the current over-dependence on tourism and uncoordinated foreign aid, and reduce the likelihood that addressing vulnerability will supersede (or even adversely affect) other critical issues like ecosystem conservation (note: the national park does pursues long-term planning but its sole focus is environmental protection). Second, efforts should be made to promote residents' involvement in a diversity of livelihoods, a low cost objective that will maintain/improve resilience to climatic and social disruption. Third, investigation into environmentally viable and culturally acceptable crop substitutes should begin.

This study's findings have implications for national and international level responses, too. With increasing agreement that climate change is "undermining development and increasing the burdens on the poorest people in the world" international funding to assist LDCs in adaptation is becoming available (i.e. UNFCCC Adaptation Fund) (UNFCCC, 2009). Nepal recently submitted a National Adaptation Program of Action (NAPA) to the UNFCCC—a prerequisite for receiving adaptation assistance. While its findings are *broadly* consistent with the outcomes of this study

(see Government of Nepal, 2010), this work adds a level of detail and geographic specificity that *Project* and *District Coordination Committees* (see NAPA p. 23) will need to formulate applied adaptation strategies (which could build on the above recommendations). Though accessing funding remains problematic due to the legacy of first generation conceptions of vulnerability (e.g. technological and engineering approaches to adaptation) and political backpedaling (Fankhauser and Burton, 2011), information like that obtained in this study enhances the credibility and urgency of appeals to the international community. Insofar as funding can be obtained and administered by the Nepalese government (which will enhance its capacity to engage in regional development), it is possible that—with coordinated programs involving regional stakeholders and targeting the determinants of locally relevant hydrological challenges––significant inroads in reducing Khumbu's region-wide vulnerabilities could be made.

6.5 HDCC research in mountain regions

This study is an initial indication that the conceptual, analytical, and methodological tools from the broader HDCC literature (the 'vulnerability approach' specifically) are well suited to assessing the human dimensions of climate change in remote mountain regions. Moreover, it reinforces current (inter)disciplinary tenets based on extensive HDCC research conducted in non-mountainous socio-cultural and geographic contexts: that place-based research is essential; that involving stakeholders improves research outcomes and the relevance of findings; that vulnerability is a product of dynamic socio-economic/political conditions; that these conditions are determined by processes operating and interacting at different scales; and that vulnerability is differentiated as a function of peoples' relation to these factor.

Despite agreement in many areas, this study also identified mountain-specific vulnerability issues, which are not emphasized in HDCC scholarship. Implicit in most studies is that climatic exposures will be constant when working at the analytical scales typical of

vulnerability research (e.g. community, region). However, findings from Khumbu indicate that—as a result of heterogeneous terrain and extreme elevation gradients—large variability in climatic exposures over small spatial scales is the norm for mountain regions. Thus, in addition to the role of variable socio-economic/political factors, future mountain region vulnerability studies should be cognizant of the contribution differential exposures may have on vulnerability patterns within mountainous study areas. By and far, recent HDCC literature suggests that socio-economic/political conditions are the ultimate determinates of adaptive capacity (i.e. non-climatic drivers). This study, however, clarifies that in mountain regions there can be significant biophysical barriers to adaptation, too. This point has serious implications with regard to addressing the vulnerability of mountain populations. Given the potentially large number of vulnerable mountain peoples' globally (mountain population in LDCs ~ 630 million) (Huddleston et al., 2003), it is imperative that improving the ability to identify and face biophysical barriers to adaptation receive more attention.

Chapter 7: Conclusion

This thesis presented what is likely the first systematic, region-wide assessment of human vulnerability to Khumbu's changing water resource dynamics. The text was comprised of six content chapters. Following the Introduction, Chapter 2 presented the human dimensions of climate change research paradigm and discussed the 'vulnerability approach', which provided the theoretical framework of the study. Chapter 3 described the physiographic, hydrological, climatic and socio-economic/political characteristics of Khumbu and the study communities sampled within. Chapter 4 detailed the methods used while Chapter 5 summarized results. Chapter 6 provided a comprehensive discussion of the study's findings. The research objectives detailed in the introduction—to employ place-based, mixed method techniques to identify locally relevant hydrological changes, subsequent effects, and responses; to use information obtained in four community level surveys to identify region-wide vulnerabilities; and to generate results that are meaningful for decision-makers working at multiple scales—were accomplished. Moreover, it is believed that the study makes a meaningful contribution to the nascent scholarship on climate change vulnerability in mountainous contexts.

This study identified four region-wide vulnerabilities currently faced by Khumbu residents: vulnerability to reduced water access for household uses, vulnerability to declining crop yields, vulnerability to reduced water access for meeting the high water demands of tourists, and vulnerability to reduced hydro-electricity production. It was argued that, in the context of Nepal's limited economic and political resources, responses targeting these vulnerabilities may be the best approach to reducing current and future climate related threats to human well-being.

A controversial position was taken in regard to the westernization of Khumbu, which has been touted as a major benefit for the region. Indeed, it was found that—despite advancements in regard to the provision of basic needs—this transition is a fundamental determinant of current

vulnerabilities. As well, in contrast to existing literature, it was found that glacial change is not a significant challenge for Khumbu's residents (because large glacier fed rivers are not used by residents). Rather, changing precipitation regimes were identified as the major biophysical driver of current vulnerabilities (because of the effect on stream flow and rain fed agriculture). It was also established that Khumbu's marginal environmental conditions pose significant barriers to adaptation, barriers that compound already difficult socio-economic/political obstacles.

This study's findings demonstrate a need to elevate the position of mountain regions on the climate change vulnerability research agenda. As this study shows, the paucity of information regarding human vulnerability to climate change in mountain regions should not be associated with an absence of climate related challenges. In fact, based on research experience in other climatically sensitive regions, it is the position of the author that the vulnerability of mountain populations may be as significant, if not more, than that of communities found in regions receiving far more attention in the HDCC literature.

Though the research questions emerging from a mountain regions focus are many, this study indicates that important insights may be gained from further assessment of the role cash-based economic development, dependence on international actors, and environmentally limiting conditions play in the emergence of climate change vulnerability—both in Khumbu and LDC mountain areas generally. There is a clear need to examine sustainable development strategies that can meet basic needs while avoiding culturally distorting changes, which enhance vulnerability. And in view of humanity's commitment to some degree of climate warming in the twenty-first century (IPCC, 2007a), this research should be complemented with analysis of ways to reduce vulnerability when biophysical conditions preclude conventional capacity building options. Finally, and more generally, perhaps the time has come to move beyond the dichotomous human, non-human divide in climate change vulnerability research (a divide which

this thesis has clearly not bridged). Indeed, responses to human vulnerability may lead to significant ecological degradation if they are not mindful of the effects remedial actions have on social groups *and* ecosystems (degradation that may eventually impair human systems). Such holistic thinking will be particularly relevant for the development of vulnerability reducing/capacity building responses in inherently marginal mountain environments.

Nepal is responsible for less than 0.01% of global greenhouse gas emissions (UNFCCC, 2011), with residents of Khumbu contributing to an insignificant fraction of this figure. While it is true that vulnerability is conditioned by factors operating at global to local scales, the challenges of hydrological change in Khumbu are ultimately the result of unsustainable activities taking place predominantly in North America, Europe, and rapidly emerging East Asian economies. Adaptation funding from the international community may help alleviate some of Khumbu's climate related challenges; however, taking meaningful action towards addressing climate change implies more fundamental social, economic, and political changes among leading greenhouse gas emitters: "Philanthropy is commendable, but it must not cause the philanthropist to overlook the circumstances…which make philanthropy necessary" (King Jr, 1963).

The international community has committed to avoiding dangerous anthropogenic interference with the climate systems (see UNFCCC article 2). The human dimensions of climate change in the Khumbu region of Nepal are a clear indication that much remains to be done if this praiseworthy aim is to be realized.

References

Adger, N., Lorenzoni, I., O'Brien, K., (2009) Adaptation Now, in: Adger, N., Lorenzoni, I., O'Brien, K. (Eds.), Adapting to Climate Change: Thresholds, Values, Governance. Cambridge University Press, Cambridge.

Adger, W.N., (2006) Vulnerability. Elsevier Sci Ltd, pp. 268-281.

Ageta, Y., Higuchi, K. (1984) Estimation of Mass Balance Components of a Summer-Accumulation Type Glacier In the Nepal Himalaya. Geografiska Annaler 66A, 249-255.

Aggarwal, P., Sivakumar, M.V.K. (2011) Global climate change and food security in South Asia: An adaptation and mitigation framework. Climate Change and Food Security in South Asia, 253-275.

Babel, M., Wahid, S., (2008) Freshwater Under Threat South Asia: Vulnerability Assessment of Freshwater Resources to Environmental Change. UNEP, Nairobi.

Bajracharya, S., Mool, P. (2009) Glaciers, glacial lakes and glacial lake outburst floods in the Mount Everest region, Nepal. Annals of Glaciology 50, 81-86.

Barnett, T., Adam, J., Lettenmaier, D. (2005) Potential impacts of a warming climate on snow-dominated regions. Nature 438, 303-309.

Belliveau, S., Smit, B., Bradshaw, B. (2006) Multiple exposures and dynamic vulnerability: Evidence from the grape industry in the Okanagan Valley, Canada. Global Environmental Change 16, 364-378.

Beniston, M. (2003) Climatic change in mountain regions: a review of possible impacts. Climatic Change 59, 5-31.

Birendra, B., Shrestha, A.B., Lokap, R. (2007) Glacial lake outburst floods in the Sagarmatha region: hazard assessment using GIS and hydrodynamic modeling. Mountain Research and Development 27, 4, 336-344.

Bolch, T., Pieczonka, T., Benn, D. (2010) Longest time series of glacier mass changes in the Himalaya based on stereo imagery. The Cryosphere Discussions 4, 2593-2613.

Boynton, P., Wood, G., Greenhalgh, T. (2004) Reaching beyond the white middle classes. Bmj 328, 1433.

Burke, M., Lobell, D. (2010) Food Security and Adaptation to Climate Change: What Do We Know? Climate Change and Food Security, 133-153.

Burton, I., Huq, S., Lim, B., Pilifosova, O., Schipper, E. (2002) From impacts assessment to adaptation priorities: the shaping of adaptation policy. Climate Policy 2, 145-159.

Buytaert, W., Vuille, M., Dewulf, A., Urrutia, R., Karmalkar, A., Celleri, R. (2010) Uncertainties in climate change projections and regional downscaling in the tropical Andes: implications for water resources management. Hydrol. Earth Syst. Sci 14, 1247-1258.

Byers, A. (2008) An assessment of contemporary glacier fluctuations in Nepal's Khumbu Himal using repeat photography. Himalayan Journal of Sciences 4, 21.

CIA, (2009) Nepal. The Central Intellegence Agency, Washington DC.

DNPWC, (2006) Sagarmatha National Park. Government of Nepal/Department of National Parks and Wildlife Conservation, Kathmandu.

Eakin, H., Luers, A. (2006) Assessing the vulnerability of social-environmental systems. Annual Review of Environment and Resources 31, 365.

Eriksen, S., Brown, K., Kelly, P. (2005) The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. Geographical Journal 171, 287-305.

Fankhauser, S., Burton, I. (2011) Spending adaptation money wisely.

Ford, J., Keskitalo, E., Smith, T., Pearce, T., Berrang-Ford, L., Duerden, F., Smit, B. (2010) Case study and analogue methodologies in climate change vulnerability research. Wiley Interdisciplinary Reviews: Climate Change.

Ford, J., Pearce, T., Smit, B., Wandel, J., Allurut, M., Shappa, K., Ittusujurat, H., Qrunnut, K. (2009) Reducing vulnerability to climate change in the Arctic: the case of Nunavut, Canada. Arctic 60, 150.

Ford, J.D., Smit, B. (2004) A framework for assessing the vulnerability of communities in the Canadian arctic to risks associated with climate change. Arctic 57, 389-400.

Ford, J.D., Smit, B., Wandel, J. (2006) Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. Global Environmental Change-Human and Policy Dimensions 16, 145-160.

Ford, J.D., Smit, B., Wandel, J., Allurut, M., Shappa, K., Ittusarjuat, H., Qrunnut, K. (2008) Climate change in the Arctic: current and future vulnerability in two Inuit communities in Canada. Geographical Journal 174, 45-62.

Fujita, K., Thompson, L.G., Ageta, Y., Yasunari, T., Kajikawa, Y., Sakai, A., Takeuchi, N. (2006) Thirty-year history of glacier melting in the Nepal Himalayas. Journal of Geophysical Research-Atmospheres 111.

Furgal, C. (2005) Monitoring as a Community Response for Climate Change and Health. International Journal of Circumpolar Health 64, 440-441.

Fussel, H., Klein, R. (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change 75, 301-329.

Glantz, M. (1996) Forecasting by analogy: local responses to global climate change. Adapting to Climate Change: An International Perspective, 407-426.

Godde, P., Price, M., Zimmermann, F. (2000) Tourism and development in mountain regions moving forward into the new millennium. Tourism and Development in Mountain Regions, 1-25.

Government of Nepal, (2001) Caste Ethnicity Population. Central Bureau of Statistics, Kathmandu.

Government of Nepal, (2010) National Adaptation Program of Action, Kathmandu.

Hannah, D.M., Kansakar, S.R., Gerrard, A.J., Rees, G. (2005) Flow regimes of Himalayan rivers of Nepal: nature and spatial patterns. Journal of Hydrology 308, 18-32.

Himalayan Trust, (2008) Himalayan Trust, Kathmandu.

HKKH, (2009) Situation Analysis of Sagarmatha National Park and Buffer Zone: A Review of Park, Tourism Management and Stakeholder Participation. Hindu Kush-Karakoram-Himalaya Partnership, Kathmandu.

Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H. (2007) Adapting agriculture to climate change. Proceedings of the National Academy of Sciences 104, 19691.

Huddleston, B., Ataman, E., de Salvo, P., Zanetti, M., Bloise, M., Bel, J., Franceschini, G., Ostiani, L. (2003) Towards a GIS-based analysis of mountain environments and populations. Food and Agriculture Organization of the United Nations.

Hunzai, K., Gerlitz, J., Hoermann, B., Kollmair, M., (2010) Understanding Mountain Poverty: Exploring the specificities of poverty in the mountain areas of the greater Himalayan region. ICIMOD, Kathmandu.

ICIMOD/CBS, (2003) Mapping Nepal Census Indicators 2001 & Trends. ICIMOD/CBS, Kathmandu.

Immerzeel, W., van Beek, L., Bierkens, M. (2010) Climate Change Will Affect the Asian Water Towers. science 328, 1382.

IPCC, (2007a) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge

IPCC, (2007b) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge.

Ives, J.D. (2004) Himalayan perceptions: Environmental change and the well-being of mountain peoples. Psychology Press.

Janssen, M., Schoon, M., Ke, W., Bˆrner, K. (2006) Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. Global Environmental Change 16, 240-252.

Jansson, P., Hock, R., Schneider, T. (2002) The concept of glacial storage: a review. Journal of Hydrology 282, 116-129.

Kadota, T., Fujita, K., Seko, K., Kayastha, R., Ageta, Y. (1997) Monitoring and prediction of shrinkage of a small glacier in the Nepal Himalaya. Annals of Glaciology 24, 90-94.

Kadota, T., Seko, K., Aoki, T., Iwata, S., Yamaguchi, S. (2000) Shrinkage of the Khumbu Glacier, east Nepal from 1978 to 1995. IAHS PUBLICATION, 235-244.

Kelly, P., Adger, W. (2000) Theory and practice in assessing vulnerability to climate change and Facilitating adaptation. Climatic Change 47, 325-352.

King Jr, M.L., (1963) Strength to Love. Philadelphia: Fortress Press.

Korner, C. (2009) Global Statistics of Mountain and Alpine Research. Mountain Research and Development 29, 97-102.

Lal, M., (2005) Climatic Change - Implications for India's water resources, in: Mirza, M., Ahmad, Q. (Eds.), Climate Change and Water Resources in South Asia. A.A. Balkema Publishers, Leiden.

Lang, T., Barros, A. (2004) Winter storms in the central Himalayas. 82, 829-844.

Luitel, S. (2010) Dependency and Underdevelopment: The Nepalese Context. Occasional Papers in Sociology and Anthropology 11, 202.

Macours, K. (2010) Increasing inequality and civil conflict in Nepal. Oxford Economic Papers.

Manandhar, S., Vogt, D.S., Perret, S.R., Kazama, F. (2010) Adapting cropping systems to climate change in Nepal: a cross-regional study of farmersí perception and practices. Regional Environmental Change, 1-14.

Mark, B., Bury, J., McKenzie, J., French, A., Baraer, M. (2010) Climate Change and Tropical Andean Glacier Recession: Evaluating Hydrologic Changes and Livelihood Vulnerability in the Cordillera Blanca, Peru. Annals of the Association of American Geographers 100, 794-805.

Mark, B., Seltzer, G. (2003) Tropical glacier meltwater contribution to stream discharge: a case study in the Cordillera Blanca, Peru. Journal of Glaciology 49, 271-281.

McLeman, R., Hunter, L. (2010) Migration in the context of vulnerability and adaptation to climate change: insights from analogues. Wiley Interdisciplinary Reviews: Climate Change 1, 450-461.

McSweeney, K., Coomes, O.T. (2011) Climate-related disaster opens a window of opportunity for rural poor in northeastern Honduras. Proceedings of the National Academy of Sciences 108, 5203.

Messerli, B., Viviroli, D., Weingartner, R. (2004) Mountains of the world: Vulnerable Water Towers for the 21(st) century. Ambio, 29-34.

Mool, P., Bajracharya, S., Joshi, S., (2001) Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods. ICIMOD, Kathmandu.

Nesje, A., Dahl, O. (2000) Glaciers and Environmental Change. Arnold, London.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., West, J. (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Global Environmental Change Part A 14, 303-313.

O'Brien, K., Leichenko, R.M. (2000) Double exposure: assessing the impacts of climate change within the context of economic globalization. Global Environmental Change-Human and Policy Dimensions 10, 221-232.

O'Brien, K., Sygna, L., Leichenko, R., Adgar, N., Barnett, J., Mitchell, T., Schipper, L., Tanner, T., Vogel, C., Mortreux, C., (2008) Disaster Risk Reduction, Climate Change Adaptation and Human Security. University of Olso, Oslo.

O'Brien, K.L., Leichenko, R.M. (2003) Winners and losers in the context of global change. Annals of the Association of American Geographers 93, 89-103.

Paavola, J., Adger, W.N. (2006) Fair adaptation to climate change. Ecological Economics 56, 594-609.

Papatheodorou, A., Rossellu, J., Xiao, H. (2010) Global economic crisis and tourism: consequences and perspectives. Journal of Travel Research 49, 39.

Pappas, N. (2010) Terrorism and tourism: the way travellers select airlines and destinations. Journal of Air Transport Studies 1, 76-96.

Patt, A., Klein, R.J.T., de la Vega-Leinert, A. (2005) Taking the uncertainty in climate-change vulnerability assessment seriously. Comptes Rendus Geosciences 337, 411-424.

Patt, A., Schroter, D., de la Vega-Leinert, A., Klein, R. (2009) Vulnerability research and assessment to support adaptation and mitigation: common themes from the diversity of approaches. Earthscan/James & James, London.

Pearce, T., Ford, J., Laidler, G., Smit, B., Duerden, F., Allarut, M., Andrachuk, M., Baryluk, S., Dialla, A., Elee, P. (2009) Community collaboration and climate change research in the Canadian Arctic. Polar Research 28, 10-27.

Polsky, C., Neff, R., Yarnal, B. (2007) Building comparable global change vulnerability assessments: The vulnerability scoping diagram. Global Environmental Change 17, 472-485.

Pouliotte, J., Smit, B., Westerhoff, L. (2009) Adaptation and development: Livelihoods and climate change in Subarnabad, Bangladesh. Climate and Development 1, 31-46.

Sacareau, I. (2009) Changes in environmental policy and mountain tourism in Nepal. Revue de geographie alpine. Journal of Alpine Research.

Salerno, F., Buraschi, E., Bruccoleri, G., Tartari, G., Smiraglia, C. (2008) Glacier surface-area changes in Sagarmatha national park, Nepal, in the second half of the 20th century, by comparison of historical maps. Journal of Glaciology 54, 738-752.

Sharma, E., Chetri, N., Tse-ring, K., Shrestha, A., Jing, F., Mool, P., Eriksson, M., (2009) Climate Change Impacts and Vulnerability in the Eastern Himalayas, ICIMOD.

Sharma, S., (2009) Poverty, Growth and Economic Inclusion in Nepal. United Nations Department of Economic and Social Affairs, New York.

Sherpa, L., Bajracharya, B., (2009) View of a High Place: Natural and Cultural Landscape of Sagarmatha National Park. HKKH partnership Project/ICIMOD, Kathmandu.

Sherpa, Y., Kayastha, R. (2009) A Study of Livestock Management patterns in Sagarmatha National Park, Khumbu Region: Trends as affected by Socio-economic and Climate Change Kathmandu University Journal of Science, Engineering and Technology 5, 110-120.

Shrestha, A.B., Aryal, R. (2011) Climate change in Nepal and its impact on Himalayan glaciers. Regional Environmental Change 11, 65-77.

Singh, P., Singh, V. (2001) Snow and Glacier Hydrology. Kluwer Academic Publishing, Norwall.

Smit, B., Wandel, J. (2006) Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16, 282-292.

Smith, J., Lazo, J. (2001) A Summary of Climate Change Impact Assessments from the U.S. Country Studies Program. Climatic Change 50, 1-29.

Spoon, J. (2009) Beyul Khumbu: the Sherpa and Sagarmatha (Mount Everest) National Park and Buffer Zone, Nepal. Protected landscapes and cultural and spiritual values, 68.

Stevens, S. (1993) Claiming the High Ground: Sherpas, Subsistence, and Environmental Change in the Highest Himalaya. Motilal Banarsidass Publishers, Delhi.

Thapa, K., Shakya, B. (2008) Integrated study on hydrology and meteorology of Khumbu Region with climate change perspectives. WWF Nepal, Kathmandu.

Thayyen, R.J., Gergan, J.T. (2010) Role of glaciers in watershed hydrology: a preliminary study of a "Himalayan catchment". The Cryosphere 4, 115-128.

Tremblay, M., Furgal, C., Larrivee, C., Annanack, T., Tookalook, P., Qiisik, M., Angiyou, E., Swappie, N., Savard, J.P., Barrett, M. (2008) Climate Change in Northern Quebec: Adaptation Strategies from Community-Based Research. Arctic 61, 27-34.

Turner, B., Kasperson, R., Matson, P., McCarthy, J., Corell, R., Christensen, L., Eckley, N., Kasperson, J., Luers, A., Martello, M. (2003) A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the United States of America 100, 8074.

UN DESA, (2005) Household Sample Surveys in Developing and Transition Countries. The Department of Economic and Social Affairs of the United Nations, New York.

UNDP, (2010) International Human Development Indicators: Nepal, New York.

UNEP (2007) Global Outlook for Snow & Ice. UNEP, Nairobi.

UNESCO, (2007) Case Studies on Climate Change and World Heritage. UNESCO, Paris.

UNFCCC, (2009) Adaptation Fund.

UNFCCC, (2011) Greenhouse Gas Inventory Data. United Nations, Bonn.

Viviroli, D., Archer, D., Buytaert, W., Fowler, H., Greenwood, G., Hamlet, A., Huang, Y., Koboltschnig, G., Litaor, M., Lopez-Moreno, J. (2010) Climate change and mountain water resources: overview and recommendations for research, management and politics. Hydrology and Earth System Sciences Discussions 7, 2829-2895.

Viviroli, D., Archer, D., Buytaert, W., Fowler, H., Greenwood, G., Hamlet, A., Huang, Y., Koboltschnig, G., Litaor, M., Lupez-Moreno, J. (2011) Climate change and mountain water resources: overview and recommendations for research, management and policy. Hydrol. Earth Syst. Sci 15, 471-504.

Viviroli, D., Durr, H., Messerli, B., Meybeck, M., Weingartner, R. (2007) Mountains of the world, water towers for humanity: Typology, mapping, and global significance. Water Resources Research 43, W07447.

World Bank, (2006) Reducing Poverty in South Asia. World Bank.

World Bank, (2010a) Nepal Data. World Bank.

World Bank, (2010b) World Development Report: Development and Climate Change. World Bank, Washington D.C.

Xu, J.C., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X.F., Wang, Y., Wilkes, A. (2009) The Melting Himalayas: Cascading Effects of Climate Change on Water, Biodiversity, and Livelihoods. Conservation Biology 23, 520-530.

Appendix A: Questionnaire

Date _____, Settlement name _____, Type of settlement: (Yul, Gunsa, Yersa) ____
Approximate number of households_____, Elevation _____m

***Interpreter**: May I introduce Graham McDowell; he is a researcher from Canada who is trying to learn about the role of water in the lives of Khumbu residents. He would like to invite you to participate in a questionnaire about the role of water in your life. I will serve as an interpreter and will be asking the questions he has prepared. Your participation is voluntary. However, if you choose to participate, your answers will be completely anonymous. The information gathered will be used to understand the ways in which people depend on water and also how changes in Khumbu could affect peoples' water access and use. The results of the study will be sent back to community leaders in Khumbu. The questionnaire will take about 20 minutes to answer. Would you like to help with this study?*

Ask respondent where they would like to complete the Questionnaire

***Interpreter**: As we go through this questionnaire, I will be asking two types of questions. For the first type of question I will read the question then tell you a list of answers to choose from. For some of these questions you will be told that it is ok to choose multiple answers. For the second type of question, I will read the question and then let you tell me your thoughts in your own words. Short responses are fine. And don't worry; there are no right or wrong answers.*

Before asking specific questions about water, I would like to ask some general questions about you. This will help Graham understand the ways in which different people use water

1. **Sex** M, F (not asked explicitly)

2. **How long have you lived in the Khumbu?**
    1. Whole life
    2. Most of life
    3. Recently moved to Khumbu
    4. Temporary resident
3. **How many people live in your household**? ___
4. **What is your age? ___**
5. **Upon which of the following activities do you depend to support yourself and your family. Please indicate <u>all that apply</u> (read options aloud first).**
    1. Agriculture and related activities
        - **a.** In terms of supporting yourself and your family is agriculture of:
            1. Low importance – your other activities are more important
            2. Medium importance – your other activities are of similar importance
            3. High importance – this activity is more important than your other activities
        - **b.** Are your agricultural goods used mostly:
            1. For personal consumption and use
            2. To sell
            3. To trade
    2. Livestock and related activities
        - **a.** In terms of supporting yourself and your family are livestock of:
            1. Low importance – your other activities are more important
            2. Medium importance – your other activities are of similar importance
            3. High importance – this activity is more important than your other activities
        - **b.** Are the goods and services of your livestock used mostly:
            1. For personal consumption and use
            2. To sell
            3. To trade
    3. Tourism and related activities
        - **a.** In terms of supporting yourself and your family is tourism of:
            1. Low importance – your other activities are more important
            2. Medium importance – your other activities are of similar importance
            3. High importance – this activity is more important than your other activities

4. Other waged labour (for example, carpentry)
    a. In terms of supporting yourself and your family is other waged labour of:
        1. Low importance – your other activities are more important
        2. Medium importance – your other activities are of similar importance
        3. High importance – this activity is more important than your other activities

6. Do you own the things that allow you to support yourself and your family (for example, land, livestock, or a tourist lodge)?
    0. No
    1. Yes

7. How would you describe your level of cash income?
    1. No cash income
    2. Low
    3. Neither low nor high
    4. High

8. Do you also work outside of Khumbu or receive income from family members who works outside of Khumbu?
    0. No
    1. Yes
        a. Is this income of more, less, or equal importance to the income earned within Khumbu?
            1. More
            2. Less
            3. Equal

9. In what type of settlements do you live during the year? Choose <u>all that apply</u>.
    1. Yul
    2. Yersa
    3. Gunsa
    4. Settlements outside of Khumbu

10. What type of education have you received?
    1. Informal
    2. Primary school
    3. High school
    4. College/university
    5. Adult education
    6. Gampa education

<u>Interpreter</u>: Thank you. Now we will talk more directly about water. When I ask about water, I am asking about water used for all purpose, for example, drinking water, growing crops, watering yak and all other uses.

11. Where does the water that you use--for all uses--come from? Please indicate <u>all that apply</u> (Read main options aloud first).

1. Main river channel (for example, the Bhote Kosi, Dudh Kosi, or Imja Khola)
   - **a.** In terms of water access, is the main river channel:
     1. Not very important – one of many water sources
     2. Of no distinct importance
     3. Very important – without this source life would be more difficult
2. Smaller streams (for example, streams that come from a glacier or snowfield)
   - **a.** In terms of water access, are smaller streams from snow:
     1. Not very important – one of many water sources
     2. Of no distinct importance
     3. Very important – without this source life would be more difficult
3. Direct rainfall (for example, rain that falls directly onto agricultural fields)
   - **a.** In terms of water access, is direct rainfall:
     1. Not very important – one of many water sources
     2. Of no distinct importance
     3. Very important – without this source life would be more difficult
4. Another source _____ (please identify)
   - **a.** In terms of water access, is _____:
     1. Not very important – one of many water sources
     2. Of no distinct importance
     3. Very important – without this source life would be more difficult

12. In general, are there times when there is too little water available to meet your needs?

2. No
3. Yes
   - **a.** When (check <u>all that apply</u>)?
     1. All year
     2. Spring
     3. Summer
     4. Fall
     5. Winter
   - **C.** Please briefly explain how you are affected in times of too little water (***for example, not being able to use as much water for cleaning).

_____
_____
_____
_____

D. Please briefly what you do to make it through times of too little water (***for example, traveling to different areas to get water).

_____
_____
_____
_____

13. In general, are there times when there is too much water available?

0. No
1. Yes
   a. When (check all that apply)?
      1. All year
      2. Spring
      3. Summer
      4. Fall
      5. winter

   A. Please briefly explain you are affected in times of too much water (***for example, having crops destroyed by flooding).

   _____
   _____
   _____
   _____

   B. Please briefly explain what you do to make it through times of too much water (***for example, working with other farmers to protect land)

   _____
   _____
   _____
   _____

14. In general, do you think that water availability is predictable?

0. No

   A. Please briefly explain how you are affected by unpredictable water availability (***for example, uncertainty about when and where water for yak can be accessed).

   _____
   _____
   _____
   _____

B. Please briefly explain what you do to deal with unpredictable water availability (***for example, limiting yak grazing to areas of predictable water access).

_____
_____
_____
_____

1. Yes

15. Are there any limits on your ability to make it through times of too little, too much, or unpredictable water availability (*for example, financial, political, or cultural limits)?**

0. No.
1. Yes

A. Please briefly describe these limits:

_____
_____
_____
_____

16. Overall, would you say that your water use is:

1. Increasing
2. Unchanging
3. Decreasing

A. (If 1 or 3) Please briefly explain why you think your water use is changing:

_____
_____
_____
_____

17. Some have said that the climate is changing and that this can affect glaciers, snow, rainfall, and river flow in Khumbu; have you observed any changes?

0. No.
   a. Have you heard about the climate changing?
      0. No
      1. Yes
1. Yes

A. Please briefly explain what changes you have observed and if these changes are most noticeable at certain times of the year:

_____
_____
_____
_____

b. Have these changes affected you?

1. No.
    c. Are you concerned that these changes could affect you in the future?
        0. No
        1. Yes
2. Yes
    d. At present, are these changes having a:
        1. Negative impact on your ability to support yourself and your family
        2. No noticeable impact on your ability to support yourself and your family
        3. Beneficial impact on your ability to support yourself and your family

B. Please briefly explain why:

_____
_____
_____
_____

e. If these changes were to become more common or more intense do you think they would have a:

1. Negative impact on your ability to support yourself and your family
2. No noticeable impact on your ability to support yourself and your family
3. Beneficial impact on your ability to support yourself and your family

C. ***(IF different from above)*** Please briefly explain why:

_____
_____
_____
_____

18. Is there anything else you would like to tell me?

_____
_____
_____
_____

***Interpreter**: Thank you very much for sharing your time and knowledge, it is greatly appreciated.*

Appendix B: Descriptive statistics results

Non-Cumulative = category totals are non-cumulative since any given article may be classified into multiple non-exclusive categories (all percentages calculated based on 80 for Khumbu-wide and 20 for individual communities unless otherwise noted).

Khumbu-Wide Summary Statistics

Variable			**Frequency (%)**
Sex of respondents (1)			**80 (100)**
M			*40 (50)*
F			*40 (50)*
Time lived in Khumbu (2)			**80 (100)**
Whole life			*68 (85)*
Most of life			*0 (0)*
Recently moved to Khumbu			*10 (13)*
Temporary resident			*2 (3)*
Household size (3)	**mean**	**min.**	**max.**
Number of persons	*5.1*	*2*	*11*
Age of respondents (4)			
Age	*39.6*	*18*	*87*
Livelihoods pursued (5)			**Non-Cumulative**
Agriculture			*71 (89)*
Pastoralism			*13 (16)*
Tourism			*49 (61)*
Other wage labour			*7 (9)*
Importance of agriculture (5.1.a)			**71 (100)**
***% based on responses to 5.1			
Low			*1 (1)*
Medium			*29 (41)*
High			*40 (56)*
Primary use of agricultural goods (5.1.b)			**71 (100)**
***% based on responses to 5.1			
Personal consumption			*71 (100)*
To sell			*0 (0)*
To trade			*0 (0)*
Importance of livestock (5.2.a)			**13 (100)**
***% based on responses to 5.1			
Low			*0 (0)*
Medium			*10 (77)*
High			*3 (23)*

Primary use of livestock goods and services (5.2.b)	**13 (100)**
***% based on responses to 5.1	
Personal consumption	*13 (100)*
To sell	*0 (0)*
To trade	*0 (0)*
Importance of tourism (5.3.a)	**49 (100)**
***% based on responses to 5.1	
Low	*2 (4)*
Medium	*18 (37)*
High	*29 (59)*
Importance of other waged labour (5.4.a)	**7 (100)**
***% based on responses to 5.1	
Low	*0 (0)*
Medium	*3 (42)*
High	*4 (57)*
Own the things that allow to support self and family? (6)	**80 (100)**
Yes	*67 (84)*
No	*13 (16)*
How would you describe you level of cash income? (7)	**80 (100)**
No cash income	*0 (0)*
Low income	*15 (19)*
Neither low nor high	*64 (80)*
High	*1 (1)*
Do you work or receive income from outside of Khumbu? (8)	**80 (100)**
Yes	*11 (14)*
No	*69 (86)*
Importance of income earned or received from outside Khumbu (8.a)	**11 (100)**
***% based on response to 8 (yes)	
More	*6 (55)*
Less	*2 (18)*
Equal	*2 (18)*
Type of settlements lived in during the year (9)	**Non-Cumulative**
Yul	*79 (99)*
Yersa	*5 (6)*
Gunsa	*2 (3)*
Settlement outside Khumbu	*23 (29)*
Education received (10)	**80 (100)**
Informal	*33 (41)*
Primary school	*28 (35)*
High school	*15 (19)*
College/University	*4 (5)*
Adult education	*0 (0)*
Gompa	*0 (0)*

Sources of water (11)	**Non-Cumulative**
Main river channel	*0 (0)*
Smaller streams	*80 (100)*
Direct rainfall	*71 (89)*
Another source	*0 (0)*
Importance of smaller streams (11.2.a)	***80 (100)**
***% based on response to 11	
Not very important	*1 (1)*
No distinct importance	*5 (6)*
Very important	*74 (93)*
Importance of direct rainfall (11.3.a)	**71 (100)**
***% based on response to 11	
Not very important	*2 (3)*
No distinct importance	*5 (7)*
Very important	*64 (90)*
In general, are there times of too little water? (12)	**80 (100)**
***obs. 37 had 2 responses (i.e. yes to 12 and 13)	
Yes	43 (54)
No	37 (46)
When is there too little water (12.a)	**Non-Cumulative, 43 (100)**
***% based on responses to 12 (yes)	
All year	*0 (0)*
Spring	*13 (30)*
Summer	*1 (2)*
Fall	*2 (5)*
Winter	*43 (100)*
In general, are there times of too much water? (13)	**80 (100)**
***obs. 37 had 2 responses (i.e. yes to 12 and 13)	
Yes	*12 (15)*
No	*68 (85)*
When is there too much water (13.a)	**Non-Cumulative, 12 (100)**
***% based on responses to 13 (yes)	
All year	*0 (0)*
Spring	*0 (0)*
Summer	*12 (100)*
Fall	*0 (0)*
Winter	*0 (0)*
In general, is water availability predictable? (14)	**80 (100)**
Yes	*78 (98)*
No	*2 (3)*
Any limits to dealing with water stress? (15)	**54 (100)**
***% based on responses to 12 and 13 (yes)	
Yes	*12 (22)*
No	*42 (78)*

Is your water use… (16)	**80 (100)**
Increasing	*34 (43)*
Decreasing	*43 (54)*
Unchanging	*3 (4)*
Have you observed any climatic changes? (17)	**80 (100)**
Yes	*62 (78)*
No	*18 (23)*
(if no) Have you heard about the climate changing? (17.a)	**18 (100)**
***% based on responses to 17 (no)	
Yes	*1 (6)*
No	*17 (94)*
Have these changes affected you? (17.b)	**62 (100)**
***% based on responses to 17 (yes)	
Yes	*50 (81)*
No	*12 (19)*
(if no) Are you concerned these changes could affect you? (17.c)	**12 (100)**
***% based on responses to 17.b (no), omit 1 (i.e. 3333)	
Yes	*6 (50)*
No	*5 (42)*
At present are these changes having a… (17.d)	**50 (100)**
***% based on responses to 17.b (yes)	
Negative impact	*45 (90)*
No noticeable impact	*4 (8)*
Beneficial impact	*1 (2)*
If changes became more common or intense, would they have a… (17.e)	**50 (100)**
***% based on responses to 17.b (yes), omit 4 (i.e. 3333)	
Negative impact	*45 (90)*
No noticeable impact	*1 (4)*
Beneficial impact	*0 (0)*

Thame/tang Summary Statistics

Variable			Frequency (%)
Sex of respondents (1)			**20 (100)**
M			*10 (50)*
F			*10 (50)*
Time lived in Khumbu (2)			**20 (100)**
Whole life			*19 (95)*
Most of life			*0 (0)*
Recently moved to Khumbu			*0 (0)*
Temporary resident			*1 (5)*
Household size (3)	**mean**	**min.**	**max.**
Household size	*5.5*	*2*	*11*
Age of respondents (4)			
Age	*40.7*	*18*	*75*
Livelihoods pursued (5)			**Non-Cumulative**
Agriculture			*18 (90)*
Livestock			*9 (45)*
Tourism			*10 (50)*
Other wage labour			*1 (1)*
Importance of agriculture (5.1.a)			**18 (100)**
***% based on responses to 5.1			
Low			*0 (0)*
Medium			*11 (61)*
High			*7 (39)*
Primary use of agricultural goods (5.1.b)			**18 (100)**
***% based on responses to 5.1			
Personal consumption			*18 (100)*
To sell			*0 (0)*
To trade			*0 (0)*
Importance of livestock (5.2.a)			**9 (100)**
***% based on responses to 5.1			
Low			*0 (0)*
Medium			*8 (89)*
High			*1 (11)*
Primary use of livestock goods and services (5.2.b)			**9 (100)**
***% based on responses to 5.1			
Personal consumption			*9 (100)*
To sell			*0 (0)*
To trade			*0 (0)*

Importance of tourism (5.3.a)	**10 (100)**
***% based on responses to 5.1	
Low	*1 (10)*
Medium	*4 (40)*
High	*5 (50)*
Importance of other waged labour (5.4.a)	**1 (100)**
***% based on responses to 5.1	
Low	*0 (0)*
Medium	*1 (100)*
High	*0 (0)*
Own the things that allow to support self and family? (6)	**20 (100)**
Yes	*18 (90)*
No	*2 (10)*
How would you describe you level of cash income? (7)	**20 (100)**
No cash income	*0 (0)*
Low income	*6 (30)*
Neither low nor high	*14 (70)*
High	*0 (0)*
Do you work or receive income from outside of Khumbu? (8)	**20 (100)**
Yes	*17 (85)*
No	*3 (15)*
Importance of income earned or received from outside Khumbu (8.a)	**3 (100)**
***% based on response to 8 (yes)	
More	*1 (3)*
Less	*1 (3)*
Equal	*1 (3)*
Type of settlements lived in during the year (9)	**Non-Cumulative**
Yul	*20 (100)*
Yersa	*0 (0)*
Gunsa	*0 (0)*
Settlement outside Khumbu	*0 (0)*
Education received (10)	**20 (100)**
Informal	*10 (50)*
Primary school	*6 (30)*
High school	*3 (15)*
College/University	*1 (5)*
Adult education	*0 (0)*
Gompa	*0 (0)*
Sources of water (11)	**Non-Cumulative**
Main river channel	*0 (0)*
Smaller streams	*20 (100)*
Direct rainfall	*18 (90)*
Another source	*0 (0)*

Importance of smaller streams (11.2.a)	**20 (100)**
***% based on response to 11	
Not very important	*1 (5)*
No distinct importance	*1 (5)*
Very important	*18 (90)*
Importance of direct rainfall (11.3.a)	**18 (100)**
***% based on response to 11	
Not very important	*2 (11)*
No distinct importance	*1 (6)*
Very important	*15 (83)*
In general, are there times of too little water? (12)	**20 (100)**
Yes	1 (5)
No	19 (95)
When is there too little water (12.a)	**Non-Cumulative, 1 (100)**
***% based on responses to 12 (yes)	
All year	*0 (0)*
Spring	*0 (0)*
Summer	*0 (0)*
Fall	*0 (0)*
Winter	*1 (100)*
In general, are there times of too much water? (13)	**11 (100)**
Yes	*11 (55)*
No	*9 (45)*
When is there too much water (13.a)	**Non-Cumulative, 11 (100)**
***% based on responses to 13 (yes)	
All year	*0 (0)*
Spring	*0 (0)*
Summer	*11 (100)*
Fall	*0 (0)*
Winter	*0 (0)*
In general, is water availability predictable? (14)	**20 (100)**
Yes	*19 (95)*
No	*1 (5)*
Any limits to dealing with water stress? (15)	**12 (100)**
***% based on responses to 12 and 13 (yes)	
Yes	*6 (50)*
No	*6 (50)*
Is your water use… (16)	**20 (100)**
Increasing	*5 (25)*
Decreasing	*14 (70)*
Unchanging	*1 (5)*
Have you observed any climatic changes? (17)	**20 (100)**
Yes	*16 (80)*
No	*4 (20)*

(if no) Have you heard about the climate changing? (17.a)	**4 (100)**
***% based on responses to 17 (no)	
Yes	*0 (0)*
No	*4 (100)*
Have these changes affected you? (17.b)	**16 (100)**
***% based on responses to 17 (yes)	
Yes	*13 (81)*
No	*3 (19)*
(if no) Are you concerned these changes could affect you? (17.c)	**3 (100)**
***% based on responses to 17.b (no)	
Yes	*1(50)*
No	*2 (42)*
At present are these changes having a… (17.d)	**13 (100)**
***% based on responses to 17.b (yes)	
Negative impact	*11 (85)*
No noticeable impact	*1 (8)*
Beneficial impact	*1 (8)*
If changes became more common or intense, would they have a… (17.e)	**13 (100)**
***% based on responses to 17.b (yes), omit 1 (i.e. 3333)	
Negative impact	*11 (85)*
No noticeable impact	*1 (8)*
Beneficial impact	*0 (0)*

Khumjung Summary Statistics

Variable			Frequency (%)
Sex of respondents (1)			**20 (100)**
M			*10 (50)*
F			*10 (50)*
Time lived in Khumbu (2)			**20 (100)**
Whole life			*16 (80)*
Most of life			*0 (0)*
Recently moved to Khumbu			*3(15)*
Temporary resident			*1 (5)*
Household size (3)	**mean**	**min.**	**max.**
Household size	*4.8*	*2*	*8*
Age of respondents (4)			
Age	*38.6*	*19*	*87*
Livelihoods pursued (5)			**Non-Cumulative**
Agriculture			*18 (90)*
Livestock			*3 (15)*
Tourism			*12 (60)*
Other wage labour			*4 (20)*
Importance of agriculture (5.1.a)			**18 (100)**
***% based on responses to 5.1			
Low			*1 (6)*
Medium			*7 (39)*
High			*10 (56)*
Primary use of agricultural goods (5.1.b)			**18 (100)**
***% based on responses to 5.1			
Personal consumption			*18 (100)*
To sell			*0 (0)*
To trade			*0 (0)*
Importance of livestock (5.2.a)			**3 (100)**
***% based on responses to 5.1			
Low			*0 (0)*
Medium			*1 (33)*
High			*2 (67)*
Primary use of livestock goods and services (5.2.b)			**3 (100)**
***% based on responses to 5.1			
Personal consumption			*3 (100)*
To sell			*0 (0)*
To trade			*0 (0)*

Importance of tourism (5.3.a)	**12 (100)**
***% based on responses to 5.1	
Low	*1 (8)*
Medium	*6 (50)*
High	*5 (42)*
Importance of other waged labour (5.4.a)	**4 (100)**
***% based on responses to 5.1	
Low	*0 (0)*
Medium	*2 (50)*
High	*2 (50)*
Own the things that allow to support self and family? (6)	**20 (100)**
Yes	*17 (85)*
No	*3 (15)*
How would you describe you level of cash income? (7)	**20 (100)**
No cash income	*0 (0)*
Low income	*2 (10)*
Neither low nor high	*17 (85)*
High	*1 (5)*
Do you work or receive income from outside of Khumbu? (8)	**20 (100)**
Yes	*6 (30)*
No	*14 (70)*
Importance of income earned or received from outside Khumbu (8.a)	**6 (100)**
***% based on response to 8 (yes), omit 1 (i.e. 3333)	
More	*3 (50)*
Less	*1 (17)*
Equal	*1 (17)*
Type of settlements lived in during the year (9)	**Non-Cumulative**
Yul	*20 (100)*
Yersa	*1 (5)*
Gunsa	*1 (5)*
Settlement outside Khumbu	*11 (55)*
Education received (10)	**20 (100)**
Informal	*4 (20)*
Primary school	*7 (35)*
High school	*8 (40)*
College/University	*1 (5)*
Adult education	*0 (0)*
Gompa	*0 (0)*
Sources of water (11)	**Non-Cumulative**
Main river channel	*0 (0)*
Smaller streams	*20 (100)*
Direct rainfall	*18 (90)*
Another source	*0 (0)*

Importance of smaller streams (11.2.a)	**20 (100)**
***% based on response to 11	
Not very important	*0 (0)*
No distinct importance	*0 (0)*
Very important	*20 (100)*
Importance of direct rainfall (11.3.a)	**18 (100)**
***% based on response to 11	
Not very important	*0 (0)*
No distinct importance	*3 (17)*
Very important	*15 (83)*
In general, are there times of too little water? (12)	**20 (100)**
Yes	20 (100)
No	0 (0)
When is there too little water (12.a)	**Non-Cumulative, 20 (100)**
***% based on responses to 12 (yes)	
All year	*0 (0)*
Spring	*2 (10)*
Summer	*0 (0)*
Fall	*1 (5)*
Winter	*20 (100)*
In general, are there times of too much water? (13)	**20 (100)**
***obs. 37 had 2 responses (i.e. yes to 12 and 13)	
Yes	*1 (5)*
No	*19 (95)*
When is there too much water (13.a)	**Non-Cumulative, 1 (100)**
***% based on responses to 13 (yes)	
All year	*0 (0)*
Spring	*0 (0)*
Summer	*1 (100)*
Fall	*0 (0)*
Winter	*0 (0)*
In general, is water availability predictable? (14)	**20 (100)**
Yes	*19 (95)*
No	*1 (5)*
Any limits to dealing with water stress? (15)	**20 (100)**
***% based on responses to 12 and 13 (yes) (obs. 37 had 2 responses (yes to 12 and 13) = base as 20 not 21	
Yes	*5 (25)*
No	*15 (75)*
Is your water use… (16)	**20 (100)**
Increasing	*10 (50)*
Decreasing	*9 (45)*
Unchanging	*1 (5)*

Have you observed any climatic changes? (17)	**20 (100)**
Yes	*18 (90)*
No	*2 (10)*
(if no) Have you heard about the climate changing? (17.a)	**2 (100)**
***% based on responses to 17 (no)	
Yes	*0 (0)*
No	*2 (100)*
Have these changes affected you? (17.b)	**18 (100)**
***% based on responses to 17 (yes)	
Yes	*14 (78)*
No	*4 (22)*
(if no) Are you concerned these changes could affect you? (17.c)	**4 (100)**
***% based on responses to 17.b (no)	
Yes	*2 (50)*
No	*2 (50)*
At present are these changes having a… (17.d)	**14 (100)**
***% based on responses to 17.b (yes)	
Negative impact	*13 (93)*
No noticeable impact	*1 (7)*
Beneficial impact	*0 (0)*
If changes became more common or intense, would they have a… (17.e)	**14 (100)**
***% based on responses to 17.b (yes)	
Negative impact	*13 (93)*
No noticeable impact	*1 (7)*
Beneficial impact	*0 (0)*

Phortse Summary Statistics

Variable			Frequency (%)
Sex of respondents (1)			**20 (100)**
M			*10 (50)*
F			*10 (50)*
Time lived in Khumbu (2)			**20 (100)**
Whole life			*17 (85)*
Most of life			*0 (0)*
Recently moved to Khumbu			*3 (15)*
Temporary resident			*0 (0)*
Household size (3)	**mean**	**min.**	**max.**
Household size	*4.9*	*2*	*8*
Age of respondents (4)			
Age	*41.1*	*18*	*76*
Livelihoods pursued (5)			**Non-Cumulative**
Agriculture			*18 (90)*
Livestock			*1 (5)*
Tourism			*11 (55)*
Other wage labour			*2 (10)*
Importance of agriculture (5.1.a)			**18 (100)**
***% based on responses to 5.1			
Low			*0 (0)*
Medium			*6 (33)*
High			*12 (67)*
Primary use of agricultural goods (5.1.b)			**18 (100)**
***% based on responses to 5.1			
Personal consumption			*18 (100)*
To sell			*0 (0)*
To trade			*0 (0)*
Importance of livestock (5.2.a)			**1 (100)**
***% based on responses to 5.1			
Low			*0 (0)*
Medium			*1 (100)*
High			*0 (0)*
Primary use of livestock goods and services (5.2.b)			**1 (100)**
***% based on responses to 5.1			
Personal consumption			*1 (100)*
To sell			*0 (0)*
To trade			*0 (0)*

Importance of tourism (5.3.a)	**11 (100)**
***% based on responses to 5.1	
Low	*0 (0)*
Medium	*2 (18)*
High	*9 (81)*
Importance of other waged labour (5.4.a)	**2 (100)**
***% based on responses to 5.1	
Low	*0 (0)*
Medium	*0 (0)*
High	*2 (100)*
Own the things that allow to support self and family? (6)	**20 (100)**
Yes	*17 (85)*
No	*3 (15)*
How would you describe you level of cash income? (7)	**20 (100)**
No cash income	*0 (0)*
Low income	*5 (25)*
Neither low nor high	*15 (75)*
High	*0 (0)*
Do you work or receive income from outside of Khumbu? (8)	**20 (100)**
Yes	*2 (10)*
No	*18 (90)*
Importance of income earned or received from outside Khumbu (8.a)	**2 (100)**
***% based on response to 8 (yes)	
More	*2 (100)*
Less	*0 (0)*
Equal	*0 (0)*
Type of settlements lived in during the year (9)	**Non-Cumulative**
Yul	*19 (95)*
Yersa	*3 (15)*
Gunsa	*0 (0)*
Settlement outside Khumbu	*5 (25)*
Education received (10)	**20 (100)**
Informal	*10 (50)*
Primary school	*7 (35)*
High school	*1 (5)*
College/University	*2 (10)*
Adult education	*0 (0)*
Gompa	*0 (0)*
Sources of water (11)	**Non-Cumulative**
Main river channel	*0 (0)*
Smaller streams	*20 (100)*
Direct rainfall	*18 (90)*
Another source	*0 (0)*

Importance of smaller streams (11.2.a)	**20 (100)**
***% based on response to 11	
Not very important	*0 (0)*
No distinct importance	*4 (20)*
Very important	*16 (80)*
Importance of direct rainfall (11.3.a)	**18 (100)**
***% based on response to 11	
Not very important	*0 (0)*
No distinct importance	*1 (6)*
Very important	*17 (94)*
In general, are there times of too little water? (12)	**20 (100)**
Yes	20 (100)
No	0 (0)
When is there too little water (12.a)	**Non-Cumulative, 20 (100)**
***% based on responses to 12 (yes)	
All year	*0 (0)*
Spring	*10 (50)*
Summer	*1 (5)*
Fall	*1 (5)*
Winter	*20 (100)*
In general, are there times of too much water? (13)	**20 (100)**
Yes	*0 (0)*
No	*0 (0)*
When is there too much water (13.a)	**Non-Cumulative, 0 (100)**
***% based on responses to 13 (yes)	
All year	*0 (0)*
Spring	*0 (0)*
Summer	*0 (0)*
Fall	*0 (0)*
Winter	*0 (0)*
In general, is water availability predictable? (14)	**20 (100)**
Yes	*20 (100)*
No	*0 (0)*
Any limits to dealing with water stress? (15)	**20 (100)**
***% based on responses to 12 and 13 (yes)	
Yes	*1 (5)*
No	*19 (95)*
Is your water use… (16)	**20 (100)**
Increasing	*12 (60)*
Decreasing	*7 (35)*
Unchanging	*1 (5)*
Have you observed any climatic changes? (17)	**20 (100)**
Yes	*16 (80)*
No	*4 (20)*

(if no) Have you heard about the climate changing? (17.a)	**4 (100)**
***% based on responses to 17 (no)	
Yes	*0 (0)*
No	*4 (100)*
Have these changes affected you? (17.b)	**16 (100)**
***% based on responses to 17 (yes)	
Yes	*13 (81)*
No	*3 (19)*
(if no) Are you concerned these changes could affect you? (17.c)	**3 (100)**
***% based on responses to 17.b (no), omit 1 (i.e. 3333)	
Yes	*0 (0)*
No	*2 (67)*
At present are these changes having a… (17.d)	**13 (100)**
***% based on responses to 17.b (yes)	
Negative impact	*12 (92)*
No noticeable impact	*1 (8)*
Beneficial impact	*0 (0)*
If changes became more common or intense, would they have a… (17.e)	**13 (100)**
***% based on responses to 17.b (yes), omit 2 (i.e. 3333)	
Negative impact	*10 (77)*
No noticeable impact	*1 (8)*
Beneficial impact	*0 (0)*

Lower Pangboche Summary Statistics

Variable			Frequency (%)
Sex of respondents (1)			**20 (100)**
M			*10 (50)*
F			*10 (50)*
Time lived in Khumbu (2)			**20 (100)**
Whole life			*16 (80)*
Most of life			*0 (0)*
Recently moved to Khumbu			*4 (20)*
Temporary resident			*0 (0)*
Household size (3)	**mean**	**min.**	**max.**
Household size	*5.3*	*2*	*10*
Age of respondents (4)			
Age	*38*	*20*	*73*
Livelihoods pursued (5)			**Non-Cumulative**
Agriculture			*17 (85)*
Livestock			*0 (0)*
Tourism			*16 (80)*
Other wage labour			*0 (0)*
Importance of agriculture (5.1.a)			**17 (100)**
***% based on responses to 5.1			
Low			*0 (0)*
Medium			*5 (29)*
High			*12 (71)*
Primary use of agricultural goods (5.1.b)			**17 (100)**
***% based on responses to 5.1			
Personal consumption			*17 (100)*
To sell			*0 (0)*
To trade			*0 (0)*
Importance of livestock (5.2.a)			**0 (100)**
***% based on responses to 5.1			
Low			*0 (0)*
Medium			*0 (0)*
High			*0 (0)*
Primary use of livestock goods and services (5.2.b)			**0 (100)**
***% based on responses to 5.1			
Personal consumption			*0 (0)*
To sell			*0 (0)*
To trade			*0 (0)*

Importance of tourism (5.3.a)	**16 (100)**
***% based on responses to 5.1	
Low	*0 (0)*
Medium	*6 (38)*
High	*10 (63)*
Importance of other waged labour (5.4.a)	**0 (100)**
***% based on responses to 5.1	
Low	*0 (0)*
Medium	*0 (0)*
High	*0 (0)*
Own the things that allow to support self and family? (6)	**20 (100)**
Yes	*15 (75)*
No	*5 (25)*
How would you describe you level of cash income? (7)	**20 (100)**
No cash income	*0 (0)*
Low income	*2 (10)*
Neither low nor high	*18 (90)*
High	*0 (0)*
Do you work or receive income from outside of Khumbu? (8)	**20 (100)**
Yes	*0 (0)*
No	*20 (100)*
Importance of income earned or received from outside Khumbu (8.a)	**0 (100)**
***% based on response to 8 (yes)	
More	*0 (0)*
Less	*0 (0)*
Equal	*0 (0)*
Type of settlements lived in during the year (9)	**Non-Cumulative**
Yul	*20 (100)*
Yersa	*1 (5)*
Gunsa	*1(5)*
Settlement outside Khumbu	*7(35)*
Education received (10)	**20 (100)**
Informal	*9 (45)*
Primary school	*8 (40)*
High school	*3 (15)*
College/University	*0 (0)*
Adult education	*0 (0)*
Gompa	*0 (0)*
Sources of water (11)	**Non-Cumulative**
Main river channel	*0 (0)*
Smaller streams	*20 (100)*
Direct rainfall	*17 (85)*
Another source	*0 (0)*

Importance of smaller streams (11.2.a)	**20 (100)**
***% based on response to 11	
Not very important	*0 (0)*
No distinct importance	*0 (0)*
Very important	*20 (100)*
Importance of direct rainfall (11.3.a)	**17 (100)**
***% based on response to 11	
Not very important	*0 (0)*
No distinct importance	*0 (0)*
Very important	*17 (100)*
In general, are there times of too little water? (12)	**20 (100)**
Yes	2 (10)
No	18 (90)
When is there too little water (12.a)	**Non-Cumulative, 2 (100)**
***% based on responses to 12 (yes)	
All year	*0 (0)*
Spring	*1 (50)*
Summer	*0 (0)*
Fall	*0 (0)*
Winter	*2 (100)*
In general, are there times of too much water? (13)	**0 (100)**
Yes	*0 (0)*
No	*0 (0)*
When is there too much water (13.a)	**Non-Cumulative, 0 (100)**
***% based on responses to 13 (yes)	
All year	*0 (0)*
Spring	*0 (0)*
Summer	*0 (0)*
Fall	*0 (0)*
Winter	*0 (0)*
In general, is water availability predictable? (14)	**20 (100)**
Yes	*20 (100)*
No	*0 (0)*
Any limits to dealing with water stress? (15)	**2 (100)**
***% based on responses to 12 and 13 (yes)	
Yes	*0 (0)*
No	*2 (100)*
Is your water use… (16)	**20 (100)**
Increasing	*7 (35)*
Decreasing	*13 (65)*
Unchanging	*0 (0)*
Have you observed any climatic changes? (17)	**20 (100)**
Yes	*12 (60)*
No	*8 (40)*

(if no) Have you heard about the climate changing? (17.a)	**8 (100)**
***% based on responses to 17 (no)	
Yes	*1 (13)*
No	*7 (88)*
Have these changes affected you? (17.b)	**12 (100)**
***% based on responses to 17 (yes)	
Yes	*10 (83)*
No	*2 (17)*
(if no) Are you concerned these changes could affect you? (17.c)	**2 (100)**
***% based on responses to 17.b (no)	
Yes	*2 (100)*
No	*0 (0)*
At present are these changes having a… (17.d)	**10 (100)**
***% based on responses to 17.b (yes)	
Negative impact	*9 (90)*
No noticeable impact	*1 (10)*
Beneficial impact	*0 (0)*
If changes became more common or intense, would they have a… (17.e)	**2 (100)**
***% based on responses to 17.b (yes), omit 1 (i.e. 3333)	
Negative impact	*1 (50)*
No noticeable impact	*0 (0)*
Beneficial impact	*0 (0)*

Appendix C: Inferential statistics results

- Only tests cited in text included (Chi-squared and Fisher's exact)
- All tests significant at the 95% confidence level
- Observed values appear first followed by expected values in brackets

Agriculture-Based Livelihood and Current Exposure-Sensitivity (Fisher's Exact)

	Not currently sensitive	Currently sensitive	Total
Not involved in agriculture	4 (0.8)	0 (3.2)	4
Involved in agriculture	8 (11.2)	50 (46.8)	58
Total	12	50	62
Chi-squared = 17.8161		Fisher's exact = 0.00	

- Their is a statistically significant relationship between Agricultural-based livelihoods and current climate change exposure sensitivity

Agriculture-Based Livelihood and Current Vulnerability (Fisher's Exact)

	Not currently vulnerable	Currently vulnerable	Not applicable*	Total
Not involved in agriculture	0 (0.5)	0 (5.1)	9 (3.5)	9
Involved in agriculture	4 (3.5)	45 (39.9)	22 (27.5)	71
Total	4	45	31	80
Chi-squared = 16.0291		Fisher's exact = 0.00		

*Not applicable refers to those who had not observed any climatic changes

- Their is a statistically significant relationship between Agricultural-based livelihoods and vulnerability current climatic changes

Tourism-Based Livelihood and Increasing Water Use (X^2)			
	Unchanging water use	**Increasing water use**	**Total**
Not involved in tourism	23 (17.8)	8 (13.2)	31
Involved in tourism	23 (28.2)	26 (20.8)	49
Total	46	34	80
Chi-squared = 5.7716		P = 0.016	

- There is a statistically significant relationship between tourism based livelihoods and increasing water use