Water Stress Vulnerability in the Himalayas of Nepal

Local farmer in a plot of garlic in Tallo Lorpa

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Abstract

Agricultural communities in the Himalayas are highly dependent on the availability of fresh water. Changes in precipitation and snowpack storage due to climate change are expected to greatly alter water availability in mountainous headwater catchments. While changes in water resources may prove problematic for communities in the Himalayas, these communities are capable of dynamic response. Their vulnerability to water stress caused by climate change is, therefore, dependent on both changes in the amount of water available and changes in how this resource is used. While studies exist which address each of these issues in isolation, no attempt has been made to explicitly reconcile the two. This thesis evaluated the degree to which climate change contributes to water stress vulnerability in two mountain communities in Nepal. This vulnerability was then compared to opportunities for adaptation in order to elucidate its effect on population in these communities.

The investigation focussed on the village of Panglin in the district of Mustang and the village of Tallo Lorpa in the district of Jumla, and proceeded in three steps. First, scientific understanding of the possible effects of climate change on water availability in the surrounding areas was reviewed. Next, the vulnerability and adaptive capacity in each respective community was assessed using household surveys, focus group discussions and participatory rural appraisal techniques. Finally, the expected effects of climate change on water availability were linked to findings on community vulnerability to these changes.

The findings show that both communities are vulnerable to changes in water availability under climate change. Vulnerability is particularly prevalent in the agricultural sector and poorer households in each community. Overall, this vulnerability is greater in Tallo Lorpa than in Panglin. Vulnerability to changes in water availability is, however, small in comparison to the opportunities for adaptation in each community. The ability of people to appropriate benefits from these opportunities is constrained by a number of conditions. It is the degree to which these conditions inhibit the effective realisation of adaptation opportunities that determines vulnerability in Panglin and Tallo Lorpa.

Acknowledgements

This thesis presented numerous and wide ranging challenges. I would have been ill-equipped to meet these challenges without assistance from a number of highly skilled, knowledgeable and worldly people.

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Chapter One

Introduction

1.1 Context and Rationale

The human cost of climate change this century is expected to be enormous (IPCC, 2007a&b; Stern, 2006; WHO, 2003; Agrawal, 2008; World Bank, 2008). This is particularly true in developing countries which show high human and socio-economic vulnerabilities (IPCC, 2007b; World Bank, 2008; Agrawala *et al.*, 2003; Hunzai *et al.*, 2011; Jing & Leduc, 2010). The World Bank's Social Development Department recently labelled climate change as "the defining development challenge of our generation" (Agrawal, 2008, p.8). It is estimated that, by 2100, between 165,000 to 250,000 children could die each year in South Asia and Sub Saharan Africa because of extreme poverty caused by climate change (Stern, 2006). The impacts of climate change on the world's poorest are serious and immediate. There is an urgent need to both understand these impacts and respond effectively to them.

Changes in water availability are seen as being among the most serious threats to human livelihoods under climate change (Bates *et al.*, 2008; Sullivan & Meigh, 2006; World Bank, 2008; IPCC, 2007b). The impacts of climate change on water availability will be large in many mountainous regions because of the combined effects of changes in precipitation and changes in water storage as snow and ice (Beniston, 2003; IPCC, 2007a; Barnett *et al.*, 2005; Kaser *et al.*, 2010; Schild, 2008). The Hindu Kush-Himalayas (HKH) hold the largest stores of snow and ice outside the polar regions and are home to some of the poorest people on Earth (Schild, 2008; Hunzai *et al.*, 2011; Xu *et al.*, 2009; Bajracharya & Shrestha, 2011). Human vulnerability to changes in water availability under climate change is, therefore, likely to be extreme in this region (Schild, 2008; Jing & Leduc, 2010; NCVST, 2009).

Many studies refer to the human impacts of climate change in the HKH region with Malthusian undertones. With respect to changes in water availability under climate change, Malthusian logic generally reflects that of Suweis *et al.* (2013), who suggest that population is constrained by agricultural production which in turn depends on water availability. On a global level, Upreti (2004, p.14) suggests that the number of countries facing water shortage could increase fivefold by 2025 and labels increasing pressure on water resources as a looming catastrophe. Arnell (1999) notes that an estimated five billion people could live in water stressed countries by 2025. The Secretary General of the United Nations, Ban Ki-moon, recently warned that nearly half of the world could face water scarcity by 2030 (Associated Press, 2013).

At the regional scale, many studies suggest that reductions in river flow threaten food production in South Asia (Sing & Bengtsson, 2004; Nellmann & Klatenborn, 2009; Barnett *et al.*, 2005). Writing in *Nature*, and echoed in the IPCC's Fourth Assessment Report (AR4), Barnett *et al.* (2005, p.306) suggest that "some areas of the most populated region on Earth (referring to Asia) are likely to 'run out of water' during the dry season if the current warming and glacial melting trends continue for several more decades". Nellmann and Klatenborn (2009) point out that due to degradation, flooding and reduced river flow, cereal production in Asia may be between 10% and 30% lower than what will be required by 2050 – enough to reduce global food supply by between 1.7% and 5%. Based on estimates from the World Bank, FAO and UNEP, the authors suggest that this may increase food prices by 30% to 50% and further increase volatility. Nellmann and Klatenborn (2009) show the impact of this by pointing to the 2008 food price surge which drove 110 million people into poverty and left an additional 44 million people undernourished.

At the local level, Shah (2010) claimed that the first recognised case of climate forced migration in Nepal was occurring in the settlement of Dhe, Upper Mustang. The report suggests that reductions in local water availability have reduced irrigated land by half and brought about substantial declines in animal husbandry. As a consequence, 150 people were forced to relocate from this community in 2010 (Shah, 2010). Klatzel and Murray (2009) explain that, while mountain people of the HKH have coping strategies to deal with hazards, these are often insufficient in the face of changes in climate and associated extreme events.

The implications of these reports at all levels is that change in water availability under climate change is likely to place increasing pressure on communities and that this may restrict the number of people who can prosper in certain places. Do these claims go too far? Certainly at the regional level there is evidence suggesting that glacial contribution to many of the great rivers of Asia is, in fact, modest (Kaser *et al.*, 2010; Rees & Collins, 2004). Singh *et al.* (2011) point out that projected increases in monsoon rainfall in the Ganges basin render changes in snowmelt and glacier melt insignificant. Further, the authors hold that increased precipitation may dominate decreases in melt water even in the relatively arid Indus basin. Rees and Collins (2004, p.49) suggest that "the catastrophic water shortages forecast by some experts are unlikely to happen for many decades, if at all". It seems that general statements suggesting water shortage and famine for the billions who rely on the great rivers of Asia may be tenuous.

At a local level, however, changes in water availability are likely to be much larger than those found at the regional level, particularly in alpine headwater catchments where snow and ice greatly modulate runoff (Kaser *et al.*, 2010). Are changes in water availability in alpine headwater catchments under climate change likely to determine the number of people who can prosper in mountain communities? Current literature seems to suggest they will. But is this known or simply assumed? What weight do these Malthusian statements hold?

Statements concerning the effects of climate change on people are often extrapolations from the primary disciplines of reports. These statements are often the only mention of social and economic forces in scientific reports and the only mention of physical drivers in social scientific reports. How can we ensure that these statements properly represent the influence of climate change on people? Is there a loss of understanding between disciplines?

The effects of climate change on people concern a wide range of academic disciplines. The need for interdisciplinary approaches to understanding them is widely echoed (Xu *et al.*, 2009; Dixit *et al.*, 2009; Garg *et al.*, 2007; Gosain *et al.*, 2010; Jing & Leduc, 2010; Agrawal, 2008; Singh *et al.*, 2011). Such research, however, is often lacking, particularly at the micro level (Vedwan & Rhoades, 2001; Xu *et al.*, 2009; Klatzel & Murray, 2009; Jing & Leduc, 2010). As Gosain *et al.* (2010, preface) explain: “the nature of the mountains, fragile and poorly accessible landscapes with sparsely scattered settlements and poor infrastructure, means that research and assessment are least just where they are needed most”. Furthermore, Jing and Leduc (2010) point out that most research is biased towards negative effects so that opportunities for adaptation and response are paid little attention. It is only through an interdisciplinary approach, which includes analysis of the expected physical effects of climate change along with the ability of communities to respond and adapt, that the human effects of climate change can be understood. This interdisciplinary approach is pursued in this thesis.

1.2 Research Objectives

This thesis investigates the vulnerability of two high mountain Nepalese communities (called Panglin and Tallo Lorpa) to water stress under climate change. The research combines physical scientific and social scientific enquiry. According to Brooks (2003), climate change vulnerability is best broken into three separate notions: ‘hazard’, ‘social vulnerability’ and ‘biophysical vulnerability’. In this thesis, ‘hazard’ refers to changes in water availability under climate change and is assessed through a review of the physical science and analysis of general circulation model output. ‘Social vulnerability’ refers to the inherent vulnerabilities displayed by the communities of

Panglin and Tallo Lorpa, and is assessed through a field investigation in both communities, informed by a review of the social scientific literature on vulnerability and adaptive capacity. ‘Biophysical vulnerability’ is the integration of social vulnerability and hazard and describes the degree to which the study communities are vulnerable to changes in water availability under climate change. It is, therefore, biophysical vulnerability that we are principally concerned with. Biophysical vulnerability is investigated here through an analysis and subsequent reconciliation of hazard and social vulnerability.

Biophysical vulnerability to water shortage is determined by a large number of factors including population growth, economic growth and globalisation. Our understanding of the nature and interactions of these parameters is, however, limited (Singh *et al.*, 2011; Macchi, 2011; Jianchu *et al.*, 2007; Chalise & Khanal, 2001; Nellemann & Klatenborn, 2009). This investigation is constrained to assessing the degree to which climate change contributes to biophysical vulnerability, rather than the degree to which biophysical vulnerability may occur in reality. The research is best thought of as a theoretical regression analysis in which hazard and social vulnerability are independent variables and biophysical vulnerability is the dependent variable with all other variables held equal. The regression progresses in a stepwise manner. The first part of the analysis treats hazard as the only independent variable by asking the question:

1) How vulnerable are the communities of Panglin and Tallo Lorpa to water stress caused by climate change *ceteris paribus*?

This question is shown diagrammatically in Figure 1.1:

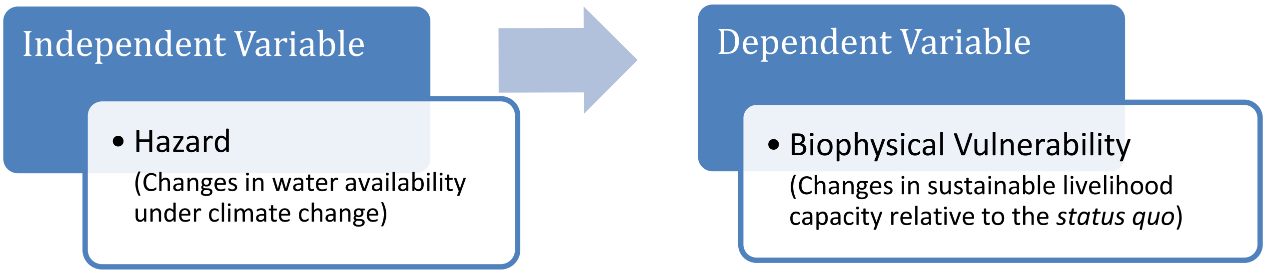


Figure 1.1: Flow diagram representing the structure of the first step of the regression described in the first research question.

The second part of the analysis moves beyond this to include the influence of a second independent variable: social vulnerability. The second research question addresses the contest between increasing water stress hazard under climate change and reducing social vulnerability through adaptation. The question is framed with a view to assessing the validity of the Malthusian statements outlined in the previous section. This is done by asking:

2) Will water shortage under climate change constrain population in Panglin and/or Tallo Lorpa or does this depend on adaptation?

This question is shown diagrammatically in Figure 1.2:

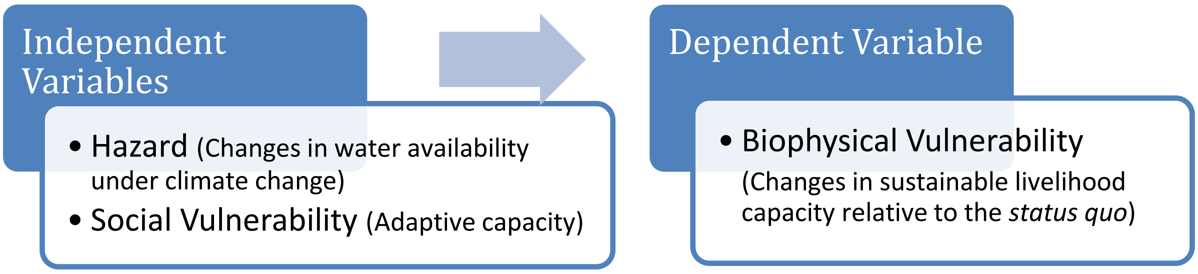


Figure 1.2: Flow diagram representing the structure of the second step of the regression described in the second research question.

With regard to the first research question, it is hoped that greater understanding of where and why human vulnerability exists will better target the assistance given to vulnerable communities. Sullivan and Meigh (2006) point out that current aid given in the water sector is not well targeted at areas of water poverty and seems to be monopolised by large recipient countries. Much more effort needs to be put towards properly identifying those communities and households most in need of this assistance (Sullivan & Meigh, 2006). Furthermore, in-depth analysis of expected changes in water availability coupled with investigation of adaptation strategies should help to inform responses and planning in each community (Singh *et al.*, 2011).

With regard to the second research question, identification of whether water shortage under climate change determines human populations or whether this is determined by adaptation can help to focus attention on the dominant variable. A deeper understanding of the origins and causal development of human vulnerability to climate impacts can also improve the validity of scholarship on this issue.

1.3 Thesis Structure

The objectives of this thesis are addressed over the following seven chapters, as shown in Figure 1.3. Chapter Two introduces the study communities of Panglin and Tallo Lorpa and describes their physical, socioeconomic and historical contexts. Chapter Three assesses ‘hazard’ through a review of the scientific literature on the hydrological effects of climate change in the region and analysis of general circulation model output. These approaches are combined to produce ‘best guess' scenarios for water resource change in each community. This understanding of hazard forms the platform for investigating social vulnerability and adaptive capacity in each community over chapters four, five and six. Chapter Four reviews the social scientific literature on social vulnerability and adaptive capacity in the Himalayan context. Chapter Five describes the methods used to assess social vulnerability and adaptive capacity in this investigation within a wider methodological discussion. Chapter Six describes the results of field research into social vulnerability and adaptive capacity in Panglin and Tallo Lorpa.

Chapter Seven then reconciles the findings about social vulnerability with the hazard identified in Chapter Three using a two-step theoretical regression. The first step treats hazard as the sole independent variable and describes biophysical vulnerability if the hydrological effects of climate change were to happen instantaneously. The second step includes changes in social vulnerability through adaptation as a second independent variable and assesses the relative influence of these two independent variables on biophysical vulnerability. Finally, Chapter Eight provides conclusions which link the findings of this investigation to its objectives.

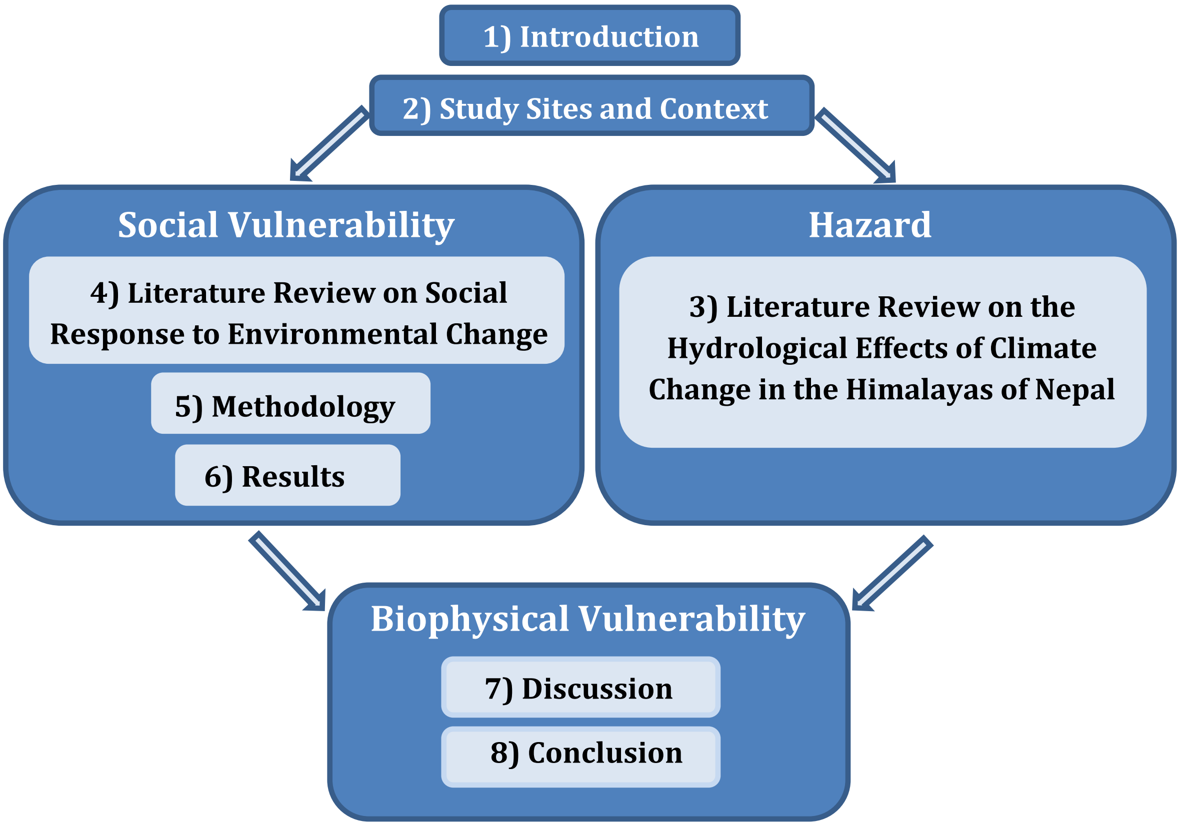


Figure 1.3: Flow diagram of the structure of this thesis.

Chapter Two

Study Sites and Context

2.1 Introduction

The biophysical vulnerability of a community to water stress is influenced by the physical and socio-economic context within which that community exists. The current investigation focuses on the communities of Panglin and Tallo Lorpa as case studies for assessing water stress vulnerability under climate change. Panglin and Tallo Lorpa are located in the mountain regions of western and mid-western Nepal respectively. The physical, social and economic contexts of these communities have a number of broad similarities and many specific differences which are described in this chapter. The chapter begins by outlining the rationale to studying water stress vulnerability in Panglin and Tallo Lorpa. The physical and socio-economic characteristics known as ‘mountain specificities’ are then introduced. These are elaborated upon through a description of location, geomorphology, climate and resource availability in each community. Human geographies are also described through examination of social statistics, equality, institutional involvement and historical social forces in each community.

2.2 Site Selection Rationale

Panglin and Tallo Lorpa were chosen for investigation based on the following rationale. Both communities are located at high altitude in small mountainous catchments. The water available to these communities is therefore modulated by seasonal snow accumulation and melt, a process that is highly sensitive to climate change (Barnett *et al*., 2005; Bates *et al*., 2008; Beniston, 2003). The availability of downscaled GCM data (Devkota, 2010) for the districts of Mustang and Jumla, which encompass Panglin and Tallo Lorpa respectively, enhances our understanding and allows investigation of hydrological change in each area. Furthermore, water shortage has been identified as a major concern by community members in both Panglin and Tallo Lorpa during previous field research (Khanal *et al.*, 2011; ICIMOD, 2012). Panglin and Tallo Lorpa are, therefore, exposed to hazard from water stress under climate change and have identified social vulnerability to this hazard.

2.3 Mountain Specificities

The communities of Panglin and Tallo Lorpa exist within the general social, environmental and economic conditions referred to as ‘mountain specificities’. Mountain specificities refer particularly to the characteristics of inaccessibility, poverty, marginality, hazard, fragility, and poor access to infrastructure and support (Whiteman, 1985; Hoermann, 2010b; Eriksson *et al.*, 2008; Rasul & Karki, 2007). In addition, mountain communities often suffer from problems of verticality and a lack of social, environmental and economic research and assessment (Gosain *et al.*, 2010; Bandyopadhyay & Gyawali, 1994). Beyond these common mountain conditions, the communities of Panglin and Tallo Lorpa are highly dependent on natural resources and are, therefore, likely to be sensitive to environmental stress and natural disasters (Macchi, 2011).

Mountain specificities create a unique historical context with which to assess vulnerability to possible change. In many ways, they increase social vulnerability. For example, mountain communities have been unable to appropriate direct benefit from the green revolution and economic growth in mountain regions has been much slower than the global average (Rasul & Karki, 2007; Singh *et al.,* 2011). Many modern advances in sectors like transport, communication and technology have been slow to reach mountain regions and as a result the development gap between these regions and more accessible locations has widened (Singh *et al.*, 2011).

In many other ways, however, mountain specificities foster resilience. It is often pointed out that mountain communities have lived in harsh, dynamic, unpredictable and changing environments for millennia (Jianchu *et al.*, 2007; Klatzel & Murray, 2009; Dixit *et al.*, 2009). As Klatzel and Murray (2009, p.3) point out, “the [Himalayan] region has always had either too much or too little water”. Naturally, therefore, mountain communities are highly adapted to these challenges and have developed sophisticated coping strategies. For instance, historical examples of seasonal migration to avoid the harsh winter and forced migration in reaction to stresses or shocks are found throughout the literature (Gill, 2003; Jianchu *et al.,* 2007; Lama, 2010; Dixit *et al.,* 2009). As Jianchu *et al.* (2007) and Eriksson *et al.* (2008) point out however, the rates of physical and socio economic change expected over the next century are more rapid than those experienced before. Biophysical vulnerability in Panglin and Tallo Lorpa depends, therefore, on the evolution of hazard and the reduction of social vulnerability which reflect physical and human geographies respectively.

2.4 Physical Geographies

Physical geographies describe the context within which hazard exists in this investigation. The physical geographies of Panglin and Tallo Lorpa present a number of challenges reflecting mountain specificities. These challenges are described in this section with respect to location, geomorphology, the degree of connection to urban centres, watershed character and climate.

2.4.1 Location and Geomorphology

Panglin and Tallo Lorpa are located in the Nepalese districts of Mustang and Jumla respectively (Figure 2.1). Mustang and Jumla are situated in high mountain regions in the northern parts of Western and Mid-western Nepal, respectively. Panglin lies at an altitude of 2,950m above sea level (asl) in the Trans-Himalayan region to the north of the Annapurna, Nilgiri and Dhaulagiri Himalayas (ICIMOD, 2012). Dhaulagiri I (8,167m) and Annapurna I (8,091m) are the 7th and 10th highest mountains on Earth respectively and the ranges they are part of form a substantial barrier to the flow of the Indian Summer Monsoon (ISM), causing the rain shadow effect seen from satellite in Figure 2.2. As a consequence of this rain-shadowing, Mustang has an arid climate more similar to that of Tibet than the rest of Nepal (Lama, 2010).

Tallo Lorpa lies at 2,523m asl and is less affected by rain shadowing than Panglin. Himalayan ranges that include the peaks of Bahlu Lek (5,424m) and Hiunchuli Patan (5,271m) are moderate barriers to the monsoonal flow. As a result, while Jumla receives substantially more rainfall than Mustang, it also receives substantially less rainfall than the average for the rest of Nepal (ICIMOD, 2012). Again the partial rain shadow effect in Jumla is clear from space (Figure 2.2).

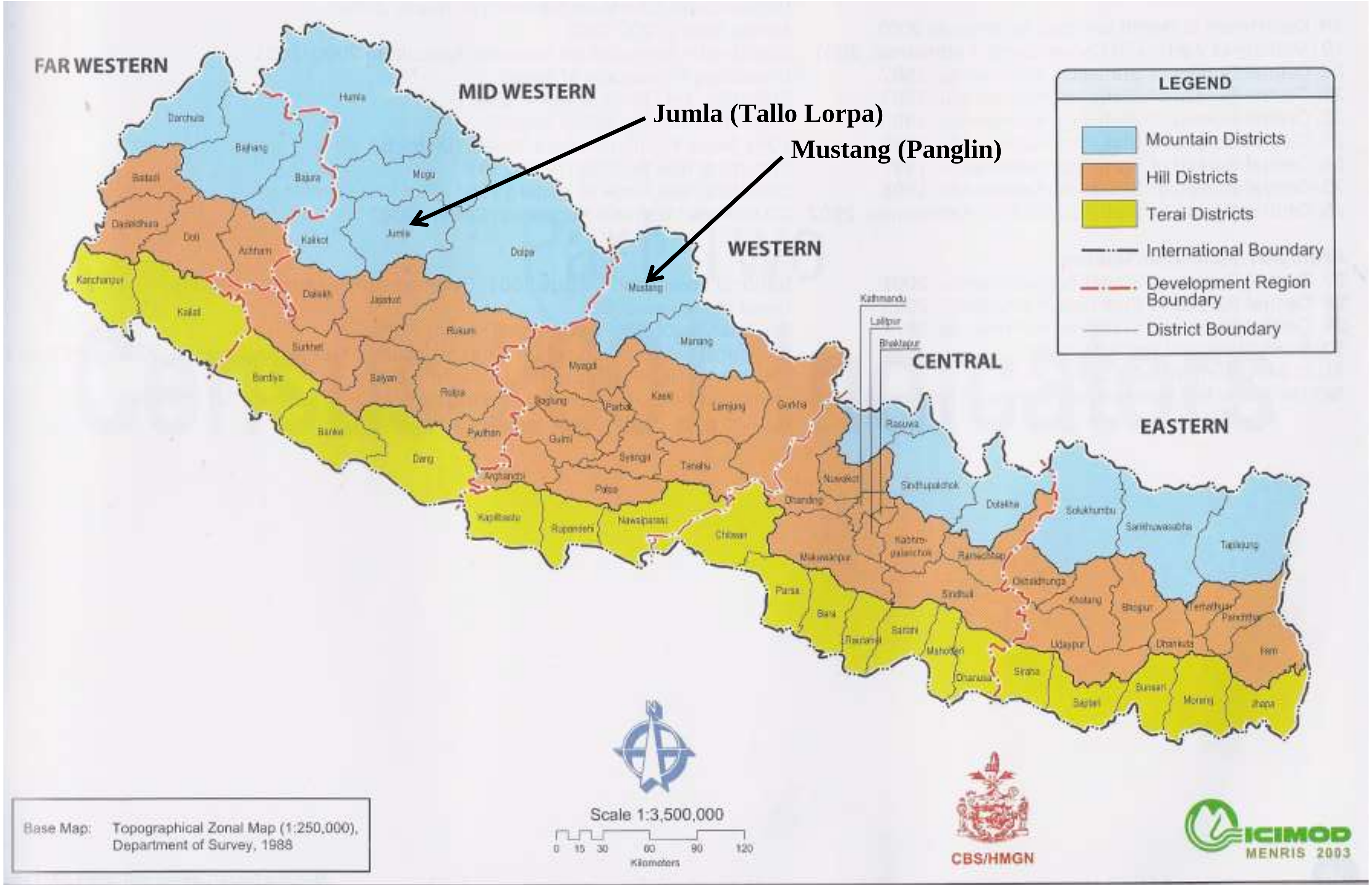


Figure 2.1: Administrative map of Nepal taken from CBS (2003) showing district borders, physiographic zones and development region boundaries.

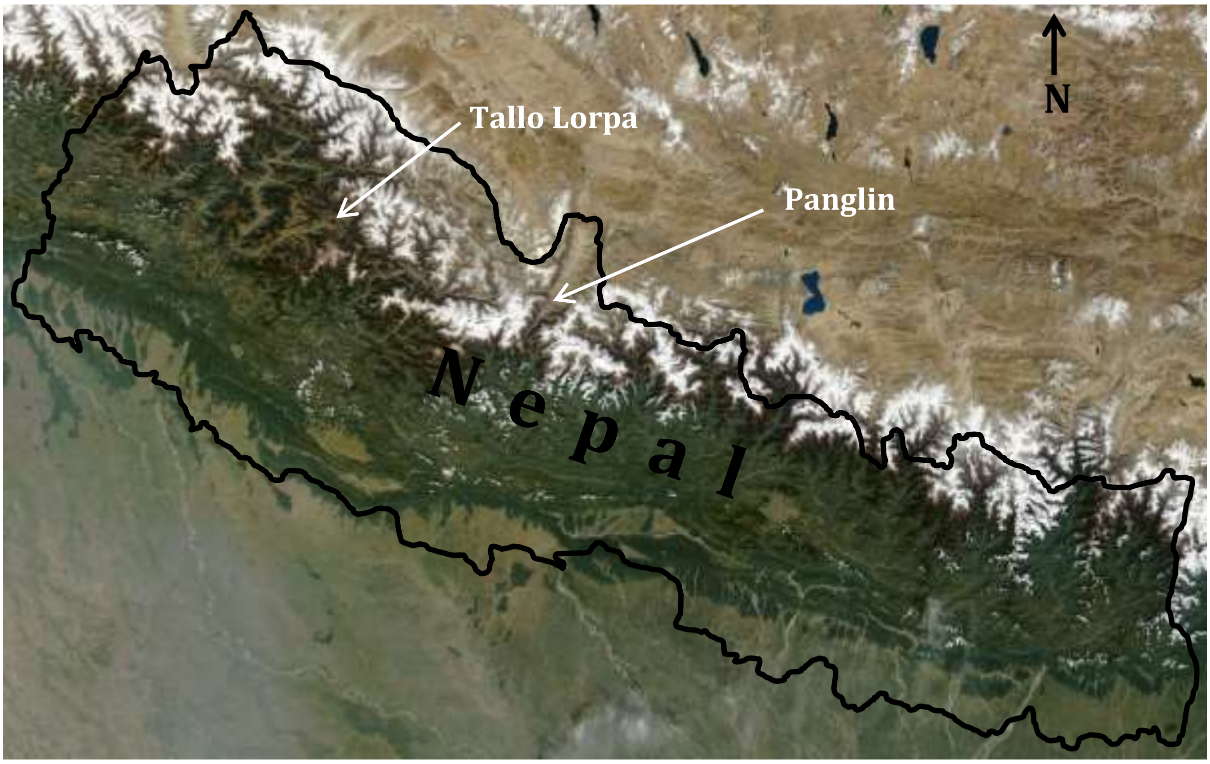


Figure 2.2: Satellite image of the Central Himalayan Range taken on the 27th of October 2002 (Modified from NASA(2002)). The rain shadow effect of the Himalayas is clearly visible with the foothills on the southern side of the range able to support dense vegetation while the Tibetan Plateau to the North is almost barren. Panglin's position north of the Annapurna and Dhaulagiri Himalayas makes it visibly drier than the area to the south. Likewise, Tallo Lorpa's position, while south of the highest part of the range, is also visibly drier than areas to the south.

2.4.1.1 Connections to Urban Centres

Panglin and Tallo Lorpa experience differing degrees of isolation. Panglin is connected to the Jomsom-Muktinath trekking route via a suspension bridge over the Kali Gandaki River, as shown in Figure 2.3. This route is part of the world famous Annapurna circuit which attracts an average of 18,583 trekkers per annum (Lama, 2010). Jeeps are able to use this trail between Jomsom and Muktinath, however there is no vehicle bridge linking it to the recently constructed Jomsom-Beni road running south from Jomsom, therefore almost all the jeeps are run on a commercial basis. These jeeps are expensive but affordable for many in Panglin. Tractors are able to cross the Kali Gandaki River in most conditions outside the monsoon season, and are therefore able to deliver produce to markets and bring outside materials and supplies to the community. It takes around two hours to walk the ten kilometres between Panglin and the district headquarters of Jomsom while commercial jeeps do the journey in 10-15 minutes.

Tallo Lorpa is more isolated than Panglin, located approximately four kilometres from the small community of Urthu, a journey which takes around one hour on foot. Urthu is connected to the district headquarters of Jumla by six kilometres of four wheel drive trail as shown in Figure 2.4. There are few privately operated vehicles in the district and commercial charter of jeeps is considerably more expensive than in Mustang. As a result, almost all produce and supplies are carried, either on foot or by livestock caravan, to and from market. The journey on foot from Urthu to Jumla takes around two hours, making the journey on foot between Tallo Lorpa and major markets in Jumla approximately three hours each way in total. The trail linking Tallo Lorpa to Urthu is being constructed as a vehicle track, however at present there is no vehicle bridge across the Jawa River at Urthu. The bridge connecting Tallo Lorpa to this trail is suitable for people and livestock, but is vulnerable to floods (ICIMOD, 2012). Planning for the construction of a suspension bridge is underway.

Figure 2.3: Google earth image of the route between Jomsom and Panglin form a virtual eye altitude of 11.41km asl.

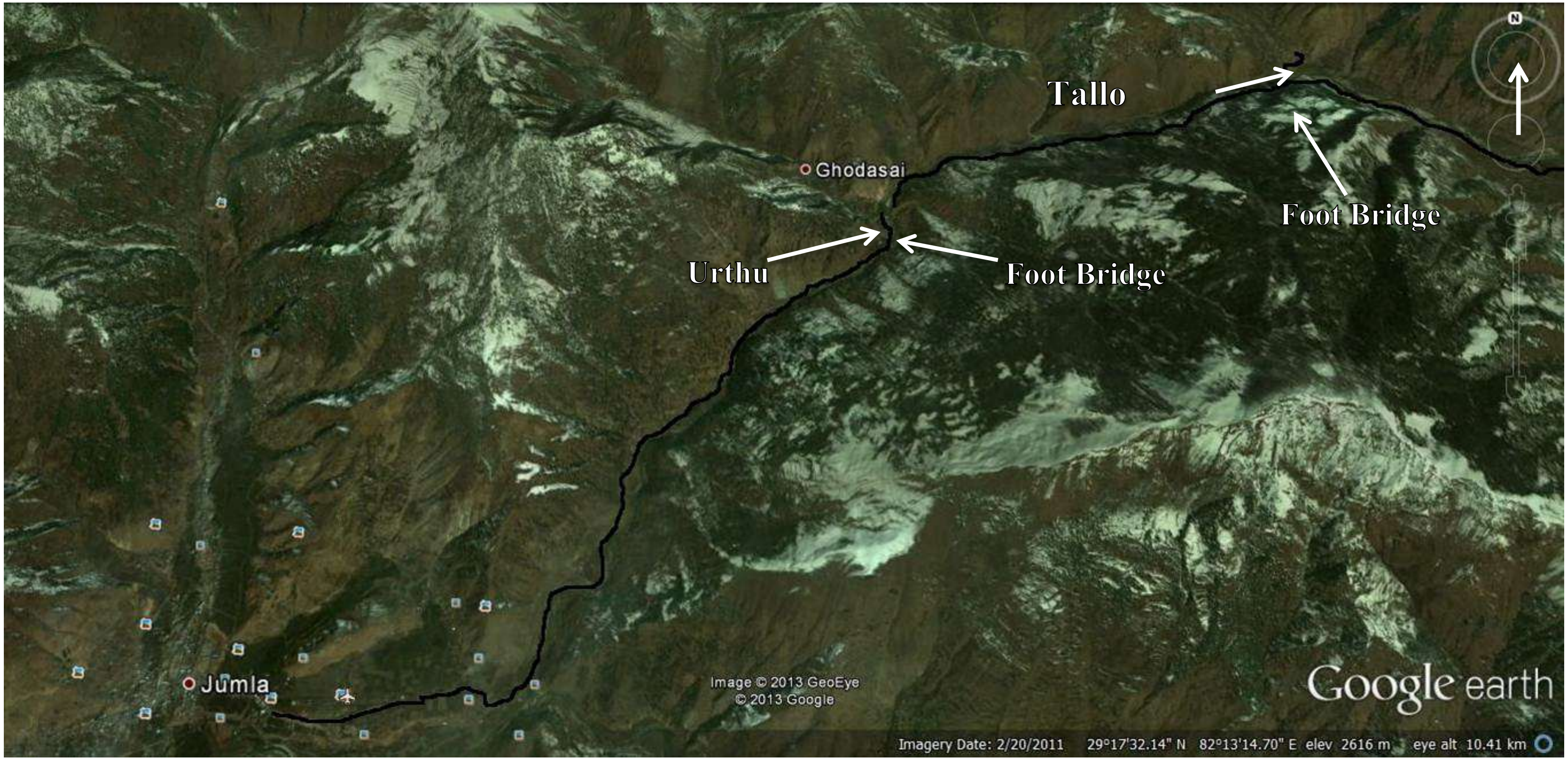


Figure 2.4: Google earth image of the route between Jumla and Tallo Lorpa from a virtual eye altitude of 10.41km asl.

2.4.1.2 Watershed Character

The watersheds in which Panglin and Tallo Lorpa are situated are both mountainous sub-catchments of larger rivers, though they differ in terms of size, land cover and relief. Panglin is located in the Panglin watershed and receives water from the Pan Khola which discharges into the Kali Gandaki River (Figure 2.5). Panglin is the lowermost of three settlements in the Panlin watershed, the others being Phalyak and Dhagarjung. Tallo Lorpa is located in the Ghatte Khola watershed and receives water from the Ghatte Khola which discharges into the Jawa River (Figure 2.6). There are two settlements in the Ghatte Khola watershed, Tallo Lorpa and Mathillo Lorpa. The Pan Khola watershed covers an area of 3,014ha and ranges between 2,902m asl and 5,304m asl. The Ghatte Khola watershed is smaller and lower by comparison, covering an area of 1,258ha and ranging between 2,523m asl and 4,105m asl.

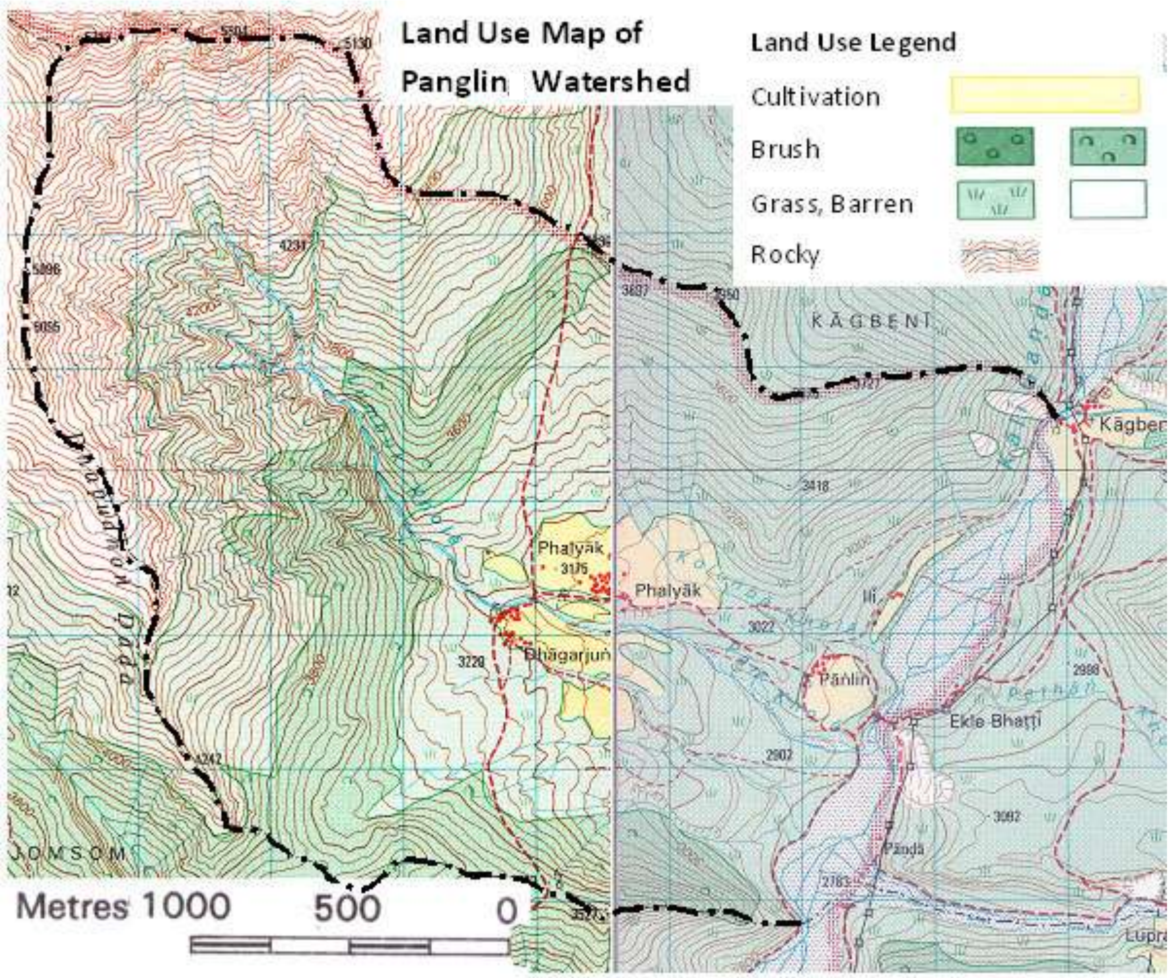


Figure 2.5: Topographical map of the Panglin watershed.

Figure 2.6: Topographical map of the Ghatte Khola watershed.

The Panglin watershed has smaller proportions of steep and moderately steep terrain than the Ghatte Khola watershed (Tallo Lorpa) (Table 2.1). Importantly, the Panglin watershed has approximately 97ha of reasonably flat land (3% of the catchment area) whereas the Ghatte Khola has only 2.25ha of reasonably flat land (0.2% of the catchment area). The deficiency of flat land around Tallo Lorpa has led to terracing of steeper land within the catchment. This is not required around Panglin.

Table 2.1: Catchment terrain in terms of slope percentage for the Panglin and Ghatte Khola watersheds.

Slope	**% of Land Cover Panglin Watershed**	**% of Land Cover Ghatte Khola Watershed**
>60%	46%	73%
30-60%	30%	21%
15-30%	21%	6%
3-15%	3%	0.2%

Land cover also differs considerably between the two watersheds (Table 2.2). The Panglin watershed has a smaller proportion of agricultural land cover than the Ghatte Khola watershed (although the absolute areas of 80ha and 105ha respectively, are not hugely different). The Panglin watershed is covered primarily by grassland followed by shrub and rocky areas. By contrast, the Ghatte Khola watershed is covered predominantly by forest and secondarily by grassland. The differences in land cover outlined in Table 2.2 are clearly illustrated by comparing photographs of the Panglin and Ghatte Khola watersheds, shown in Figures 2.7 and 2.8 respectively.

Table 2.2: Land cover in the Panglin and Ghatte Khola watersheds. Data taken from ICIMOD (2012).

Land Cover	**% of Land Cover Panglin Watershed**	**% of Land Cover Ghatte Khola Watershed**
Agricultural Land	3%	8%
Shrub Land	18%	2%
Grassland	61%	32%
Forest Area	-	58%
Rocky Area	18%	-

Figure 2.7: Photograph of the Panglin watershed with Panglin village in the foreground.

Figure 2.8: Photograph of the Ghatte Khola watershed with Tallo Lorpa village in the foreground.

Variations in slope and aspect are small in the agricultural land of Panglin. In Tallo Lorpa by contrast, large variations in slope and aspect create highly variable agricultural conditions (Whiteman, 1985). Much of the sloping agricultural land in the Ghatte Khola catchment faces south and therefore benefits from the greater radiation receipts of this aspect. Smaller sections face in more south easterly or south westerly directions and receive reduced radiation receipts affecting temperature and soil moisture profiles (Dixit *et al.*, 2009; Whiteman, 1985). In short, while the productivity of agricultural land surrounding Panglin is reasonably consistent, the productivity of agricultural land surrounding Tallo Lorpa is variable. These differences in land quality greatly affect productivity as explained in Section 6.3.2 of the results section.

2.4.2 Climate

Climate in the South Asian region is dominated by the Indian Summer Monsoon (ISM). In the Himalayas of Nepal, the ISM manifests as a seasonal change in winds, from a dominant westerly flow over the relatively cooler winter months to a dominant easterly flow during the monsoon months, which brings humid air from the Bay of Bengal (Immerzeel *et al.*, 2012). In central Nepal, this moist monsoon air flow has been seen to bring as much as 77% of the annual precipitation in just four months (Immerzeel *et al.*, 2012). The absolute amount of monsoon precipitation is, however, highly variable (Shrestha *et al.*, 1999).

Precipitation is heavy where the moist air flow collides with the Himalayan foot hills (known as the Mahabharat Range or the Middle Range Mountains), particularly on the southern slopes due to orographic lifting (Shreshta & Aryal, 2011). These mountains provide the first major barrier to the monsoon (Shrestha & Aryal, 2011), and as a consequence of the rain shadowing effect of these barriers, monsoon precipitation decreases from east to west along the Himalayas and from south to north within them (Devkota, 2010; Chalise & Khanal, 2001). In the high mountain districts of Mustang and Jumla, the strength of the monsoon is substantially less than in southern and eastern parts of Nepal. Research has also shown that the Eastern Himalayas generally experience around eight months of monsoon flow, while the central Himalayas, which encompass the districts of Jumla and Mustang, experience only four months (Mani, 1981, in Devkota, 2010).

Winter climate in the Himalayan region is characterised by the intermittent procession of depressions from the west, known as ‘westerly disturbances’. In contrast to the monsoon flow (but through the same attenuation caused by rain shadowing effects), these depressions show a decreasing precipitation gradient from west to east in the Nepalese Himalayas (Singh *et al.*, 2011; Nayava, 1980, in Devkota, 2010). Although the amount of precipitation they bring is small relative to the monsoon, westerly disturbances are an important source of precipitation during the drier winter months (Merz *et al.*, 2002; Shrestha & Aryal, 2011). Furthermore, westerly disturbances commonly bring snowfall to the Himalayas, replenishing seasonal snow packs, particularly in western regions (Singh *et al.*, 2011). This snowpack provides vital water resources during the hot and dry pre-monsoon period (Singh *et al.*, 2011). The water resources available to the communities of Panglin and Tallo Lorpa are, therefore, intimately linked with the character of both the ISM and the westerly disturbances.

The northern and western parts of Nepal which encompass Panglin and Tallo Lorpa show a greater range in seasonal temperature than the rest of Nepal due to both higher latitudes and more continental climatic conditions (Devkota, 2005, in Devkota, 2010). Air temperatures are generally coldest during December, January and February and warmest during April and May. High air temperatures combine with low precipitation to make the pre-monsoon a particularly dry period (ICIMOD, 2012). Air temperatures generally decrease slightly during the monsoon season proper due to cloudiness, shading and precipitation (Devkota, 2010).

The mountainous nature of the Panglin and Ghatte Khola watersheds results in differing climatic zones in different parts of each watershed. Much of the Panglin watershed can be classified as having an alpine climate. The air temperature in Panglin ranges between a maximum of 26°C between May and July to a minimum of -9°C between December and February (ICIMOD, 2012). Above 4,500m asl this turns to a tundra classification as freezing conditions occur year round (ICIMOD, 2012). Water is scarce in Mustang and water bodies make up just 2% of the land cover in the district (Lama, 2010). Due to the dry air masses, convective precipitation is rare in Mustang, and precipitation from the monsoonal flow between the Annapurna and Dhaulagiri Himalayas tends to be light in nature and stratiform in origin (Lang & Barros, 2002). Soil moisture is low in the region, limiting vegetation growth and crop production (Lama, 2010; ICIMOD, 2012). Precipitation of less than 200mm per year on average, combined with high evapotranspiration and strong winds render the Pan Khola region an alpine semi-desert (Lama, 2010).

With respect to temperature, the lower part of the Ghatte Khola watershed can be classified as having a cold temperate climate, ranging between a maximum of 33°C between May and July and a minimum of -15°C between December and February (ICIMOD, 2012). Above 3,000m in the Ghatte Khola watershed, the climate can be classified as alpine (ICIMOD, 2012). The Ghatte Khola watershed is more humid than the Panglin watershed, receiving up to 800mm of precipitation per annum (ICIMOD, 2012). The climate in Jumla allows for the growth of needleleaf forests, but does not favour the growth of the broadleaf forests found at similar altitudes in other parts of the Nepalese Himalayas.

2.5 Resource Availability

2.5.1 Water Resources

Nepal is a water rich country containing more than 6,000 rivers delivering water from the Himalayas - which are often referred to as the water tower of Asia - to the plains of India (CBS, 1995, in Upreti, 2004). Much of the sacredness associated with the Himalayas is thought to relate to their perennial provision of water to communities below (Bandyopadhyay & Gyawali, 1994). Notwithstanding this vast water resource, Himalayan communities still suffer water stress due to inconsistency in headwater flow and difficulty in diverting or transporting river and stream water to crops on steep terrain (Bandyopadhyay & Gyawali, 1994). The nature and influence of these difficulties, as well as the absolute amounts of water available, differs between the communities of Panglin and Tallo Lorpa.

The absolute flux of fresh water available in Panglin is small because of its arid surroundings. Drinking water is sourced from a spring above the community and piped to a storage tank which feeds four village taps. Flow from this spring has been measured at 0.28 litres per second and is seen as sufficient for drinking water purposes at present (Sthapit & Dhakal, 2010; ICIMOD, 2012). Irrigation water is diverted from the Pan Khola at two points. While these two diversions do not capture sub surface flow, they are able to capture the vast majority of surface water in the Pan Khola, leaving little flow immediately downstream (Figure 2.9). Average flow in the upper canal is 12.4 litres per second, while in the lower canal, average flow is 2.9 litres per second, making the total available irrigation discharge 15.3 litres per second (Sthapit & Dhakal, 2010). This flow is captured overnight in two storage ponds and flushed to crops on a rotational basis during the daytime. Previous field work conducted under the High Mountain Agribusiness and Livelihood Improvement (HIMALI) project has identified substantial water loss through seepage from unlined canals. It has also been noted that the flash flood irrigation methods employed in Panglin are water inefficient (Khanal *et al.*, 2011; ICIMOD, 2012).

Figure 2.9: Surface flow of the Pan Khola immediately downstream from the two irrigation diversion points on the 12th of May 2012.

Khanal *et al.* (2011) identified the lack of irrigation water as a major problem in Panglin and suggest that this supply has been decreasing in recent years. The vulnerability spider chart (Figure2.10) produced by Khanal *et al.* (2011) clearly shows that a ‘lack of irrigation water’ and ‘dryness’ followed closely by ‘less rain’ and ‘less snowfall’ are the community’s main environmental concerns.

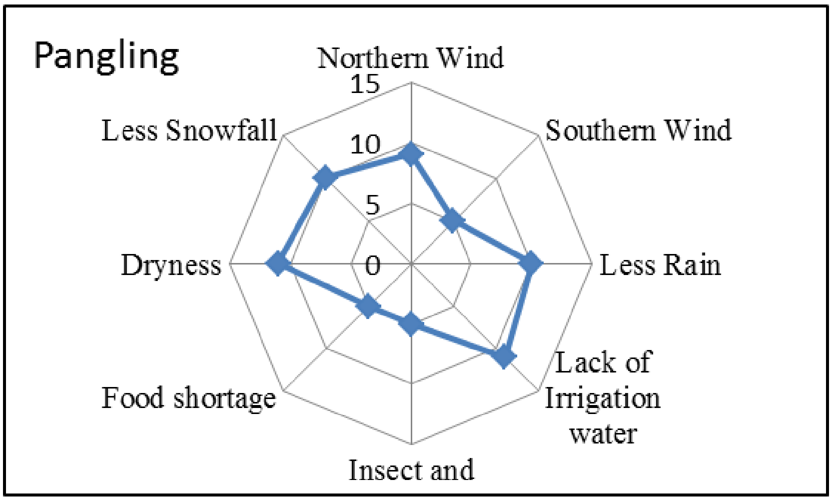


Figure 2.10: Vulnerability spider chart negotiated by members of the Panglin community and produced by Khanal *et al.* (2011). Higher values indicate higher perceived vulnerability.

Relative to Panglin, Tallo Lorpa is a water rich community in terms of absolute availability. Average annual flow in the Ghatte Khola is 292 litres per second, ranging between a monthly average minimum of 99 litres per second in February and maximum of 866 litres per second in August. Domestic water is supplied to the community through 14 private taps and 6 public taps. In the past, water was diverted from the Ghatte Khola by eight irrigation canals. While some irrigation continues, these canals have largely been abandoned due to cropping changes from barley to maize and potatoes (ICIMOD, 2012). As with many mountain regions in Nepal, the amount of water used for irrigation is small relative to the amount available (Bandyopadhyay & Gyawali, 1994). Agricultural land in Tallo Lorpa is predominantly rain fed. Water flowing from the Ghatte Khola into the Tila River represents irrigation potential. Despite this water endowment and irrigation potential, dryness is still identified by members of the community as the primary environmental concern, as shown by Shrapit *et al.* (2010) in Figure 2.11.

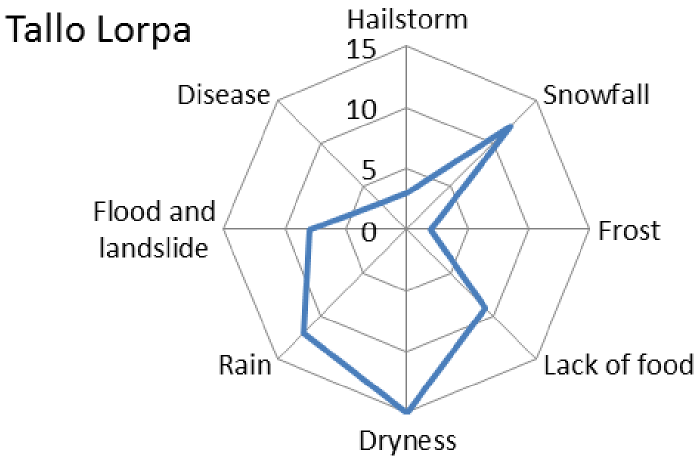


Figure 2.11: Vulnerability spider chart negotiated by members of the Tallo Lorpa community and produced by Sthapit et al. (2010). Higher values indicate higher perceived vulnerability.

Water in the Ghatte Khola is used for energy in a number of traditional and modern water mills as well as in a micro hydroelectric plant. Water use for this purpose has the potential to compete with water use for agriculture if irrigation were to expand.

2.5.2 Agricultural Land and Rangeland

Access to agricultural land and rangeland differs substantially between Panglin and Tallo Lorpa. The Panglin watershed has large areas of uncultivated flat land which, given nutrients and irrigation, could be used productively (ICIMOD, 2012). As a consequence, land area is not a limiting factor for agriculture in this community. The fragility of the surrounding rangeland, however, makes overgrazing by livestock a concern (Sthapit & Dhakal, 2010). Private land produces only 26% of domestic livestock fodder needs in Panglin; the rest is fulfilled by grazing on public land (Sthapit & Dhakal, 2010). Steppe grazing area in the Panglin watershed is only 72.6% of what is required for sustained grazing by community livestock and as a result, rangelands have been degrading rapidly (Khanal *et al.*, 2011; Sthapit & Dhakal, 2010). As noted by Khanal *et al.* (2011), stakeholders in the village point out that there is sufficient rangeland in the region, however much of it is inaccessible due to the challenging geography. The need for access paths to rangelands is stressed by representatives from the District Livestock Sales Office (Khanal *et al.*, 2011).

Tallo Lorpa by contrast suffers from geographic limitations on agricultural land; however degradation of rangeland is less of an issue. All of the flat land in the Ghatte Khola watershed, along with large areas of moderately sloping or steep land, is cultivated. Potential for agricultural expansion is therefore limited in the Ghatte Khola watershed.

2.5.3 Agricultural Resources

Panglin and Tallo Lorpa are both agriculturally based communities. The mountain regions of Nepal face a number of agricultural challenges. A total of 7.3% of Nepal’s population live in mountain regions, however these people use only 0.3% of the country’s cultivated land (Gill, 2003). Mountain regions also suffer from extreme temperatures, short growing seasons, slow growth rates and poor soils (Gill, 2003). Furthermore, the agricultural advancements of the green revolution have been relatively ineffective in mountain regions and productivity increases have been small compared to those on the plains (Rasul & Karki, 2007). Staple foodstuff deficiency is common in Nepal’s mountain regions and is experienced to differing extents in Panglin and Tallo Lorpa.

Panglin is surrounded by 28 hectares of cultivated land on which the main crops include buckwheat, barley, oats, potato, beans and apples (ICIMOD, 2012; Khanal *et al.*, 2011; Sthapit & Dhakal, 2010). Between the months of November and April, minimum air temperatures in the area are below the tolerance range of staple crops, leaving only a short growing season (ICIMOD, 2012). The community faces a cereal crop deficit of 17.86 tons (Khanal *et al.*, 2011), however cash crop sales amounting to 1.6 million rupees per year more than compensate for this deficit (Sthapit & Dhakal, 2010; ICIMOD, 2012), and as a result food sufficiency is rarely an issue.

Livestock complement crop production in Panglin through a diversification of production and as a source of manure (Lama, 2010). There are more than 350 livestock units in Panglin (Khanal *et al.*, 2011). These are mainly goats but there are also cattle, sheep, and mules. These livestock provide adequate manure for less than half (11.4ha to 15ha) of Panglin's agricultural land (Khanal *et al.*, 2011); however expansion of livestock numbers would further strain rangeland in the area.

The main crops grown in Tallo Lorpa are maize, barley, wheat, millet, potatoes and beans (ICIMOD, 2012). Minimum and maximum air temperatures are generally below the optimal range for these crops throughout the growing season (ICIMOD, 2012; Whiteman, 1985). Tallo Lorpa lies on the upper limit of where two crops can be grown per year. This condition is tenuous and whether the first crop ripens before the second crop needs planting depends on how favourable conditions are in each individual season (Whiteman, 1985). Crops on south facing slopes generally have more chance of ripening in sufficient time (Whiteman, 1985); although this land is limited and already heavily cultivated in Tallo Lorpa. These challenging conditions combined with small landholding size (Whiteman, 1985) limit food production in the area. Tallo Lorpa produces sufficient cereal foods for its population; however a proportion of this is sold to market, generating around 465,000 rupees of revenue (ICIMOD, 2012). Much of this revenue is spent on non-foodstuffs and as a result, food shortage is a common condition in Tallo Lorpa.

2.5.4 Other Industries

Panglin and Tallo Lorpa show similarities and differences in terms of non-agricultural opportunities and industries. The areas surrounding both communities are rich in high value medicinal and aromatic plants (NTNC, 2008, in Khanal et al, 2011; ICIMOD, 2012). For example, yarsagumba (*Ophinocordyceps sinensis*), a parasitic fungus that colonises and mummifies ghost moth larvae, is found in high altitude parts of both Mustang and Jumla. yarsagumba is highly valued in Chinese traditional medicine and is used as an aphrodisiac, among other things. Collection and sale of this fungus constitutes an important non-agricultural source of income in both communities.

Opportunities for income from tourism are far greater in Panglin than in Tallo Lorpa. As mentioned in Section 2.4.1.1, Panglin lies close to the Annapurna Circuit which attracts an average of 18,583 tourists per year (Lama, 2010). This stretch of trail is also the main route to the temple of Muktinath, one of the most highly revered pilgrimage sites in Nepal for both Hindus and Buddhists. The number of pilgrims visiting the site has risen dramatically since the Beni-Jomsom road opened in 2007. In 2005, 722 South Asian nationals were recorded as having visited the site whereas by 2009 this had risen to 8,846 (Lama, 2010). These high visitor numbers benefit the community of Panglin by increasing demand for local produce and providing further employment opportunities.

Relative to Mustang, very few tourists visit Jumla. Of those who do, many travel to see Rara Lake, the largest lake in Nepal. This does not take them near Tallo Lorpa and therefore the tourist industry in this community is negligible.

2.6 Human Geographies

Human geographies influence social vulnerabilities as they exist in this investigation. Socioeconomic difficulties present in Panglin and Tallo Lorpa again reflect common mountain specificities. These difficulties are described in this section through an examination of broad social statistics and inequality; an exploration of recent Nepalese history; and a description of the institutional context in Panglin and Tallo Lorpa.

2.6.1 Social Statistics

The socio-economies of Panglin and Tallo Lorpa differ greatly. The most obvious differences relate to population and population density. As shown in Table 2.3, Panglin has less than half the population, and exactly half the number of households, as Tallo Lorpa. The district of Mustang is one of the most sparsely populated in Nepal, with a population of only 15,225 projected for 2011 (ICIMOD, 2012). Jumla, by contrast, is more densely populated, with a population of 101,223 projected for 2011 (ICIMOD, 2012).

Table 2.3: Population statistics for the communities of Panglin and Lorpa, sourced from ICIMOD (2012).

	# of Households	Male Population	Female Population	Total Population
Panglin	35	101	83	184
Tallo Lorpa	70	212	203	415

Census data analysed by the Central Bureau of Statistics (CBS, 2003) illustrate the performance of individual districts against development indicators as well as an overall composite development index (Table 2.4). Mustang ranked 14th out of the 75 districts in Nepal in terms of overall development, placing it in the most developed quartile. Jumla ranked 68th, indicating that it is one of the least developed districts in Nepal. Differences between the two districts are clear when comparing individual development indicators, where 1st is the most positive scenario and 75th the least. As shown in Table 2.5, Mustang performs substantially better than Jumla in terms of access to improved sources of drinking water, child dependency ratio, child malnourishment, school enrolment, literacy and cereal crop yield. These figures indicate that communities in Mustang are wealthy compared to communities in Jumla. This disparity is likely to be reflected in respective social vulnerabilities.

Table 2.4: District ranking (out of a total of 75 districts) in terms of individual development indicators as well as an overall composite development index ranking. Data taken from Nepal's Central Bureau of Statistics (2003).

	Mustang Ranking	**Jumla Ranking**
Overall Development Index	**14**	**68**
Access to Improved source of Drinking Water	28	44
Child Dependency Ratio	3	53
Proportion of Malnourished Children Under 3 Years	2	58
Primary School Net Enrolment Ratio	1	57
Literacy Rate of Population 15-24 Years	30	73
Yield of Cereal Crops (KG/Hectare)	53	73

2.6.2 Equality/Inequality

Moving beyond macro level development statistics gives a clearer understanding of the socio-economy in each study community. Disparities in wellbeing are interlinked with disparities of wealth and capital. Inequalities in terms of productive land ownership and water access are widespread in Nepal (Upreti, 2004). The 1998 Human Development Report for Nepal shows that the smallest 40% of landholdings make up only 9% of the total agricultural area in Nepal. Inequalities like this strongly influence social vulnerabilities to water stress.

Gender inequality must also be considered for its effect on social vulnerabilities. National census data show that the district of Mustang is in the best performing quartile in terms of gender equality in non-agricultural employment, adult literacy and primary education (Table 2.6) (CBS, 2003). By contrast, Jumla is in the bottom district quartile for these three indicators.

Table 2.5: District ranking (out of a total of 75 districts) in terms of gender equality indicators. Adapted from Nepal's Central Bureau of Statistics (2003).

	Mustang Ranking	**Jumla Ranking**
Share of Women in Wage Employment in Non-Agricultural sector	16	60
Ratio of Literate Female to Literate Male – 15-24	17	70
Ration of Girls to Boys in Primary Education	4	70

Consistent with the findings for the districts of Mustang and Jumla, gender equality appears to be greater in Panglin than in Tallo Lorpa. In Panglin, labour responsibilities are seen to be shared equally between males and females (ICIMOD, 2012; Khanal *et al.*, 2011). In Tallo Lorpa by contrast, men are engaged in work for only 235 days a year whereas women work for 295 days per year (ICIMOD, 2012).

2.6.3 Historical Context

Recent Nepalese history is dominated by the Maoist insurgency which ran between 1996 and 2006. The effects of this armed conflict were greater in Jumla than in Mustang. Mustang is geographically separated from much of the rest of Nepal and as a result, political tensions, conflicts and strikes rarely affect life in Panglin, even after the construction of the Beni-Jomsom road. Jumla by contrast was a Maoist stronghold at times during the conflict, which shaped everyday life and development in the district. The influence of the Maoist insurgency can therefore be seen as substantial in Jumla and only moderate in Mustang.

The insurgency had many negative consequences for the everyday lives of Nepalese people as well as for the nation's overall development (Nirmal *et al.*, 2009). The provision of state services declined markedly during the insurgency period, particularly in rural areas (Banjade & Timsina, 2005; Jing & Leduc, 2010). Furthermore, transportation was often disrupted and the transportation network deteriorated, making trade in produce and important commodities, such as fuel, medicine and labour, difficult (Jing & Leduc, 2010). These impediments made it hard to meet development goals, and those who stood to benefit from these became indirect victims of the conflict (Nirmal *et al.*, 2009). While the conflict formally ended in 2006, continuing political instability commonly leads to strikes and road closures, further disadvantaging rural market involvement (Dixit *et al.*, 2009). A lack of service provision and reduced access to market can be seen as consequences of the conflict in Jumla. In Mustang, however, the transportation network was in fact greatly improved toward the end of the conflict through the construction of the Beni-Jomsom road, completed in 2007 (Lama, 2010).

In parallel with its impediments, the Maoist insurgency also brought substantive benefits to the livelihoods of many in rural Nepal. Nirmal *et al.* (2009), using examples from community forest users' groups, show that the conflict had a number of pro-poor outcomes. Nirmal *et al.* (2009) cite an ancient Nepali proverb that states 'unless the old order is destroyed, no new order can emerge'. Their argument is that, in many cases, the benefits which have emerged from the new pro-poor social order outweigh the overall negative impact that the insurgency had on development. The Maoist insurgency was fundamentally based on the interests of the poor and it began largely because the benefits of development and advancement were not being seen in all areas and by all people. It was with the poor that insurgents generally sheltered; and their narratives, whether passive or militant, were largely intertwined (Nirmal *et al.*, 2009). Before the conflict, local institutions such as forestry councils and development boards were run by the elite and responded to the interests of the elite, altruistic or otherwise. Maoist influence during the conflict challenged these leadership structures and forced these institutions to include the interests of the poor (Nirmal *et al.*, 2009). This allowed the poor access to institutional funds and capital which have since been used for pro-poor development projects. Where elites still control local institutions, their awareness of, and support for poorer populations have been enhanced. For example, since the uprising, some local institutions have redirected funds from projects such as temples (from which Dalit and other marginalised peoples are excluded) to more inclusive and productive means (Nirmal *et al.*, 2009). Maoist pressure has led some elites to reduce the interest on loans provided to the poor (Nirmal *et al.*, 2009). These changes in power structures and governance are examples of the 'new order' that the Nepali proverb alludes to. The emergence of this 'new order' is likely to have played a large part in the conflict's eventual resolution (Upreti, 2004).

It is highly likely that pro-poor restructuring occurred in both Mustang and Jumla during the conflict. These effects were probably more apparent in Jumla than Mustang, given the relative influence of the conflict in these two districts. It is important to understand that, while the conflict had a number of pro-poor outcomes, hierarchical class structures based on religious notions of purity persist in Nepali culture (Lama, 2010), and these structures still greatly influence individual vulnerabilities.

2.6.4 Institutional Involvement

Community and external institutions affect livelihoods, development and social vulnerabilities in both communities. An obvious example in the case of Panglin and Tallo Lorpa is their selection as study communities in the HIMALI project, run by the International Centre for Integrated Mountain Development (ICIMOD). During this project, institutional involvement within each community was assessed in consultation with community members. This produced Venn diagrams identifying the importance of institutions and their position in relation to the community (Figures 2.12 and 2.13). In Panglin, this exercise identified four village level institutions and five institutions from outside the village which are important to the community (Figure 2.12).

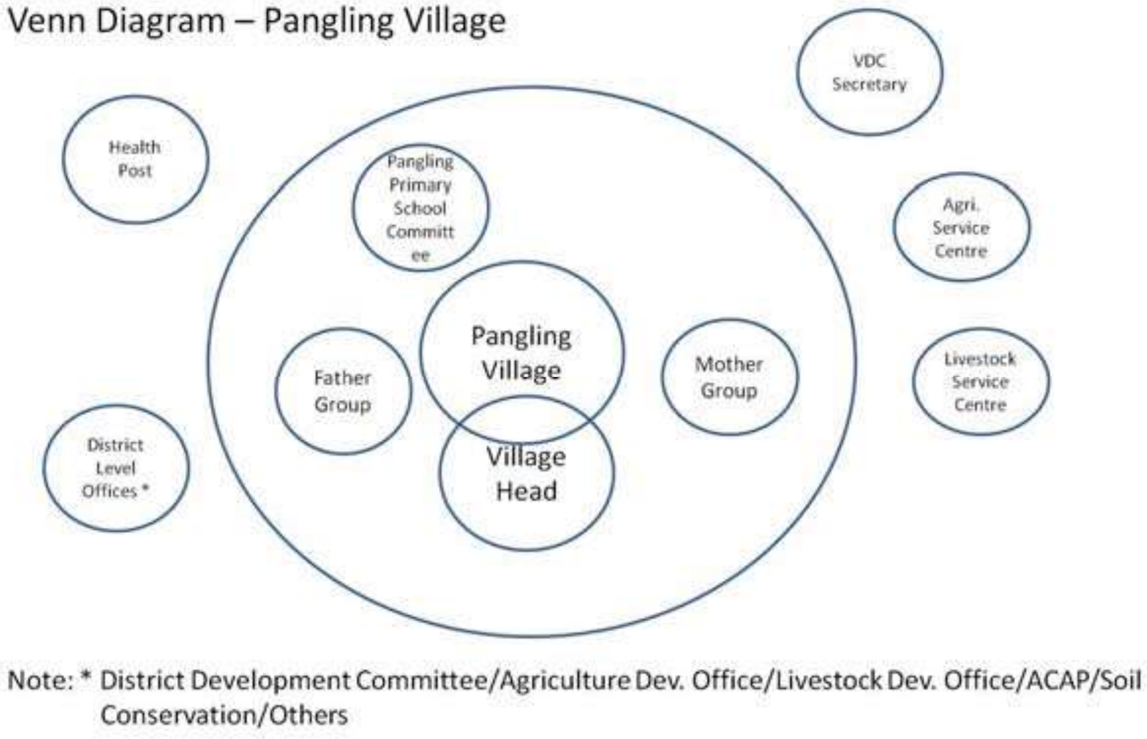


Figure 2.12: Venn diagram of institutional involvement in the community of Panglin. Taken from ICIMOD (2012).

Local level institutions were more numerous in Tallo Lorpa, with ten being identified by community members. In addition, five external institutions were identified as important for community members in Tallo Lorpa (Figure 2.13).

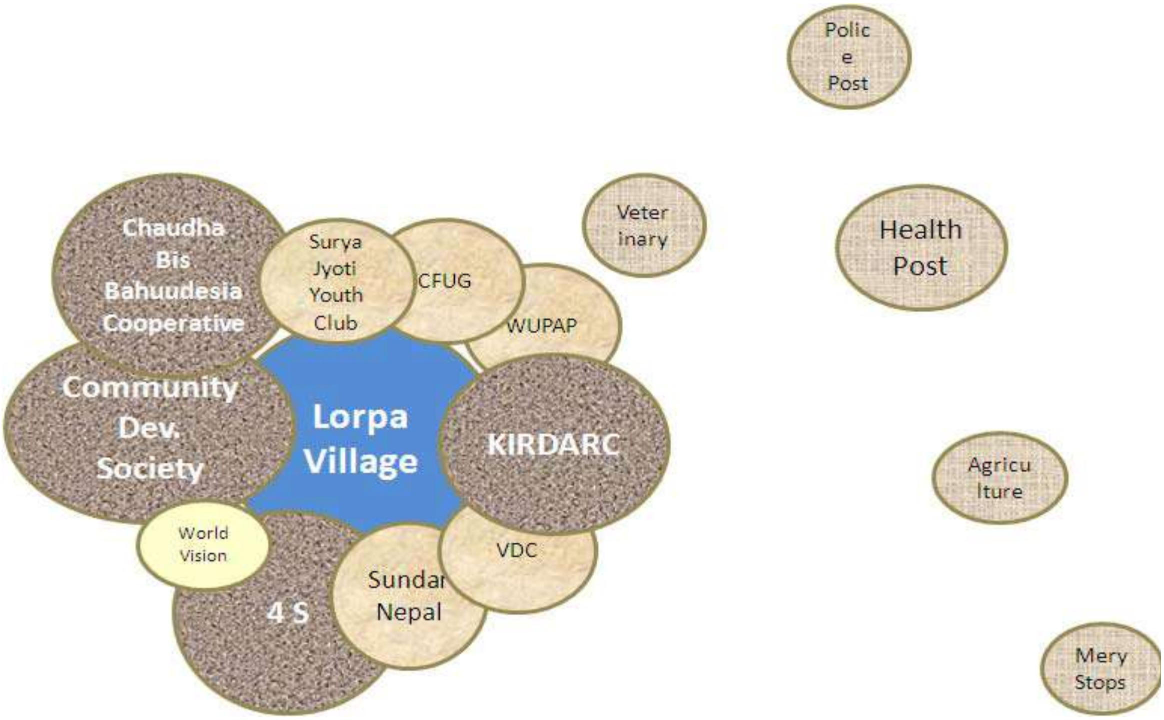


Figure 2.13: Venn diagram of institutional involvement in the community of Tallo Lorpa. Taken from ICIMOD (2012).

It is important to understand here that not all institutional involvement brings positive benefit. Technocratic interventions which ignore indigenous knowledge leading to negative outcomes for community members have been identified in the realm of natural resource management (Richards, 1986; Upreti, 2004). The influence of institutions on vulnerability and adaptive capacity is elaborated upon in Section 4.4.2.

The institutions identified in the two previous figures are likely to have differing degrees, and possibly even differing directions, of influence on community and household vulnerabilities. Beyond their simple identification, however, little is known about their effectiveness. Institutional efficacy was therefore investigated in field research for this thesis and analysis is presented in Section 6.7.5 of the Results Chapter.

2.7 Summary

The communities of Panglin and Tallo Lorpa are appropriate case studies for the investigation of biophysical vulnerability to water stress under climate change. Both communities are exposed to hazard from water stress under climate change and have identified social vulnerability to this hazard. These communities share a number of general characteristics; however the physical and socio-economic contexts of each community differ substantially.

Panglin is situated in an alpine semi-desert with reasonable access to markets. The community suffers from a cereal crop deficit, though through trade of cash crops, does not face food shortage. Tallo Lorpa by contrast has limited access to markets and exists in a humid cold-temperate climate. Enough cereal food is grown in Tallo Lorpa to feed its population, however some of this cereal produce is traded, leading to periodic food shortage.

The district of Mustang is both more developed and more gender equal than the district of Jumla. It can be expected that Tallo Lorpa was affected to a greater degree by the Maoist insurgency than Panglin, resulting in both negative and positive livelihood outcomes. Internal institutions are more numerous in Tallo Lorpa than in Panglin, however external institutional involvement is similar between these two communities. These physical and socio-economic contexts affect the realisation of biophysical vulnerability and must therefore be considered throughout this investigation.

Chapter Three

Review of the Hydrological Effects of Climate Change in the Himalayas of Nepal

3.1 Introduction

This chapter describes the emerging understanding of the effects of climate change on water availability in the Himalayas of Nepal. Changes in water availability are defined as a ‘hazard’ following the definitions of Brooks (2003). This hazard is physically defined and independent of the character of the communities in question insofar as changes in their contributions to greenhouse gas emission are negligible. The findings of this chapter inform both steps of the theoretical regression set up in Chapter One.

The chapter begins by outlining what is currently understood about climate change and how it affects water availability. Projected climate changes in the Himalayan region are then discussed. These changes in climate are subsequently linked to changes in runoff using a perceptual model which describes the links between climatic characteristics and runoff and the links between catchment characteristics and runoff. Existing studies into the hydrological effects of climate change in the Himalayas are then reviewed. Finally, in light of this analysis, the review seeks to answer the question ‘How is water availability likely to change in Panglin and Tallo Lorpa under climate change?’

3.2 Climate Change

3.2.1 Global Climate Change

Scientific understanding of global climate change has improved substantially in recent time. The Intergovernmental Panel on Climate Change (IPCC) reports on the current state of knowledge on climate change. The IPCC periodically releases Assessment Reports, the fourth and most recent of which was released in 2007. While parts of this report can now be seen as dated, given ever emerging research and anticipating the release of a Fifth Assessment Report in 2014, much of the general understanding remains accepted.

According to the Fourth Assessment Report (AR4), globally averaged land air temperatures rose by 0.74°C in the 100 years to 2005. This observed warming trend was seen to accelerate in the latter part of the century to double the rate observed over the time period as a whole (IPCC, 2007). Confidence has grown that this warming trend is real, and can be primarily attributed to anthropogenic emissions of greenhouse gas (IPCC, 2007).

Beyond the observation of climatic change, Atmosphere and Ocean General Circulation Models (GCMs) are being developed continually in order to simulate the global scale dynamics of climate. GCMs are used to form projections of changes in the global climate system under different scenarios of greenhouse gas emission. The GCMs being used by the IPCC are based on accepted physical principles and have been developed to a level where “there is considerable confidence that climate models (GCMs) provide credible quantitative estimates of future climate change, particularly at continental scales and above” (IPCC, 2007, P. 594). Over the last two decades, GCM projections have generally been validated by observations of current climate (IPCC, 2007).

The IPCC reports on projections of climate sensitivity in a comprehensive review of scientific studies using a range of GCM ensembles. Climate sensitivity is a measure of the change in climate for a defined greenhouse gas concentration in the atmosphere. The AR4 suggests that, for a doubling of CO_2 concentration from pre-industrial levels:

> “Climate sensitivity is likely to lie in the range 2°C to 4.5°C, with a most likely value of about 3°C. Equilibrium climate sensitivity is very likely larger than 1.5°C. For fundamental physical reasons, as well as data limitations, values substantially higher than 4.5°C still cannot be excluded” (IPCC, 2007, p.749).

Given these estimates of climate sensitivity, and the current rate of greenhouse gas emissions, increases in global temperatures during the 21st century are “*very likely* [to] be larger than those observed during the 20th century” (IPCC, 2007, p. 748). The expected increases in global temperatures will have substantial impacts on the hydrological cycle, and ultimately the availability of fresh water in many parts of the world (Bates *et al.*, 2008; Barnett *et al.*, 2005; Beniston, 2003; Devkota, 2010; Eriksson *et al.*, 2009; Gosain *et al.*, 2010; Immerzeel *et al.*, 2012; Kaser *et al.*, 2010; Renoj *et al.*, 2007; Shrestha & Devkota, 2010; Singh *et al.*, 2011).

3.2.2 Effects of Climate Change on Water Availability

Increased temperatures caused by climate change are expected to intensify the hydrological cycle through increases in globally averaged evapotranspiration, precipitation and vapour pressure (Singh *et al.*, 2011; Beniston, 2003; Barnett *et al.*, 2005; Jianchu *et al.*, 2007; Bates *et al.*, 2008). Evidence of these changes is emerging worldwide. For example, Dai *et al.* (1997) found that precipitation over land increased by close to 2% between 1900 and 1988. Furthermore, Groisman *et al.* (2004) found increases in precipitation, stream-flow, evapotranspiration and near surface humidity in observational records of the last 50 years in the contiguous United States. Bates *et al.* (2008) point out that while increases in precipitation were observed in high northern latitudes over the 20th century, decreases in precipitation have been apparent between 10° and 30° North since the 1970s. Barnett *et al.* (2005) suggest that along with changes in average hydrological parameters, variability has increased and seasonality has changed in some places. The influence that intensification of the hydrological cycle has had on regional water availability is, therefore, variable. Water availability has increased in some regions and decreased in others while generally becoming more erratic and unpredictable.

Changes in climate on a regional scale are highly dependent on patterns of global circulation, meaning that changes in water availability under climate change are spatially variable (Bates *et al.*, 2008). Warming on a global level is expected to result in an expansion of the global latitudinal redistribution of heat and air known as the Hadley Cell circulation. This is expected to lead to decreased precipitation in subtropical regions and increased precipitation in the high latitudes and areas of tropical maxima (IPCC, 2007). There is some suggestion that this latitudinal redistribution is already observable on a global scale, with a large contribution from decreases in precipitation over parts of Sub-Saharan and Sahelian Africa (Bradley *et al.*, 1987; Zhang *et al.*, 2007).

Changes in the hydrological cycle and changes in global circulation occur in conjunction with changes in the intensity and timing of precipitation. Increases in temperature and precipitation on a globally average basis will be accompanied by increases in variability (Bates *et al.*, 2008; Eriksson *et al.*, 2009; Singh *et al.*, 2011; Singh & Bengtsson, 2004). Again, increases in climatic variability are already being observed in many parts of the world (Dixit *et al.*, 2009; Gosain *et al.*, 2010). One striking example comes from the work of Dai et al (2004) who found that there has been a 90% increase in very dry or very wet areas globally since 1972. Exacerbation of climatic extremes occurs because climate change not only shifts the distribution of precipitation events; it also changes the shape of their statistical distribution such that extremes of high or low/heavy or light precipitation become more common in both absolute and relative terms (Boe *et al.*, 2009).

While increased water fluxes brought about by an accelerated hydrological cycle may deliver benefits to some people in some areas at some times (Georgievskii *et al.*, 1996), the aggregate effects of these changes are expected to be generally detrimental (Chalise & Khanal, 2001; IPCC, 2007). Increased flooding in some areas may be concomitant with increased drought in others, while decreases in water quality and variation in the timing of runoff are also expected (Bates *et al.*, 2008; IPCC, 2007). The IPCC states with *high confidence* that changes in water availability under climate change will have overall negative consequences for each of the IPCC regions. It is therefore important to investigate the hydrological effects of climate change at the local scale in order to identify likely water resource issues in the future.

3.2.3 Climate Change in the Himalayas of Nepal

3.2.3.1 Observed Climate Change in the Himalayas

Despite the scant observational networks in the Himalayas, a number of changes in climate have been identified. The most well monitored and documented of these changes are increases in average temperatures. A widely cited investigation by Shrestha *et al.* (1999) analysed maximum temperature data from 49 stations across Nepal. The authors found that temperatures had been consistently and continuously rising since the mid-1970s in Nepal and that the average rate of warming between 1977 and 1994 was between 6°C and 12°C per century in the middle mountains and Himalayas. These temperature increases are supported by Rees and Collins (2004) who, using temperature data from 119 temperature gauges across Nepal, found an increasing trend in temperatures of almost 7°C per century between 1961 and 1996. These rates of warming are more than double globally observed rates for the same period and approach an order of magnitude greater than the century averaged global warming trend reported in Section 3.2.1. It is widely accepted that the Himalayan region, and Nepal along with areas of Tibet in particular, is warming substantially faster than the global average (Singh *et al.*, 2011; Shrestha *et al.*, 1999; IPCC, 2007; Eriksson *et al.*, 2009; Shrestha & Devkota, 2010). Because of this, Singh *et al.* (2011, P. 11) label the HKH region “one of the world’s hotspots in terms of warming trends”.

The warming trend observed in Nepal is highly variable in both space and time. In general it has been found that temperatures have increased more rapidly during the colder winter months than during warmer monsoon months (Singh *et al.*, 2011; Jianchu *et al.*, 2007; Shreshta & Devkota, 2010; Shreshta & Aryal, 2011). In addition, temperatures have been seen to increase more rapidly at higher altitudes than at lower altitudes (Rees & Collins, 2004; Shrestha & Aryal, 2011; Singh *et al.*, 2011; Shrestha & Devkota, 2010; Jianchu *et al.*, 2007). Table 3.1, compiled by Liu and Hou

(1998, in Eriksson *et al.*, 2009) show the effects of altitude and season on temperature changes from measurements on and around the Tibetan Plateau. These observations are consistent with the fundamental physics of greenhouse forcing which is expected to reduce the rate at which temperature drops with altitude, and cause relative warming during periods of surface cooling (i.e. throughout the autumn and winter months) (IPCC, 2007).

Table 3.1: Average annual increase in temperature at different altitudes on the Tibetan Plateau and surrounding areas between 1961–1990 (°C per decade). Source: Liu and Hou 1998 (in Eriksson et al., 2009).

Altitude (m)	No. of stations	Spring	Monsoon	Autumn	Winter	Annual average change
<500	34	-0.18	-0.07	0.08	0.16	0.00
500-1500	37	-0.11	-0.02	0.16	0.42	0.11
1500-2500	26	-0.17	0.03	0.15	0.46	0.12
2500-3500	38	-0.01	0.02	0.19	0.63	0.19
>3500	30	0.12	0.14	0.28	0.46	0.25

The accelerated warming with increasing altitude results in a south-north warming gradient in Nepal in which higher Himalayan regions such as Jumla and Mustang are seen to warm faster than the plains to the south (Singh *et al.*, 2011). For example, Rees and Collins (2004) calculated the warming rate of the 15 highest (all above 1,800m asl) observational stations in their 119 strong ensemble and found it to be as high as 10°C per century during the period 1976 to 1996.

In contrast to changes in temperature, observed trends in precipitation show no consistency across the Himalayan region. While increasing or decreasing trends are seen in records of many individual stations, no overall trend in precipitation was found between 1948 and 1994 in Nepal (Shrestha *et al.*, 2000). Despite this lack of overall trend, it is interesting to note that very few individual stations showed *no* trend in precipitation (Dixit *et al.*, 2009). Thus it appears that persistent changes in precipitation are occurring throughout the region; however the direction of these changes in specific areas is highly dependent on the local context. This is perhaps unsurprising given that precipitation is known to vary greatly over distances of tens of kilometres in the Himalayas due to the extreme topography (Anders *et al.*, 2006).

In light of the variability of precipitation in the Himalayas, attempting to distinguish overall trends or patterns within the region or extrapolate the findings of specific studies to separate regions or basins goes beyond our current scientific prerogative. What *can* be taken from these sparse and varying studies is that precipitation patterns in the Himalayan regions are changing, often dramatically. These changes are accompanied by increases in climatic variability and extreme events. Observed changes in climate highlight the importance of understanding how climate may change in the Himalayas in the future.

3.2.3.2 Climate Change Projections for the Himalayas

Projections for climate change in the Himalayan region are being developed continually. At present, these projections indicate that increases in temperature, changes in precipitation and increases in the variability of these parameters are likely to continue over the coming decades. In order to form projections for regional climate in this investigation, output data from six GCMs for a 5° grid square centred at 29.02776° North and 82.9529° East (mid way between Jomsom airport (Mustang) and Jumla airport (Jumla)) were downloaded from the KNMI Climate Explorer website (http://climexp.knmi.nl/). These GCMs are all well respected and up to date IPCC AR4 models, chosen to represent a broad spectrum of possible climate futures. A five degree grid square was chosen to encompass both Panglin and Tallo Lorpa while allowing for varying GCM resolution. The data produced were analysed graphically to compare century averaged model data centred on 1950 and 2050, shown in Figures 3.1 and 3.2.

Figure 3.1 shows increases in temperature throughout the annual cycle that are unanimous between the six GCMs used. These temperature increases are in the range of approximately 2-4°C and are generally highest during the colder months of January, February and March and lower during the warmer months of July, August and September. While there is considerable uncertainty between GCMs as to the degree of warming throughout the annual cycle, this uncertainty is smaller than the projected warming. The expectation of a warmer climate by 2050 can therefore be seen as robust to the uncertainty between GCMs.

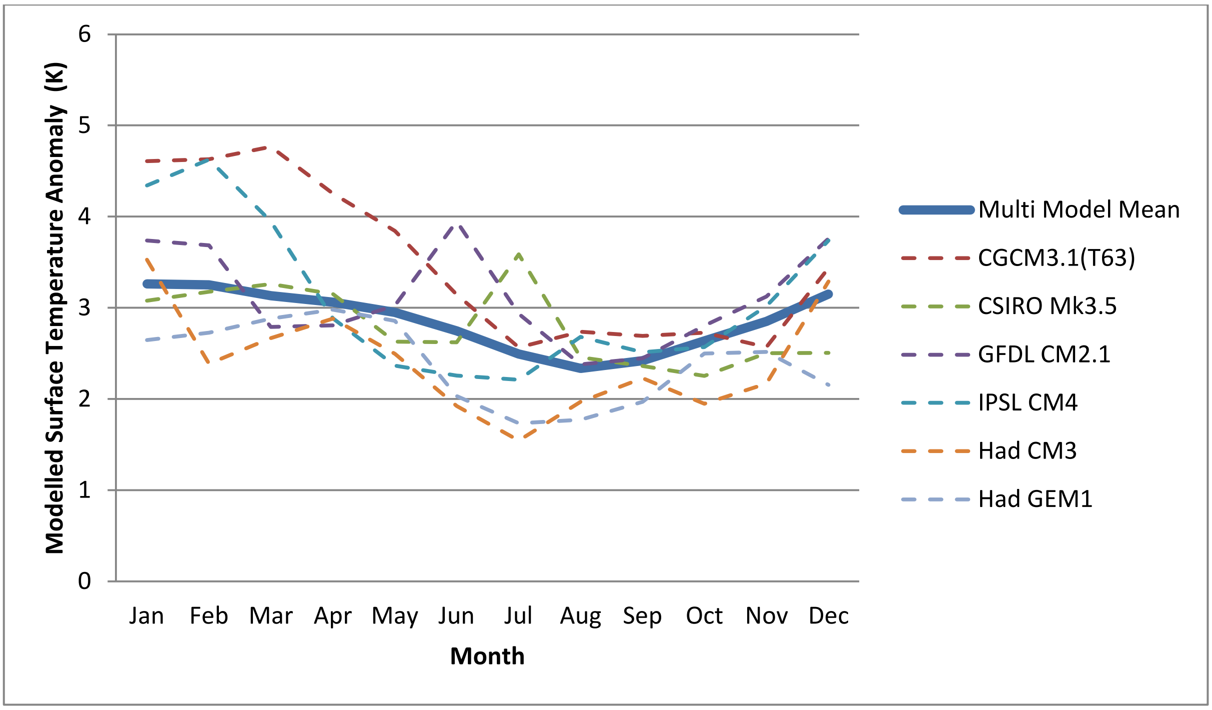


Figure 3.1: Increase in modelled surface temperature between the century centred on1950 and the century centred on 2050. Data were generated using the A1B emissions scenario for a 5° grid cell encompassing Panglin and Tallo Lorpa.

The projections for temperature increase given in Figure 3.1 are generally reflected in studies for the broader Himalayan region. For example, the IPCC (2007) projects a mean annual warming of approximately 3°C by the 2050s, rising to 5°C by the 2080s over the Asian landmass. Shrestha & Devkota (2010) find similar temperature increases of 2-3°C and 2.5-3.5°C using the finer scale HadRM2 and PRECIS models respectively. On a yet finer scale, Immerzeel *et al.* (2010) statistically downscaled GCM output for the Kyangjing catchment in the Langtang Himal, approximately 150km east of Mustang and 250 km east of Jumla in the Mid-Nepalese Himalayas. Their results suggest slightly higher rates of warming of 6°C per century between 2000 and 2100 than found in Nepal as a whole, while also noting considerable variability between GCMs.

The model studies discussed in the section above move from a continental scale to a national scale to a mountainous regional scale, and as such, bear increasing relevance to the study at hand. It must be noted, however, that this increasing spatial resolution bears the cost of increasing uncertainty as model output is further downscaled beyond the resolution for which it was calibrated and validated. Notwithstanding this, the changes in these projections with decreasing scale are consistent with both theoretical climate change dynamics in the region (outlined in section 3.2.3.1) and model studies which address regional warming patterns. For example, Eriksson *et al.* (2009) note that on continental scale, projected temperature increases are small over parts of southeast and east Asia, while being larger in the continental interior and particularly in the Himalayan highlands and on the Tibetan Plateau. In line with this, GCM simulations suggest that warming over central Asia could be more than 40% greater than the global mean

(Singh & Bengtsson, 2004). Within Nepal, Singh *et al.* (2011) note that projected temperature increases are generally greater in the northern, mountainous regions than in the mid-mountains or southern plains. Given the findings of regional and site specific studies, supported by climatological theory and assessments of spatial warming dynamics therefore, it can be seen as probable that the mountainous regions of Nepal will warm faster than the global and continental average during the coming century.

Unlike temperature, projections for changes in precipitation are capricious. Figure 3.2 shows modelled precipitation anomalies between 1950 and 2050 for the same 5° grid square encompassing the districts of Jumla and Mustang. Again, this figure was produced by an analysis of data downloaded from the KNMI Climate Explorer website. Overall changes in modelled precipitation are difficult to discern from this output and the multi model mean shows only weak and seasonally dependent changes in precipitation. This multi model mean suggests slight to moderate increases in precipitation around the monsoon (June, July, August, September) followed by slight decreases for the rest of the year. April is the only month of the year in which there is directional consensus between the six GCMs used and this consensus can be seen as very weak relative to the variability of projections throughout the seasonal cycle. The lack of agreement between models about precipitation changes during the monsoon period is striking, and reflects the poor simulation of the ISM in current climate models (IPCC, 2007). From these outputs, it is clear that very little is known about how precipitation may change in the mid-western Himalayas of Nepal other than to say that substantial changes of some nature are possible, particularly during the monsoon.

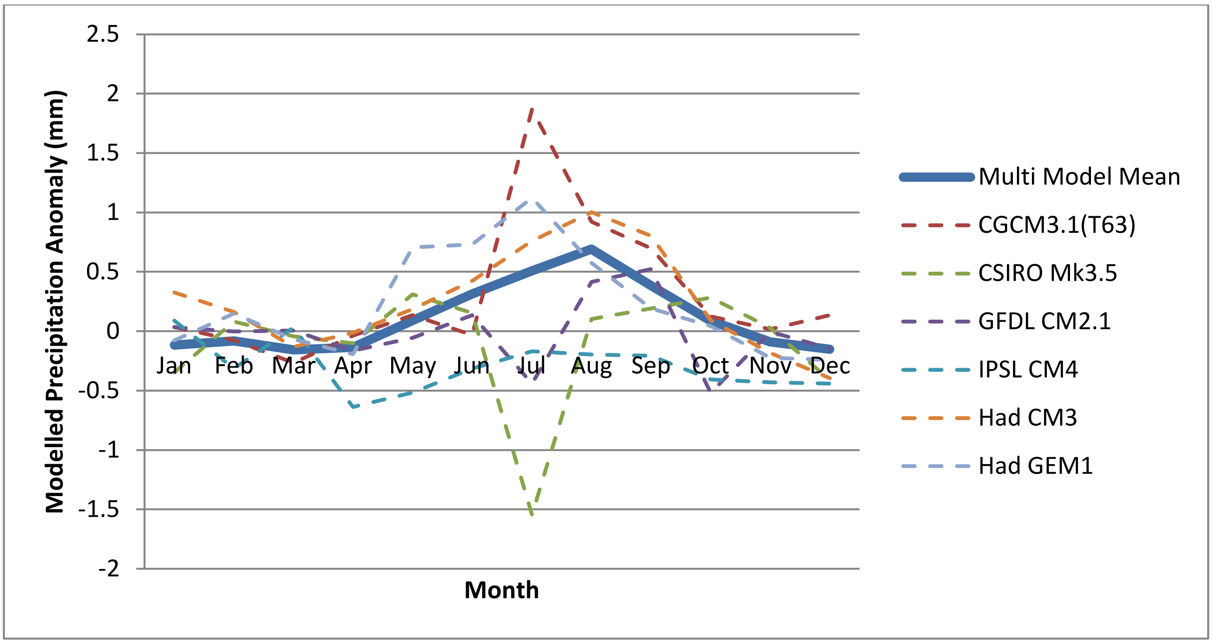


Figure 3.2: Increase in modelled surface precipitation between the century centred on1950 and the century centred on 2050. Data were generated using the A1B emissions scenario for a 5° grid cell encompassing Panglin and Tallo Lorpa.

While uncertainty in projections for precipitation in the Himalayas is reflected in the literature, some consistencies can be found. Under caveats of substantial uncertainty, Agrawala *et al.* (2003) suggest that monsoon precipitation could increase by 15-20% throughout Nepal by 2100 based on output from seven GCMs. Increases are expected to be greater in the eastern part of the country, correlated with the increased monsoonal precipitation (Agrawala *et al.*, 2003; APN, 2003). In addition, changes are expected to be greater in the southern lowlands of Nepal than in the mountainous Himalayan regions of the North (APN, 2003). Concomitant with projected increases in monsoon precipitation, a number of studies suggest that winter precipitation may decrease (APN, 2003; Dixit *et al.*, 2009; Devkota, 2010). Absolute changes in winter precipitation are generally dwarfed by changes in monsoon precipitation in Nepal (APN, 2003; Dixit *et al.*, 2009).

While findings for annual precipitation are interesting, seasonal changes in precipitation can be seen as more relevant for the communities of Panglin and Tallo Lorpa where current storage capacity is small. Table 3.2 shows relative precipitation changes between 1961-1990 and 2071-2099 using statistically downscaled GCM output for the districts of Jumla and Mustang, produced by Devkota (2010). These results suggest that relative decreases in winter precipitation may be substantial in Mustang and larger still in Jumla. These decreases are accompanied by moderate relative increases in monsoon precipitation in Mustang and slight relative increases in monsoon precipitation in Jumla. It must be acknowledged, however, that these are the results of only one GCM (the Hadley Centre's HadCM3) and thus, in the context of the uncertainty between GCMs in the Himalayan region, particularly relating to precipitation as evidenced in Figure 3.2, these results must be viewed with caution.

Table 3.2: Observed baseline (1961-1990) and HadCM3 projected precipitation anomalies (difference between mean of 2071-2099 and 1961-1990) for the districts of Jumla and Mustang under the SRES B2 and A2 emissions scenarios. From Devkota (2010).

	Observed Precipitation (mm)	**B2 Modelled Precipitation (%OBS)**	**A2 Modelled Precipitation (%OBS)**
Jumla			
Winter	78	-49	-56
Monsoon	424	8	10
Annual	781	-3	-6
MUSTANG			
Winter	23	-34	-38
Monsoon	108	18	29
Annual	168	12	22

In conjunction with changes in temperature and precipitation in the Himalayas, model studies suggest that climatic variability and extreme events will increase in the future (Singh *et al.*, 2011; Dixit *et al.*, 2009; NCVST, 2009). For example, model outputs for Nepal suggest that the number of days which would have been in the hottest 5% of days during the period 1970-1999 may increase by 55% by the 2060s and as much as 70% by the 2090s (NCVST, 2009). These projections are even more extreme for night time temperatures where the equivalent increases are 77% by the 2060s and 93% by the 2090s (NCVST, 2009). Increasing precipitation extremes are expected to couple with increasing melt rates under higher temperatures to greatly increase the likelihood of extreme runoff events and flooding in the Himalayas in the future (Dixit *et al.*, 2009; Singh *et al.*, 2011; Immerzeel *et al.*, 2012; Eriksson *et al.*, 2009; IPCC, 2007).

As explained in Chapter Two, climate in the Himalayan region is dominated by the Indian Summer Monsoon (ISM). The ISM occurs during the months of June, July and August in Nepal, delivering much of the annual precipitation during these months, enhancing river flow and replenishing aquifers (Andermann *et al.*, 2012). The ISM is highly variable through time. Changes in its strength on a seasonal basis by up to a factor of eight (Lang & Barros, 2002), as well as substantial decadal scale variability, are evident in observational records (Shrestha *et al.*, 2000).

Much of the variability in monsoon precipitation in Nepal can be attributed to the large proportion of this precipitation that is delivered by one, or a small number of individual monsoon depressions. These depressions, which originate in the Bay of Bengal, are commonly associated with the onset of the monsoon and can bring as much as one third of the seasonal rainfall totals in just 2-3 days (Lang & Barros, 2002; Stephenson *et al.*, 1999). Seasonal totals in specific areas therefore depend on both the strength as well as the trajectories of these depressions, both of which are seen to vary (Lang & Barros, 2002; Stephenson *et al.*, 1999). For example, Lang & Barros (2002) found that between 33% and 50% less precipitation fell in the Marsyandi river basin in the year 2000 than in 1999 because of differences in the point at which the onset depression collided with the Himalayas.

As illustrated in Figure 3.2, current GCMs have difficulty simulating the ISM, and disparity in projections for precipitation over monsoon months is large. Notwithstanding this, substantial changes in the strength and timing of the major climate systems affecting the Himalayas, including the monsoon, are unanimously expected under climate change (Eriksson *et al.*, 2009; Jianchu *et al.*, 2007). Spatial disparity in warming rates is expected to enhance the monsoon thermal contrast between the Bay of Bengal and the central Asian landmass and thus may enhance the monsoonal flow and consequent precipitation (Shrestha *et al.*, 2000; Jianchu *et al.*, 2007; Meehl, 1994).

It is clear that interactions between continental scale climate change and links with global climatic modes such as ENSO add much complexity to the simulation of the ISM. These complexities lend explanation to the fact that only six of the twenty-two GCMs used by the IPCC in the AR4 produce a reasonable representation of ISM variability (Devkota, 2010). Notwithstanding these conceptual difficulties, model studies have attempted to form projections for monsoon climatology under climate change. For example, Shrestha and Devkota (2010), using the HadRM2 and PRECIS regionally based climate models, report that monsoon precipitation could increase by 30% in the Eastern Himalayas and up to 40% in some high altitude areas within this region by the end of the century. Jianchu *et al.* (2007) point out, however, that the local effects of increased monsoonal flow are poorly understood. It is, therefore, difficult to speculate about how changes in the monsoon are likely to affect water availability in Panglin and Tallo Lorpa beyond the understanding that changes, perhaps substantial changes, are highly likely.

3.2.3.3 Uncertainties and Limitations of Climate Change Projections for the Himalayas

The projected changes outlined in the previous section must be understood in light of their uncertainties and limitations. Climate change projections are formed through a complex integration of theory and observation to form models which are conceptually based but empirically calibrated. Even in their most sophisticated form, climate models exist as gross simplifications of reality. In the context of the Himalayas, uncertainties stemming from the highly complex geography and deficiency of observational records, along with GCM and emissions scenario uncertainty, warrant further acknowledgment.

The Himalayan region in general, and the study sites of Panglin and Tallo Lorpa in particular, can be characterised by extreme topography, high relief and substantial micro-scale variations in climate. Complex rain shadow effects exist throughout the Himalayas, and the mountainous landscape and tropical latitude often result in micro-scale convective weather events. For example, Lang & Barros (2002) found precipitation to vary by up to a factor of eight between rain gauges in the Marsyandi River basin. The extreme variability of climate in the Himalayas necessitates a high density of data sampling sites in order to produce realistic insights. In reality, however, monitoring of climate in the Himalayan region, and in Nepal in particular, is sparse due to limited resources and funding (Eriksson *et al.*, 2009; Singh *et al.*, 2011; Lang & Barros, 2002; Gosain *et al.*, 2010).

Data records for precipitation can be seen as particularly inadequate in the Himalayas. Precipitation can vary on a much smaller scale than temperature and therefore requires a finer observation network to characterise properly (Singh *et al.*, 2011). Furthermore, precipitation measurements can be problematic as precipitation is difficult to measure accurately, particularly in regions where a proportion falls as snow.

Inadequacy in the observational records of climate in the Himalayan region contributes to uncertainty in its simulation in GCMs (Singh *et al.*, 2011; Eriksson *et al.*, 2009; IPCC, 2007; Devkota, 2010; Beniston, 2003). GCMs make calculations from large scale observations and on a grid scale vastly greater than the climatic sub-regions found in mountainous environments (Singh *et al.*, 2011; Beniston, 2003). Salient to this investigation, climate models generally base their simulation of high altitude climates on extrapolation from nearby low altitude stations and therefore rely on further assumptions of lapse rate and orographic precipitation (Rees & Collins, 2004).

Uncertainty surrounding future emissions of greenhouse gas also complicates projections of climate change. A number of studies in the Himalayas have found considerable disparity in projections using different emissions scenarios (Singh *et al.*, 2011). For example, Gosain *et al.* (2010) found ‘appreciable’ variations in projections informed by the B2 and A2 SRES emissions scenarios. Relative to the uncertainty introduced by GCM structure and manipulation, however, uncertainty stemming from the use of differing emissions scenarios has been seen as small (Arnell, 2003). In fact, Arnell (2003, p. 640) goes as far as to state “at least until the 2050s – all experiments with a given climate model can be seen as an ensemble of simulations, regardless of the actual emissions scenario used”. Therefore, while the choice of emissions scenarios constitutes a recognisable source of uncertainty, particularly in long range projections, this contribution can be seen as modest in relative terms.

Projections of the effects of climate change are inherently speculative and their findings must be understood with acknowledgement of their uncertainties. In the Himalayan region, these uncertainties are exacerbated by complex regional and local scale climatology and sparse and variable observation. These factors compound GCM and downscaling uncertainty. Projections are further complicated by uncertainties surrounding future greenhouse emissions.

3.3 Perceptual Model

This section uses a perceptual model to illustrate how climate change affects water availability in the Himalayas. Climate is linked to runoff through explanation of the effects of climate change on the cryosphere and examination of how changes in precipitation and evapotranspiration influence water availability at the village level. Links between catchment geomorphology and water availability are then examined. This perceptual model describes how the climate changes outlined in sections 3.1 and 3.2 are likely to affect water resources available to the communities of Panglin and Tallo Lorpa in the absence of direct human perturbation.

The relationships that link climate to water availability are described by the water balance equation:

(Equation 3.1) $$Q = P - E \pm S$$

Where Q is runoff, P is precipitation, E is actual evapotranspiration and S is the change in catchment storage. Climate change is expected to alter each of the components of the water balance equation. Increases in temperature lead to increases in evapotranspiration and precipitation (IPCC, 2007; Georgievskii *et al.*, 1996). Changes in these parameters also influence water storage as surface water, groundwater, snow and ice (Poyck *et al.*, 2011; IPCC, 2007). Changes in the components of the water balance equation in response to increased warming are non-linear and often involve complex feedbacks. Figure 3.3 shows a simplified model of the hydrological cycle in equilibrium; the remainder of this section describes how components of this system may alter under climate change and how this is likely to affect the water resources available to the communities of Panglin and Tallo Lorpa.

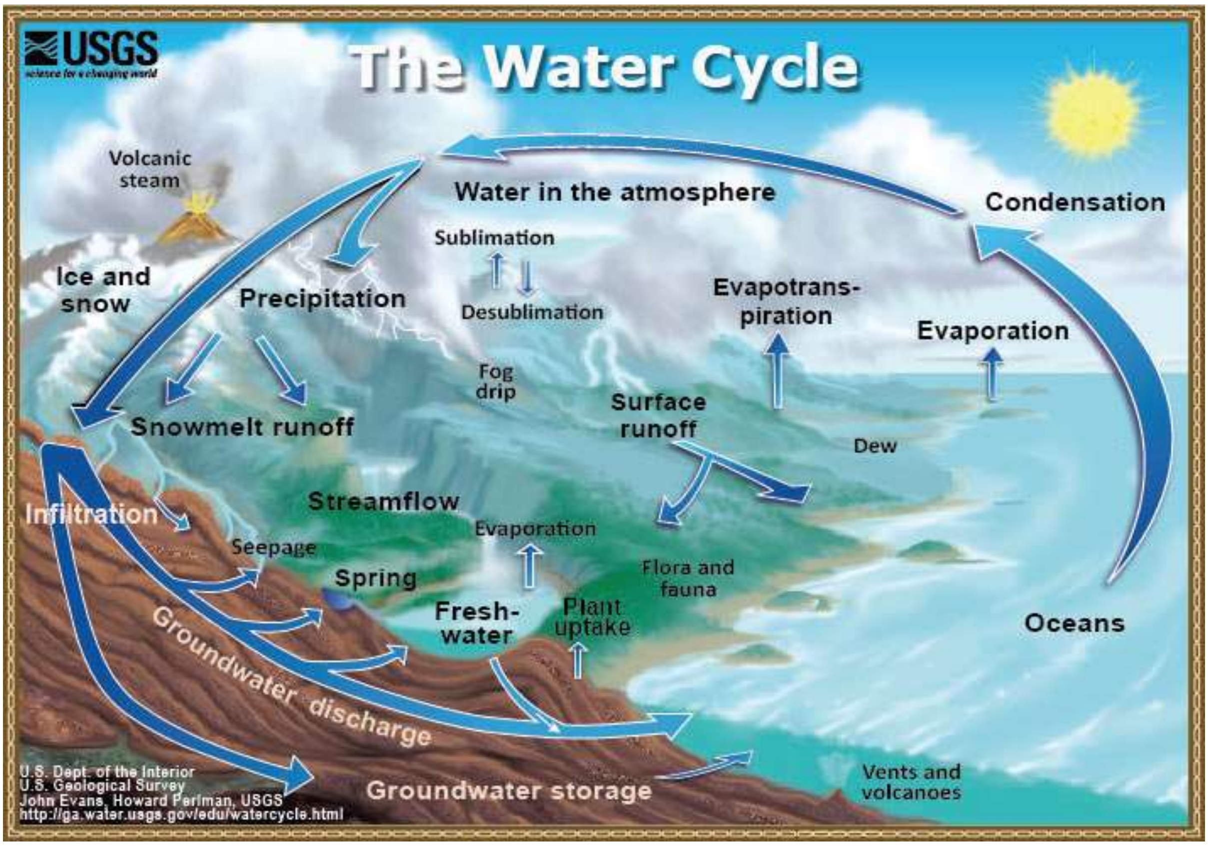


Figure 3.3: Conceptual model of catchment hydro-climatology, taken from the US Geological Survey.

3.3.1 Changes in Snowpack Storage

Storage of water as snow is an important feature of the hydrological cycle in Panglin and Tallo Lorpa. In the Central Himalayan region snowmelt contributes 25% of annual river discharge (Bookhagen, 2012). As outlined in Chapter 2, the Pan Khola and Ghatte Khola catchments receive substantial amounts of snowfall, particularly during colder months, and this snow constitutes an important reservoir of fresh water.

Snow cover and depth depend on both precipitation and temperature and are therefore extremely sensitive to climate change (Beniston, 1997; Clark *et al.*, 2009). Increasing atmospheric temperatures raise the mean freezing level, reducing the area above this level that receives snowfall (Stewart, 2009). It is thought that an absolute reduction in snowfall due to higher temperatures in the Himalayas may have as much, if not more, of an effect on stream flow than increases in glacial melt (Thayyen *et al.*, 2007; Singh *et al.*, 2011).

In addition to changes in temperature and precipitation, it is expected that snow cover will be affected by increasing particulate pollution in the vicinity of the Himalayas which, when it is deposited, lowers the ability of snow to reflect heat (termed the ‘albedo’) (Decesari *et al.*, 2010;

Barnett *et al.*, 2005; Singh *et al.*, 2011). Ming *et al.* (2009) attribute as much as 30% of observed reductions in snow and ice to the effects of increases in particulate pollution from the surrounding regions.

Observed changes in snow cover in the HKH region as a whole are inconclusive. On a smaller scale, however, it is suggested that snow cover area has reduced slightly in the central Himalayan region (encompassing western and mid-western Nepal) while expanding in eastern and western Himalayan regions (Gurung *et al.*, 2011). Moreover, Immerzeel *et al.* (2010) suggest that the mass of snow in the Ganges basin has decreased slightly. There is also suggestion that snow cover extent is decreasing to a larger extent during the winter and pre monsoon than it is during the monsoon and post monsoon (Gurung *et al.*, 2011; Immerzeel *et al.*, 2009).

Model studies generally suggest that melt water contribution to runoff in the Himalayas will decrease in the future. The snowline is expected to rise by 150m for every degree Celsius of temperature rise (Beniston, 2003). According to Bohner and Lehmkuhl (2005), temperature increases of between 1°C and 6°C will lead to a decrease in snow cover over the Himalayan region of between 43% and 81% by 2100. This would substantially increase hydrological variability, reducing runoff during dry periods, particularly during the pre-monsoon when snowmelt contribution is historically high.

It must be acknowledged that uncertainties in the observation and modelling of cryospheric processes in the Himalayas are large. As with precipitation and temperature, considerable uncertainty stems from the deficiency of snowpack monitoring (Singh *et al.*, 2011; Bajracharya & Shrestha, 2011). Monitoring based on satellite gravimetry data is inherently low resolution and possesses uncertainties around rates of orogeny (mountain growth) as well as large scale changes in groundwater (Matsuo & Heki, 2010). These observational uncertainties compound uncertainties in cryospheric parameterization and modelling (Konz *et al.*, 2007; Immerzeel *et al.*, 2012; Bajracharya & Shrestha, 2011).

Notwithstanding these reservations, in the context of the Panglin and Ghatte Khola watersheds, it can be expected that increases in temperature will elevate the snowline and substantially reduce the mean snow covered area on an annual basis as the 21st century progresses. This is likely to increase variability of water availability and may reduce water availability during the pre-monsoon where melt water contribution is historically high.

3.3.2 Changes in Precipitation

The changes in precipitation outlined in Section 3.2.3.2 will affect runoff in the Panglin and Ghatte Khola watersheds. In accordance with the water balance equation (3.1), projected increases in monsoon precipitation will increase runoff during monsoon months while decreases in winter precipitation may do the opposite during this season. The effects on runoff are, however, likely to be disproportionate to the changes in precipitation due to nuances in the precipitation-runoff relationship. Runoff is known to depend on both the intensity of precipitation as well as antecedent soil moisture (Ward, 1975; Beven, 2000). If monsoon precipitation increases, soil moisture will increase on a seasonal basis. This, combined with expected increases in precipitation intensity, will mean that a larger proportion of precipitation will contribute to infiltration excess runoff, resulting in greatly increased runoff peaks (Raudkivi, 1979; Beven, 2000). By contrast, if precipitation declines during the winter months the seasonal soil moisture will also decline. This would lead to a larger proportion of the already reduced precipitation being lost to evapotranspiration and infiltration, greatly reducing runoff during the winter (Beven, 2000). For these reasons, projected increases in the variability of precipitation on a range of temporal scales can be expected to *greatly* increase runoff variability in the Himalayas.

3.3.3 Changes in Evapotranspiration

Evapotranspiration is expected to increase in close accordance with temperatures under climate change (Georgievskii *et al.*, 1996). Changes in evapotranspiration greatly influence runoff as described in the water balance equation (3.1) (Andreasson *et al.*, 2004). Kingston and Taylor (2010) demonstrate the importance of evapotranspiration by highlighting substantial changes in runoff projections under climate change which result from differing evapotranspiration estimates. In the Eastern Himalayan region, a model study by Tse-ring *et al.* (2010, in Singh *et al.*, 2011) suggests that increases in evapotranspiration may be substantially larger than increases in precipitation. Similarly, Singh and Bengtsson (2004) suggest that increased evapotranspiration is likely to dominate increases in snowmelt in the Satluj river basin, India, resulting in decreased runoff. It is clear that increases in evapotranspiration will substantially reduce runoff during periods of reduced or unchanged precipitation. The effect of increased evapotranspiration during periods of increased precipitation depends on the relative magnitude of these two runoff parameters, and requires further investigation.

3.3.4 Differences in Catchment Geomorphology

The effects that changes in climate have on runoff also depend on catchment characteristics. The topographic nature of a catchment, as well as its position in relation to surrounding topography, greatly influence the timing and volume of runoff. The extreme nature of topography in the Himalayas makes the effects of orographic precipitation and rain shadow effects particularly important in this region, as explained in Section 2.4.1 (Lang & Barros, 2002; Chalise & Khanal, 2001: Jianchu *et al.*, 2007).

The Panglin and Ghatte Khola watersheds both exist as small, mountainous catchments within a mountainous surrounding. It is difficult, therefore, to speculate on differences in micro scale orographic precipitation in each catchment. Differences in elevation between the two catchments do, however, lead to differences in the amount of snowfall each catchment receives. The Ghatte Khola watershed ranges between 2,523m asl and 4,105m asl whereas the Panglin watershed ranges between 2,902m asl and 5,304m asl. Consequently, the Panglin watershed receives a larger proportion of its precipitation as snowfall and runoff is modulated by snowfall to a greater degree than in the Ghatte Khola watershed. This will result in differing hydrological responses to climate change.

3.4 Projected Effects of Climate Change on Water Availability in Nepal

Numerous studies in the Himalayan region have attempted to simulate the processes outlined in section 3.3 in order to form projections for the effects of climate change on water availability. The results of these studies have generally discredited forecasts of disastrous water shortage noted in Chapter one (Rees & Collins, 2004). It is difficult, however, to compare between, or generalise about, these studies as they focus on different parts of the Himalayan region. Moreover these studies often use differing model approaches and structures at differing spatial resolutions and are forced by differing GCMs with differing downscaling methods and resolutions (Singh *et al.*, 2011). In light of model study diversity, this section uses a number of hydro-climatological studies to indicate what changes may (rather than define what changes will) occur in the waterways of Panglin and Tallo Lorpa.

No overall trend has been found in the flow of large rivers in Nepal (Shrestha & Aryal, 2011; Singh *et al.*, 2011). Substantial inter-annual variability in observed runoff makes the elucidation of trends difficult: however small, statistically insignificant, trends in flow are found for a number of individual rivers. For example, the Karnali River, of which the Tila River (Jumla) is a large tributary, has shown a decreasing trend, while the Kali Gandaki River (Mustang) has been increasing slightly (Shrestha & Aryal, 2011). Smaller rivers in the southern regions of Nepal show no definite trend while snow-fed rivers of the high mountains are seen to have decreased in flow (Shrestha & Aryal, 2011). These observations form the basis for understanding runoff projections in the region.

Model studies of the hydrological impacts of climate change in the Himalayas have taken place on different scales and focused on different locations. At the regional scale, Immerzeel *et al.* (2010) assessed the effects of climate change in the five major river basins of the Himalayan region using a combined cryosphere-hydrological model forced by output from five GCMs for the A1B emission scenario. Salient to this investigation, the research team found that upstream water supply (that originating from above 2,000m asl) may decrease by 17.6% by the period 2046-2065 in the Ganges river basin, even taking into account an 8% increase in precipitation (Immerzeel *et al.*, 2010).

On a finer scale, Gosain *et al.* (2010a) used two regionally based climate models (HadRM2 and PRECIS) to investigate the effects of climate change on runoff in the eastern Himalayan region (an area including parts of Nepal, Bhutan, China and Myanmar). Results suggest that water yield may increase by 60% (using the A2 emissions scenario) and 43% (using the B2 scenario). In a follow up study, Gosain *et al.* (2010b) applied the output of the HadRM2 model to the Soil Water Assessment Tool (SWAT) hydrological model. They found that annual surface runoff may increase by up to 66% in the Koshi basin (Nepal) by the period 2070-2100.

Immerzeel *et al.* (2012) used data from an ensemble of GCMs to force a high resolution cryosphere hydrological model forming climate change projections for runoff in the small glaciated Langtang catchment (approximately 150km east of Mustang and 250km east of Jumla). Mean ensemble results suggest runoff could increase by 32% by 2050. Around 60% of this increase is attributed to increases in annual mean precipitation while the melting of glaciers in the catchment provides the rest (Immerzeel *et al.*, 2012). While the Langtang catchment is reasonably small and mountainous, it differs from the Panglin and Ghatte Khola catchments because it is higher in altitude and heavily glaciated and will thus respond differently to changes in climate.

Singh and Bengtsson (2004) investigated the hydrological sensitivity of the Sutlej river basin to plausible changes in temperature and precipitation. The Sutlej river basin is located predominantly in the Indian state of Himachal Pradesh and receives substantial seasonal snowfall. The contribution of the catchment snowpack to runoff was found to decrease considerably with warmer temperatures while the contribution from high altitude glaciered parts of the catchment was found to increase. The effects of changes in climate on runoff are therefore highly influenced by the relative contribution of snowmelt against glacier melt in the catchment in question. In the Sutlej river basin, decreased snowmelt contribution from the lower part of the catchment dominated increases in glacier melt in the upper part of the catchment, resulting in reduced catchment runoff in all but one precipitation/temperature combination (+1°C +10% precipitation).

While there are no studies on the effects of climate change on runoff in Jumla, Rees and Collins (2004) have modelled the effects of climate change on runoff in the Kali Gandaki watershed draining the district of Mustang. They used a coarse resolution hydrological model forced with four different combinations of plausible increases in temperature and changes in precipitation, as well as one scenario based on model output from the HadRM3 climate model. The authors found that runoff in the Kali Gandaki catchment increases under each of the five scenarios. This is consistent with an increase in annual precipitation and increases in glacial melt-water (Rees & Collins, 2004). It is, however, conceded that the hydrological model is low resolution and provides no indication of seasonal changes in runoff which are critically important (Shrestha & Aryal, 2011).

Changes in annual runoff totals give some insight into changes in water availability, however changes in runoff seasonality are often more dramatic. For example, Singh and Bengtsson (2004) found that, while changes in annual stream flow were modest, stream flow seasonality was greatly altered in the Sutluj river basin under climate change. Increasing temperatures are expected to shorten the melt season in areas of seasonal snowpack as these reservoirs deplete more rapidly (Sing & Bengtsson, 2004). In the Panglin and Ghatte Khola watersheds, where there are no glaciers to provide sources of perennial melt-water, a shortening of the snowmelt season can be expected to substantially affect runoff seasonality.

3.4.1 Projection Uncertainty

Modelling runoff under climate change adds hydrological model uncertainties to the already large uncertainties associated with deriving the climate change signal used to force them (described in Section 3.2.3.3) (Meehl, 1994). Hydrological model uncertainty stems from both uncertainties in input data, and uncertainties in the model structure. Hydrological models are particularly reliant on accurate measurement of precipitation and river discharge. As pointed out in Section 3.2.3.3, precipitation records are sparse and of variable quality in the Himalayan region. There are also inherent difficulties in measuring discharge. Beven (2000) points out that error in the measurement of discharge can be as high as 5% even at a well maintained flume. In the poorly gauged, highly variable and ever changing rivers of the Himalayas, therefore, uncertainty in observations of discharge are likely to be considerable.

Uncertainties in hydrological model structure reflect an inability to replicate complex hydrological processes with accuracy. Differing hydrological models treat the processes of runoff generation in different ways. Davies and Prudhomme (2009) found that these differences in model structure lead to significantly different results even when the same input and boundary data is used. This uncertainty, combined with the multitude of uncertainties accrued in the process of informing the model of climatic parameters in the future, mean that climate change-hydrological studies are highly uncertain, particularly in the Himalayan region.

3.5 Best Guess Estimates for Panglin and Tallo Lorpa

Best guess estimates of the influence of climate change on water resources in Panglin and Tallo Lorpa are now posed. These constitute the ‘hazard’ as it is defined in Chapter One. These estimates are formed using a combination of projected changes in climate (outlined in Section 3.2.3) and the perceptual model described in Section 3.3. They are first explained and then displayed as diagrams in Figures 3.3 and 3.4. The estimates formed are both qualitative and speculative and are based on theory, inference and geographically imperfect proxy investigations outlined in this chapter. They must, therefore, be interpreted as such.

Panglin

Climate

Combining the results of Devkota (2010) with analysis of the multi model projections for future climate in the 5° grid square encompassing Jumla and Mustang, it seems likely that annual precipitation will increase in Panglin, with absolute increases in monsoon precipitation dominating absolute decreases in winter precipitation. Decreases in winter precipitation are suggested with more confidence than increases in monsoon precipitation because they are greater in relative magnitude (Devkota, 2010), and occur during months of relatively (although by no means absolutely) low GCM uncertainty. Suggested increases in monsoon precipitation are more tenuous given the high degree of GCM uncertainty during this season, explained in the later part of Section 3.2.3.2. Seasonal changes are expected to be simultaneous with increases in variability and the occurrence of extreme precipitation events.

In light of its continental position and altitude, it is likely that temperatures in Panglin will warm considerably faster than the global average expected warming in the coming decades. With respect to seasonality and altitude this is particularly true during winter months and particularly true of higher parts of the Panglin watershed. This suggestion is made with some confidence in light of the unanimity of GCM projections for the area presented in Figure 3.1.

Runoff Response

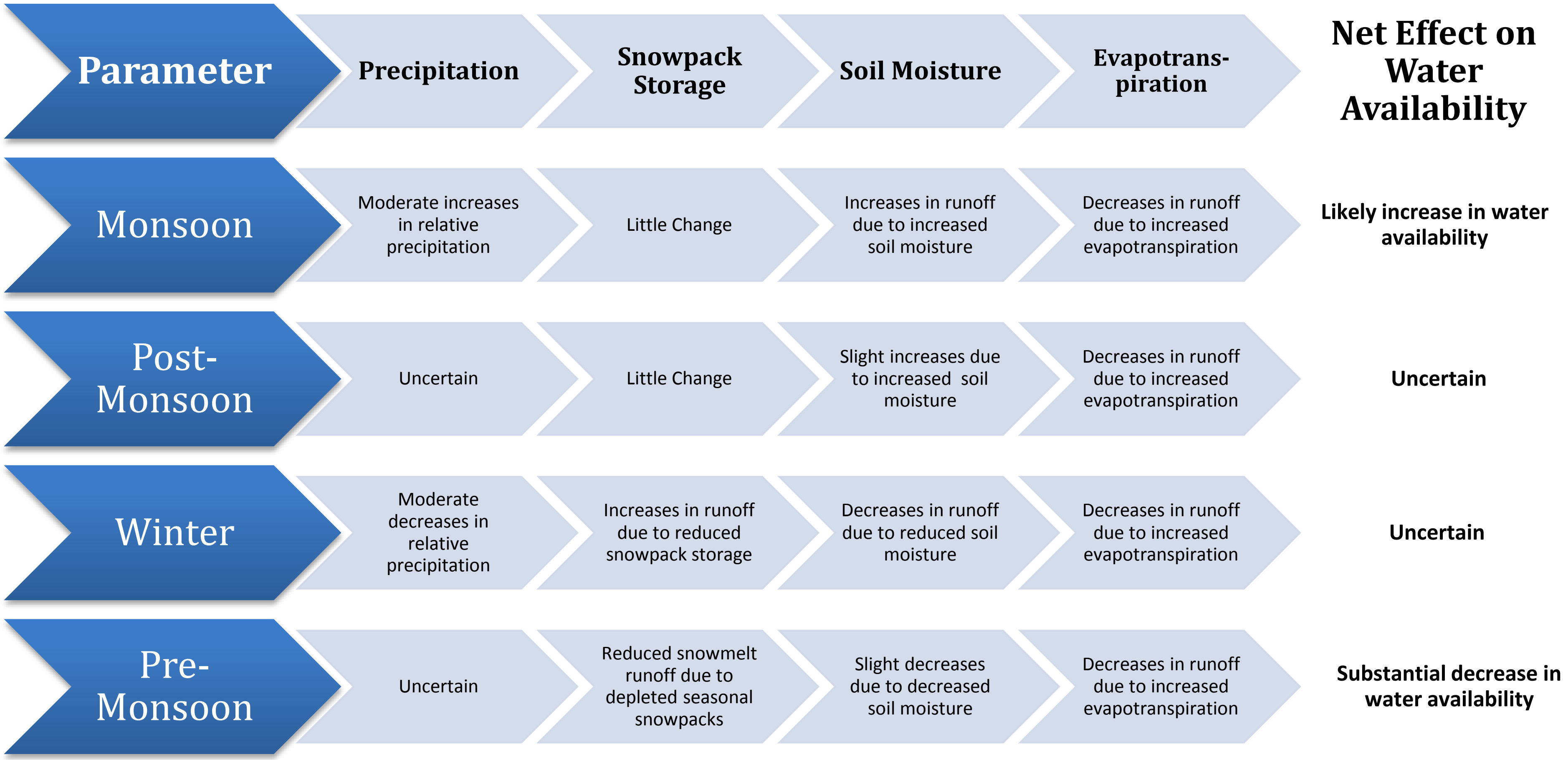
Increases in temperature are expected to couple with decreases in winter precipitation to greatly reduce annual snowfall and the longevity of seasonal snow packs in the Panglin watershed. Particularly large temperature increases in the higher parts of the Panglin watershed and during cooler winter months, when and where snow commonly falls, may make reductions especially stark. Reduced snowfall is expected to affect water availability in the Panglin watershed by reducing the temporal storage of precipitation. On a seasonal basis, this acts to increase runoff during the winter months and decrease runoff during the historically dry pre-monsoon.

Increases in monsoon precipitation are expected to be amplified in runoff responses. If precipitation increases during the monsoon months, runoff can be expected to increase by a greater proportion as soil moisture increases on a seasonal basis and a greater proportion of the more abundant (and more variable) precipitation forms infiltration excess runoff. Runoff decreases during winter months, through the converse of these conditions, are expected to be dominated by increases in runoff caused by reductions in snowfall and increases in snowmelt.

Increases in evapotranspiration caused by increased temperatures are expected to be substantial given the large area of the Panglin watershed and low humidity in the area. These increases are expected to greatly reduce runoff during winter months and shoulder seasons in the Panglin watershed. Increased evapotranspiration will also diminish the proportion of precipitation contributing to runoff during monsoon months to some degree. The magnitude of this decrease relative to increases in monsoon precipitation is, however, uncertain, further complicating expectations for monsoon runoff.

In summary, decreases in precipitation and seasonal soil moisture coupled with increases in evapotranspiration may act to reduce winter runoff, while reductions in snowfall and snowmelt may act to increase winter runoff. During the pre-monsoon, where snowmelt historically contributes to runoff, these changes may align to greatly reduce runoff and available water resources during this season. Increased and increasingly intense precipitation during the monsoon may act to increase monsoon runoff, while increased evapotranspiration may act to reduce monsoon runoff. In light of the uncertainties surrounding changes in monsoon precipitation under climate change and the relative influence of this against increases in evapotranspiration, expectations of change in runoff during this season in Panglin are made with considerable uncertainty.

Panglin



Parameter	Precipitation	Snowpack Storage	Soil Moisture	Evapotrans-piration	Net Effect on Water Availability
Monsoon	Moderate increases in relative precipitation	Little Change	Increases in runoff due to increased soil moisture	Decreases in runoff due to increased evapotranspiration	**Likely increase in water availability**
Post-Monsoon	Uncertain	Little Change	Slight increases due to increased soil moisture	Decreases in runoff due to increased evapotranspiration	**Uncertain**
Winter	Moderate decreases in relative precipitation	Increases in runoff due to reduced snowpack storage	Decreases in runoff due to reduced soil moisture	Decreases in runoff due to increased evapotranspiration	**Uncertain**
Pre-Monsoon	Uncertain	Reduced snowmelt runoff due to depleted seasonal snowpacks	Slight decreases due to decreased soil moisture	Decreases in runoff due to increased evapotranspiration	**Substantial decrease in water availability**

Figure 3.4: Flow diagram of the seasonal effects of climate change on runoff parameters in Panglin.

Tallo Lorpa

Climate

It is difficult to suggest whether annual precipitation will increase or decrease in Tallo Lorpa. The results of Devkota (2010) suggest that dramatic decreases in winter precipitation will dominate slight increases in monsoon precipitation, culminating in a reduction in annual precipitation. Multi model projections for the 5° grid square centred between Mustang and Jumla, however, suggest a much smaller decrease in winter precipitation followed by larger increases in monsoon precipitation. The results of Devkota can be used to delineate expectations for Panglin and Tallo Lorpa, suggesting that winter precipitation decreases will be greater and monsoon increases will be smaller in Tallo Lorpa. As is the case in Panglin (and by the same reasoning), suggested decreases in winter precipitation in Tallo Lorpa are viewed with more confidence than projected increases in monsoon precipitation. Increases in variability and the occurrence of extreme precipitation events are also expected in Tallo Lorpa.

Temperatures around Tallo Lorpa are also expected to rise faster than the global average. It is at slightly lower altitude and experiences a slightly less continental climate than Panglin (as a result of differences in surrounding topography rather than distance from the coast), and therefore increases in temperature are not expected to be as rapid. Again, with respect to seasonality and altitude, winter temperatures in high elevation parts of the Ghatte Khola catchment are expected to rise faster than the annual or area mean. Suggestions for temperature are again made with some confidence given unanimity among GCM projections for temperature for the area.

Runoff Response

As is the case in Panglin, increases in temperature are expected to couple with changes in precipitation to greatly reduce annual snowfall and the longevity of seasonal snow packs in the Ghatte Khola watershed. Again, greater rates of temperature increase during winter months and at higher elevations make reductions in snowfall and snow packs particularly likely. The larger reductions in winter precipitation expected in Tallo Lorpa relative to Panglin may deplete seasonal snowpack accumulation to an even greater degree. Again, reduced snowfall is expected to affect water availability in the Ghatte Khola catchment by reducing the temporal storage of water. On a seasonal basis, this is expected to increase the proportion of precipitation contributing to runoff during the winter months and decrease runoff during the historically dry pre-monsoon.

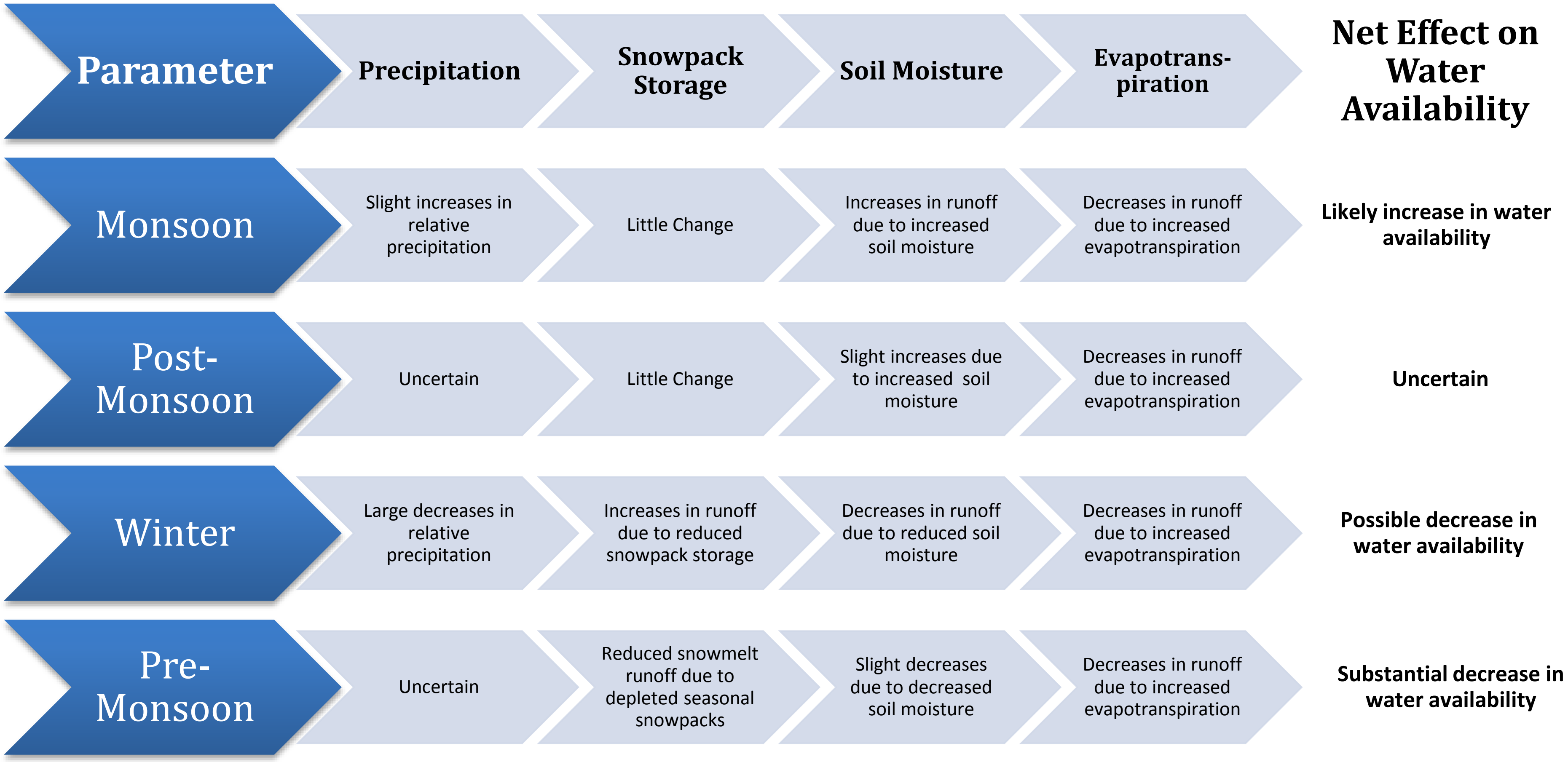
Runoff in the Ghatte Khola catchment is also expected to show disproportionately large increases in response to increases in monsoon precipitation as a result of increased seasonal soil moisture.

Infiltration excess runoff is also expected to be more common under more variable and extreme precipitation. Again, runoff decreases due to reduced soil moisture during the winter are expected to be outweighed by increases in runoff caused by reductions in snowfall and increases in snowmelt.

Increases in evapotranspiration caused by increased temperatures are also expected to be substantial in the Ghatte Khola watershed; however, given the smaller catchment area and a more humid climate, these increases are unlikely to be as large as those in the Panglin watershed. Increases in evapotranspiration are expected to reduce the proportion of precipitation contributing to runoff throughout the year. This may further reduce runoff during the winter and shoulder seasons; however, as is the case in Panglin, its effect on runoff relative to monsoon increases in precipitation is uncertain.

In summary, decreases in precipitation and seasonal soil moisture coupled with increases in evapotranspiration may act to reduce winter runoff, while reductions in snowfall and snowmelt may act to increase winter runoff. As the greater expected decreases in precipitation are counter to the more modest expected increases in evapotranspiration, there is little to delineate the expected influence of climate change on winter runoff in the Panglin and Ghatte Khola watersheds. Similarly between the two watersheds, during the pre-monsoon when snowmelt is historically high, seasonal reductions in runoff may be particularly severe. The balance between the contribution of increased and increasingly heavy precipitation to runoff and subtraction from runoff due to increased evapotranspiration again contributes uncertainty to the direction of runoff change during the monsoon in the Ghatte Khola watershed.

Tallo Lorpa



Parameter	Precipitation	Snowpack Storage	Soil Moisture	Evapotranspiration	Net Effect on Water Availability
Monsoon	Slight increases in relative precipitation	Little Change	Increases in runoff due to increased soil moisture	Decreases in runoff due to increased evapotranspiration	**Likely increase in water availability**
Post-Monsoon	Uncertain	Little Change	Slight increases due to increased soil moisture	Decreases in runoff due to increased evapotranspiration	**Uncertain**
Winter	Large decreases in relative precipitation	Increases in runoff due to reduced snowpack storage	Decreases in runoff due to reduced soil moisture	Decreases in runoff due to increased evapotranspiration	**Possible decrease in water availability**
Pre-Monsoon	Uncertain	Reduced snowmelt runoff due to depleted seasonal snowpacks	Slight decreases due to decreased soil moisture	Decreases in runoff due to increased evapotranspiration	**Substantial decrease in water availability**

Figure 3.5: Flow diagram of the seasonal effects of climate change on runoff parameters in Tallo Lorpa.

3.6 Summary

The literature discussed in this chapter summarises the current state of knowledge on the hydrological effects of climate change in the Himalayas. It is clear that the climate in the Himalayas is changing. Temperature increases in the region greatly exceed the global average and changes in precipitation, while spatially fickle, are indisputable. While uncertainties attend projections of climate change in the region, particularly during the monsoon season, increasing temperature and changes in precipitation are expected to continue into the future. These changes in climate are linked to catchment hydrology through the use of a perceptual model, which illustrates the importance of the cryosphere and catchment geomorphology in runoff generation under a changing climate. Hydro-climatological studies seek to quantify these linkages and form projections for runoff. Differences in scale, modelling approach and location coupled with substantial uncertainties make the findings of these investigations difficult to generalise in the Himalayas. Individual studies do, however, illustrate that the site specific hydrological effects of climate change are likely to be dramatic in the region. Importantly, changes in runoff seasonality and increases in runoff variability are expected in the future.

Best guess estimates for changes in water availability in Panglin and Tallo Lorpa were formed by combining projected changes in climate with the perceptual model described. In Panglin, monsoon water availability is expected to increase under climate change, while water availability during the pre-monsoon may decrease considerably. In Tallo Lorpa, increases in monsoon water availability are expected along with possible decreases in winter water availability and considerable decreases in pre-monsoon water availability. These expected changes in water availability constitute hazard as it is defined in this investigation. The influence of this hazard on biophysical vulnerability is moderated by social vulnerability. Social vulnerability is assessed over the next three chapters.

Chapter Four

Literature Review of Social Vulnerability

4.1 Overview

With an understanding of how water availability may change in Panglin and Tallo Lorpa, we now move to ask ‘how able are these communities to deal with such change?’ This moves us from assessing ‘hazard’ in the previous chapter to investigating ‘social vulnerability’ over the next three chapters. This chapter reviews what is currently known about vulnerability and responses to environmental change in mountain communities. Chapter Five describes the methods used to assess vulnerability and adaptive capacity in this investigation and Chapter Six describes the results of field research in Panglin and Tallo Lorpa.

The current chapter begins with an explanation of why the changes in water availability outlined in the previous chapter are important to livelihoods in Panglin and Tallo Lorpa. This is done through an explanation of ecosystem services as they relate to mountain agriculture and the implications that changes to these services have on agricultural production, food security and health. The chapter then seeks to frame the depth of vulnerability in mountain regions through an examination of mountain poverty and exploration of the findings of previous investigations. Finally, the ability of mountain communities to reduce their social vulnerabilities through adaptation and coping strategies is appraised.

4.2 Livelihood Dependency

Sustainable livelihood capacity is the gauge by which biophysical vulnerability is measured in this investigation. The sustainable livelihoods approach put forward by Chambers and Conway (1992) is adopted here. Chambers and Conway (1992, p.6) state that:

> “A livelihood comprises people, their capabilities and their means of living, including food, income and assets… A livelihood is environmentally sustainable when it maintains

> or enhances the local or global assets on which livelihoods depend, and has net beneficial effects on other livelihoods. A livelihood is socially sustainable which can cope with and recover from stresses and shocks and provide for future generations*”.*

The concept of sustainable livelihoods integrates the notion of capabilities (Sen, 1993) with requirements of equity and sustainability to create a definition of livelihoods more firmly grounded in broader well-being (Chambers & Conway, 1992).

Places that harbour communities currently have the capacity to support a certain number of sustainable livelihoods which can be referred to as the *status quo*. In the context of hydrological change caused by climate change, it is the sustainable livelihood capacity of places in which biophysical vulnerability is contextualised from the reference point of the *status quo*.

Sustainable livelihood capacities of Himalayan communities are fundamentally affected by environmental change. The nature of this influence depends on social vulnerability which defines how the environmental changes outlined in the previous chapter affect sustainable livelihood capacities in Panglin and Tallo Lorpa. Social vulnerability is discussed through an exploration of the importance of ecosystem services and the implications if these change.

4.2.1 Ecosystem Services

Ecosystem services provide the foundation for human survival in the Himalayas (Macchi, 2010b; Schild, 2008). They can be simply defined as ‘the benefits people obtain from ecosystems’ (MEA, 2005), however their interpretation and valuation can be difficult (Rasul *et al.*, 2011). The Millennium Ecosystem Assessment (MEA, 2005, p.76-78) identifies four general categories of ecosystem services which directly benefit human wellbeing. These are:

1) Provisioning functions which “[supply] goods and other services that sustain various aspects of human well-being”
2) Regulating services which regulate environmental phenomena and purify environmental resources.
3) Cultural services which “influence the aesthetic, recreational, educational, cultural, and spiritual aspects of human experience”
4) Supporting services which “are essential for sustaining each of the other three ecosystem services”

While each of these categories is recognised as important (Rasul *et al.*, 2011), this investigation focuses on ecosystem provisioning functions and in particular how they relate to agriculture and human health. A number of studies have assessed the value of cultural ecosystem services through empirical 'willingness to pay' methods (Badola *et al.*, 2010; Maharana *et al.*, 2000), however there have been no efforts to empirically value provisioning services in the HKH region (Rasul *et al.*, 2011; Singh *et al.*, 2011). Assessment of their value in this investigation is, therefore, necessarily qualitative.

The importance of ecosystem services is made clear by local people's attitudes towards natural resources. Based on detailed survey data from two catchments in the mid-range mountains of Nepal, Merz *et al.* (2002) found that common words to describe water were 'life' (233 out of 436 respondents used this term), 'essential thing', 'creation', and 'important'. The importance of water is highlighted by examples of water shortage. In the same two catchments, 83% of men surveyed said that they had suffered water shortages for irrigation and 57% of women surveyed told of domestic water shortage (Merz *et al.*, 2002). Changes in the ecosystem provisioning of water negatively affect a number of aspects of people's livelihoods. Among the most important of these is agriculture.

4.2.1.1 Agriculture in the Himalayas

Agriculture is both reliant on the provisioning services of ecosystems and important to livelihoods in the Himalayan region. In Nepal, 80% of the population practise agriculture, contributing 35% to the country's Gross Domestic Product (GDP) (Shrestha & Aryal, 2011; Nepal *et al.*, 2012). In the mountain regions, the percentage involved in agriculture rises to 88% contributing between 30% and 60% of GDP (Huddleston *et al.*, 2003; Nepal *et al.*, 2012).

Climate affects agriculture by determining the length of the growing season; affecting plant growth rates; affecting mean crop yields; influencing the variability of crop yields; contributing to uncertainty in the cropping system; impacting yield quality; and moderating the response of crops to agricultural inputs (Parry, 1978, in Vedwan & Rhoades, 2001; Mavi & Tupper, 2004). Climate is also known to affect agriculture indirectly through the containment of invasive species and disease (Mavi & Tupper, 2004; Devkota, 2010). Each of these influences can be seen as important in Himalayan agriculture, and each can be expected to change under climate change (Devkota, 2010). The provisioning service of reliable rainfall is particularly important in the Himalayas of Nepal because the vast majority of agriculture in this region is rain-fed (Shrestha & Aryal, 2011; Nepal *et al.*, 2012). Among many other natural hazards, the region is known to be prone to droughts (Nepal *et al.*, 2012; Eriksson *et al.*, 2008).

4.2.1.2 Seasonality

The seasonality of ecosystem provisioning services is a crucial determinant of agricultural viability in the Himalayas. Along with widely cited increases in climatic variability, a number of studies have reported perceived changes in seasonality in the HKH region (Allen, 2011, in Singh *et al.*, 2011; Vedwan & Rhoades, 2001; Chaudhary *et al.*, 2011, in Nepal *et al.*, 2012). Delays in the arrival of monsoon precipitation in the Himalayas have been widely observed (Malla, 2008, in Nepal *et al.*, 2012; Allen, 2011, in Singh, 2011; Vedwan & Rhoades, 2001). Allen (2011, in Singh *et al.*, 2011) note that reports of seasonally delayed monsoon precipitation in Nepal show a ‘fair’ correlation with meteorological data from Nepal’s Department of Hydrology and Meteorology. Changes in climatic seasonality, however, appear capricious, as Chaudhary *et al.* (2011, in Nepal *et al.*, 2012) reported perceived advances in the onset of monsoon precipitation in Nepal since the year 2000. What *is* clear is that changes in the seasonality of ecosystem provisioning services are occurring in the Himalayas. These changes have serious implications for mountain agriculture and in turn, mountain livelihoods.

4.2.2 Implications of Changes in Water Availability

The implications of changes in the benefits people derive from ecosystems are dramatic. A number of ecosystem services in the HKH region are being degraded by human activity (Xu *et al.*, 2009). The importance of these changes is often highlighted with respect to freshwater resources. In the HKH region, for example, 200 million people are seen to depend on the ecosystem provision of water with a further 1.3 billion people benefitting in downstream regions (Schild, 2008). As highlighted in Chapter One, it is often suggested that reductions in water availability will lead to a decline in agricultural productivity with serious implications for both food security and human health in the region (Macchi, 2010b). This section explores the implications of climate change on ecosystem provisioning services in the HKH region with respect to agricultural production, food security, and human health.

4.2.2.1 Agricultural production

Climate change may have a number of beneficial impacts on agricultural productivity, particularly in high mountain regions (Shreshta, 2003). Increasing temperatures may enable longer growing seasons, higher agricultural ranges, faster growth rates and increased crop rotation while reducing livestock stress caused by heavy snowfall and cold temperatures (Eriksson *et al.*, 2009; Jing & Leduc, 2010; Singh *et al.*, 2011; Macchi, 2010b, 2011). Nemani *et al.* (2003) suggest that an easing of a number of environmental constraints under climate change increased global primary productivity by 6% between 1982 and 1999.

The benefits outlined above must, however, be weighed against increased stress in other critical agricultural inputs. The IPCC (2007a) suggest that agricultural water demand will increase by between 6% and 10% for every degree Celsius of temperature rise. Furthermore, temperature increases are expected to reduce limits on invasive species and crop diseases (Shershta, 2003; Devkota, 2010). Singh *et al.* (2011) cite a number of studies which have found overall declines in rice, maize and wheat production in the HKH region as a result of increasing water stress dominating any positive effects of climate change. The combined effects of changing temperature and precipitation are expected to lead to a 30% decrease in crop yields in Central and South Asia by 2050 (UNDP, 2006, in Eriksson *et al.*, 2009). Weighed against increases in cultivation extent, decreases in yield are expected to result in net cereal production decrease of between 4% and 10% by the end of the century under the most conservative climate change scenarios (IPCC, 2007a). Declines in crop production and slaughtering of livestock during times of water stress have already been observed in the mountain regions of Nepal (Shah, 2010; Devkota, 2010; Merz *et al*., 2002; Dixit *et al*., 2009).

4.2.2.2 Food Security

Declines in agricultural productivity have serious implications for food security which is often already tenuous in the Himalayas (Shreshta, 2003). Food insecurity affects as many as 40% of people in mountain communities in developing and transition economies (Huddleston *et al.*, 2003). It is estimated that one million Nepalese may face severe food shortages under climate change (Oxfam, 2009, in Nepal *et al.*, 2012). Immerzeel *et al.* (2010) attempted to quantify the provisioning capacity of major Himalayan river basins by relating projected changes in runoff to net irrigation requirements, observed crop yields, caloric crop values and human energy requirements. Their findings suggest that the number of people who can be fed by the provisioning services of the Ganges may decrease by 2.4 ±0.2 million by 2050. Food security exists as one of the major threats climate change poses to Himalayan communities.

4.2.2.3 Health

Food insecurity contributes to malnutrition which has numerous and severe health impacts in HKH region. Malnutrition is sadly common in the mountain regions of Nepal. Of the more than 50,000 child deaths in Nepal every year, malnutrition was identified as the underlying cause of

60% (UNICEF, 2012). Half of all children are underweight and three quarters of pregnant women are chronically iron deficient (UNICEF, 2012). Malnourishment is known to cause conditions including stunted growth, low intellectual development and low immunity (WHO, 2003). Malnutrition is known to pose particularly serious threats to children, pregnant women, those in ill health and the elderly (Macchi, 2010b). It is both a health outcome in itself and a contributing factor to other health problems through a lowering of the immune system (Jing & Leduc, 2010).

Changes in ecosystem provision of water also seriously affect domestic water use, hygiene and sanitation. The first activity sacrificed in times of water shortage is often cleaning toilets (Dixit *et al.*, 2009). Household members, particularly women and children, commonly spend far more time collecting water from distant sources during dry periods and may rely on more polluted sources (Dixit *et al.*, 2009). Reductions in stream discharge during dry periods lead to the deterioration of water quality (Nepal *et al.*, 2012). This leads to increased incidence of disease (Eriksson *et al.*, 2009; Dixit *et al.*, 2009). Diarrhoeal morbidity and mortality are expected to increase in South Asia as a direct result of changes in water resources under climate change (IPCC, 2007a).

Along with the negative effects of climate change, a number of positive effects on public health are expected. In mountain regions of Nepal for example, increases in temperature are expected to decrease illness related to cold conditions (Eriksson *et al.*, 2009). Furthermore, warmer conditions reduce the need for heating and the use of fuel wood, thereby reducing the risk of respiratory disease caused by smoke (Jianchu *et al.*, 2007; Eriksson *et al.*, 2009; Macchi, 2011). Increased temperatures are, however, also expected to increase the incidence of climate constrained diseases such as malaria, Japanese encephalitis and Kala-azar (Regmi & Adhikari, 2007, in Nepal *et al.*, 2012).

4.3 Social Vulnerability

Having examined the importance of water as an ecosystem service, it is now pertinent to ask ‘what effect do changes in water availability have on sustainable livelihood capacities?’ This effect is moderated by the social vulnerabilities of the people concerned. As discussed by Brooks (2003), social vulnerability carries the discipline-specific notion of vulnerability as it is commonly viewed in the social sciences. Social vulnerability is a condition inherent to the system investigated, determined by the system’s internal characteristics, and its value is theoretically independent of hazard (Brooks, 2003). For example, in this investigation, the social vulnerability of the communities of Panglin and Tallo Lorpa is not influenced by changes in water availability under climate change; rather it refers to the inherent capacity of these communities to cope with such changes, whether or not they occur. Social vulnerability therefore depends on both the capacity of a people and the ways in which they develop and adapt. Development and adaptation are addressed in Section 4.4 on ‘Response to Environmental Change’. This section explores how capacity relates to social vulnerability through an assessment of poverty. Previous investigations of social vulnerability in the Himalayas are then discussed.

4.3.1 Poverty

Social vulnerability to water stress is closely correlated with poverty (Pandey *et al.*, 2012). An analysis carried out by Shah (2006) suggests that while water endowment has almost no correlation with the incidence of water poverty, GDP *per capita* and the Human Development Index (HDI) of the country in question are both strong indicators of water poverty. This led Shah (2006) to suggest that a more accurate term for ‘water poverty’ would be ‘water access poverty’ because of the large influence capacity has on the experience of water shortage. Eriksson *et al.* (2009) explain this correlation by pointing out that those living in poverty commonly face shortages in many livelihood resources, including water. Further, Pandy *et al.* (2012) point out that water stress is not only a product of poverty but also a contributor to it in the first place.

Poverty is defined by Hunzai *et al.* (2011) as relating to an inability to attain certain standards of living. These standards of living can be described in relative terms, where poverty is an inability to meet the standard of living enjoyed by others in society, or in absolute terms in which the standards of living refer to basic human needs (Hunzai *et al.*, 2011). In Nepal poverty is often absolute. According to the World Bank (2008), Nepal is the 15th poorest country in the world. One third of people live in absolute poverty and 50% of children are malnourished (Hunzai *et al.*, 2011). Jing and Leduc (2010) point out the majority of districts in Nepal do not produce enough food to feed their populations and more than half of households in Nepal believe their food intake is inadequate. Poverty is particularly prevalent in the hill and mountain regions of Nepal and the difference in wealth between these regions and the plains has been increasing in recent years (Jianchu *et al.*, 2007; Jing & Leduc, 2010; Hunzai *et al.*, 2011; Rasul & Karki, 2007).

Poverty can vary greatly between households in a community and within households themselves. Hunzai *et al.* (2011) found substantial variability in household wealth in the HKH region and were able to isolate factors such as high dependency ratios, poor access to basic facilities and low social status that contribute to poverty. Caste, for example, is known to be a strong determinant of household poverty. In Nepal, 90% of Dalit households were below the poverty line in 2001 (Jing & Leduc, 2010). Certain household members also have greater ability to attain the basic standards of living than others. Macchi (2011) points out that women, children and the elderly are often particularly impoverished in the HKH region.

Inequality within communities can be as much of a determinant of social vulnerability as overall poverty rates. Chambers and Conway (1992, p.2) suggest that afflictions like food insecurity are too often assessed at the community level with an eye to increasing production, a fallacy they call ‘production thinking’. The authors point out that food insecurity is more a problem of unequal ability to secure and provide food than of insufficient overall production.

In summary, it is clear that poverty is closely linked with social vulnerability to water stress. Absolute poverty, in which people struggle to meet basic human requirements, is common in Nepal, particularly in mountainous regions of the country. The experience of poverty is uneven both within and between households. Social vulnerability to water stress can therefore be expected to be high in the mountain regions of Nepal and greater for some people in some households than for others.

4.3.2 Findings of Previous Studies

A number of studies have identified high social vulnerability amongst communities in the HKH region. Social vulnerability manifests as an inability to cope with or recover from stresses and shocks and may result in a reduction in sustainable livelihood capacities (Scoones, 1998). Social vulnerability is seen to stem from the dependence of livelihoods on ecosystem services and severe poverty. Again, observed social vulnerability is unequal between and within societies.

The agrarian nature of Himalayan communities makes them socially vulnerable to water stress under climate change. While social vulnerability is theoretically independent of hazard, it remains to some degree hazard specific (Brooks, 2003; Smit & Wandel, 2006). For example, while the quality of housing may be an important determinant of social vulnerability to earthquakes, it is unlikely to greatly affect social vulnerability to water stress under climate change. With water stress under climate change the topic at hand, the predominance of climate sensitive agriculture in the livelihood strategies employed by Himalayan communities can be seen as a substantial contributor to social vulnerability (Singh *et al.*, 2011; Jing & Leduc, 2010).

High levels of poverty in Himalayan communities are found to further contribute to social vulnerability. In a regional study on the impacts of climate change on livelihoods, Jianchu *et al.* (2007) point out that high mountain communities, which are poorer and more marginalised than those at lower altitudes, have particularly high social vulnerabilities. In a similar investigation on the effects of climate change on wellbeing in the Eastern Himalayas, Jing and Leduc (2010) note poverty as an inhibitor to adaptation in the region, making it difficult to reduce social vulnerability. In this situation, people are unable to take advantage of adaptation opportunities presented to them because they could not afford the necessary inputs or investments. This condition was also noted by Macchi (2011).

A number of groups within society, particularly women and lower castes, are seen to have higher than average social vulnerabilities (Agrawal, 2008; Stern, 2007; Macchi, 2011; Jing & Leduc, 2010). Gender inequality is seen to stem from both weaker capital bases amongst women in general (Stern, 2007; Macchi, 2011) and the fact that women's household responsibilities often depend on natural resources (Nepal *et al.*, 2012; Jing & Leduc, 2007). For example, women in Upper Mustang have been found to work on average 6.5 hours longer each day than men, due largely to the tasks of collecting water and biofuels (Nepal *et al.*, 2012). If the availability of these resources declines, it is generally women who must spend more time collecting them for the household, leading, if nothing else, to drudgery and immiseration.

While social vulnerability to water stress is apparent in the Himalayan region, this situation is not static. Social vulnerability is reduced through adaptation and increasingly effective coping strategies (Brooks, 2003). These concepts of response to environmental change are now explored.

4.4 Response to Environmental Change

Himalayan communities have long histories of responding to environmental change (Dixit *et al.*, 2009; Eriksson *et al.*, 2009; Macchi, 2011). The prevalence of extreme events along with changes in temperature and water availability have necessitated the development of multiple livelihood and adaptive strategies (Eriksson *et al.*, 2009; Macchi, 2011). Citing Klatzel and Murray (2009) and communication with Pradhan (2011), Singh et al (2011) note a number of traditional responses to environmental uncertainties and change implemented by mountain communities. Among these strategies, forecasting extreme events through use of environmental indicators present in indigenous knowledge; switching to dependence on horticultural crops if cereal crops fail; and migrating for work are all historically engrained in the livelihood strategies of mountain peoples.

The adaptive capacity of poor mountain communities is a contested notion. A number of researchers suggest that the potential for livelihood densifcation among poor communities is greater than is commonly recognised because of opportunities related to resource use intensification and small scale economic synergy (Mortimore, 1989; Chambers & Conway, 1992). Others point out that poverty and marginalisation coupled with the fragility of the mountain environment limit the adaptive capacity of mountain communities (Jing & Leduc, 2010; Macchi, 2011). The interplay between the potential for, and inhibition of, adaptation forms the crux of this section on response to environmental change.

Response to environmental change occurs through a number of strategies. The current review groups responses into two categories: ‘adaptations’ and ‘coping strategies’. Adaptation is defined by Klatzel and Murray (2009, p.7) as “A process of adjusting to changes in variables that influence human well-being and survival”. Coping strategies are defined by Klatzel and Murray (2009, p.7) as “Short-term actions to ward off immediate risk, rather than to adjust to continuous or permanent threats or changes”.

The following section begins by exploring how institutional contexts and community beliefs about environmental change influence adaptive capacity. The ways in which responses to environmental stresses occur in reality in the form of adaptation and coping strategies are then assessed. The possibility that responses to environmental change can have negative outcomes for other community members or for the entire community over time, termed ‘maladaptation’, is also explored.

It must be acknowledged from the outset that coping strategies and adaptation are not necessarily adopted in response to environmental stress; rather they are the result of multiple factors which affect people’s livelihoods (Smit & Wandel, 2006; Macchi, 2011). As Dixit *et al.* (2009, p.26) explain: “farmers continually change their livelihood strategies in order to make the best living possible from the changing opportunities available”.

4.4.1 Beliefs and Awareness

The adaptive capacities of communities depend strongly on perceptions of the change that people believe they are responding to (Chambers & Conway, 1992). Adaptive capacity can be defined as the ability of a system to adjust to change in order to both mitigate expected damages and benefit from emerging opportunities (IPCC, 2007a; Brooks, 2003). As Macchi (2011, p.9) explains: “Only informed individuals or groups are able to implement planned adaptation strategies”. People’s beliefs and customs present both barriers and opportunities to the response process (Dixit *et al.*, 2009). For example, communities that view environmental phenomena as divine retribution of their religious deities are likely to focus on approaches of worship and social conduct as remedies to problems. These communities are less likely to firstly adopt scientific findings and projections, and secondly, embrace technical responses to observed changes. Religious beliefs are strongly held in the mountain regions of Nepal and uncertainties surrounding the likely effects of climate change are large. Beliefs and awareness are therefore likely to substantially affect responses to environmental change in Panglin and Tallo Lorpa and may act to inhibit adaptation in these communities.

4.4.2 Institutional Context

The institutional context within which adaptation and coping strategies are implemented is a crucial determinant of their efficacy. Institutions are defined by Davies (1997, p.24, in Scoones, 1998, p.12) as:

> "…the social cement which link stakeholders to access to capital of different kinds to the means of exercising power and so define the gateways through which they pass on the route to positive or negative adaptation".

The nature of institutions with which individuals and communities interact can present both opportunities and obstacles with regard to adaptation and coping strategies (Brooks, 2003; Scoones, 1998; Eriksson *et al.*, 2009). In the mountain regions of Nepal, institutional support can be seen as lacking and many of the institutions that do exist show frustrating biases.

Institutional support can be seen as deficient throughout the HKH region. While there is need for private sector involvement to provide services, this has also been seen to be lacking. Singh *et al.* (2011) point to a lack of agricultural insurance, food processing and storage facilities and credit providers in the HKH region. This weak institutional context allows for value chain 'leakage', meaning that the payment mountain communities receive for their goods and services is often dramatically lower than the price paid by their consumers (Hoermann *et al.*, 2010). It has been suggested that the private sector should be included in plans to provide support services to reduce climate vulnerability in Nepal. As Agrawal (2008) points out, however, the private sector has played an extremely minor part in facilitating climate adaptation to date, the majority of which has been carried out by public and civic institutions. This is largely because the inaccessibility of mountain communities acts as a market disincentive for investment in many cases.

Many of the institutions that do extend to mountain areas have been criticised for disproportionately ignoring these regions and poorly targeting the support they provide. Many institutions have been seen to exhibit a 'plains bias' in which more accessible and larger scale projects are favoured (Bandyopadhyay & Gyawali, 1994; Singh *et al.*, 2011; Hunzai *et al.*, 2011; Rasul & Karki, 2007). Khalid and Kaushik (2008) suggest that this is partly because mountain peoples have difficulty influencing the decision making process and therefore have little say over the policies implemented. Isolation from decision making processes may also partially explain why support has not been effectively targeted at those in poverty. Monopolisation of institutional support by relatively wealthy members of society has been commonplace in recent decades, even when efforts are purportedly targeted towards the poor and poorer households attempt to become involved (Agrawal, 2008; White & Pettit, 2004).

Institutional support provided to mountain communities has been further criticised for ignoring mountain specificities. As Rasul and Karki (2007) point out, development support is generally modelled on that given to communities on the plains and is therefore more suited to green revolution agriculture and economies. As a result, this support commonly fails to provide the information, knowledge and services needed in mountain regions (Rasul & Karki, 2007).

In Nepal, national level institutions play a crucial role in responding to climate change vulnerability. Eriksson *et al.* (2009) point out that structural inequality within Nepalese society will need to be levelled in order to facilitate adaptation for those living in poverty. Klatzel & Murray (2009) note that national level institutions are not well informed about adaptation interests at the local level. Further, it is suggested that national institutional support could be substantially improved if greater attention were paid to traditional and indigenous knowledge on how best to respond to changes (Richards, 1985; Xu *et al.*, 2009; Bhattacharyya *et al.*, 2004). Brooks (2003) suggests that a lack of focus on the national institutional environment may stem from an inward view of vulnerability and adaptation taken by researchers who see questioning centralised policy as futile.

Notwithstanding these issues and the continued political instability, the government of Nepal developed a National Adaptation Plan of Action (NAPA) in 2010 and a national framework for Local Adaptation Plans of Action (LAPAs) in 2011 for addressing the effects of climate change (Nepal *et al.*, 2012). In addition to the NAPA and LAPA framework, Nepal's national planning commission has written a climate resistant development document with the aim of safeguarding future developments from the effects of climate change. These developments, although relatively recent, show positive attempts to improve the national institutional framework in order to reduce climate vulnerability.

The development of a framework for LAPAs is also a positive acknowledgment of the importance of local institutions in facilitating climate change adaptation. Agrawal (2008, p.37), through an analysis of the UNFCCC adaptation and coping strategies database, found local institutions to be vital links for institutional support, concluding that: “without local institutions, rural poor groups will find it far costlier to pursue any adaptation practice relevant to their needs”. Local institutions are seen as important in facilitating collective responses to environmental change and act as conduits for external support and resources (Wade, 1994, in Sullivan & Meigh, 2006; Agrawal, 2008). As less formal entities, local institutions help to manage resources and provide social support through ties of kinship and community (Bandyopadhyay & Gyawali, 1994; Klatzel & Murray, 2009).

The existence and strength of local level institutions cannot be assumed. Dixit *et al.* (2009) point out that responses to water resource issues in the Koshi Basin have tended to be technical and individual in nature because collective response, while often cheaper, requires organisation and community support beyond the means of individual households. The strength of local institutions therefore varies widely and must be assessed on a case by case basis. As shown in Section 2.6.4, a number of local institutions are active in Panglin and Tallo Lorpa. The efficacy of these institutions was assessed as part of this investigation and is described in Section 6.7.4.

4.4.3 Adaptation

In an effective institutional context and enabled by an awareness of change, adaptation reduces social vulnerability (Macchi, 2010b). Adaptation does not necessarily reduce the overarching biophysical vulnerability because this also depends on the evolution of hazard (Brooks, 2003). Climate change is expected to increase hazard while adaptation and development can be expected to reduce social vulnerability. The interplay between these two conditions determines overall biophysical vulnerability and, ultimately, the sustainable livelihood capacities of communities.

Adaptive capacity describes the potential communities have to adapt and has been addressed in the previous sections on poverty, beliefs and awareness and institutional context. Mountain communities have relatively high adaptive capacities because of comparative advantages of high environmental diversity and historical experiences of environmental stress (Hoermann *et al.*, 2010b; Macchi, 2011). In the context of mountain poverty, however, adaptation must be weighed against the provision of basic needs. In the words of Klatzel and Murray (2009, p.10): “there is no practical reason [for mountain communities] to question whether responses to water stress and hazards will be sustainable in fifteen years’ time if they do not ensure survival today or tomorrow”.

This section explores the realisation of adaptive capacity through adaptation itself. Adaptation is a process that occurs over time and as such, at any one time the adaptations of a community trail its adaptive capacity (Brooks, 2003). Macchi (2010) suggests that in the foreseeable future, adaptation measures will follow ‘no regret’ strategies which benefit communities regardless of how climate may change in years to come. Furthermore, Macchi (2011) points out that climate change adaptation efforts should focus on women as the main food producers in the HKH region. Beneath these general directives, adaptation is explored in this section under the four general categories of capacity building, agricultural adjustments, livelihood diversification and technological adjustments.

4.4.3.1 Capacity building

One of the most effective ways to adapt to climate change is to enhance the capacities of vulnerable people through development. Garg *et al.* (2007, p.133) label this the ‘development and climate paradigm’ and suggest that it is “the key for enhancing adaptive and mitigative capacities”. Further, Eriksson *et al.* (2009) suggest that forced and technocratic adaptation approaches are unlikely to be as successful as strategies emerging organically from on-going efforts of development. It has been found that access to things like roads, markets, tools, equipment and information allows communities to effectively manage environmental stress (Moench & Dixit, 2006). Gill (2003) points out that these development activities often have co-benefits such as increasing employment and providing services to the local economy. Development and poverty reduction are likely to play a large part in climate change adaptation in the Himalayas.

4.4.3.2 Agricultural Adjustments

As explained in Section 4.2.1, agricultural production in mountain communities is important as a source of sustenance and income, but simultaneously vulnerable to environmental stress. Agricultural societies are quick to perceive environmental changes that influence their production and have proven capable of adapting practices in light of perceived changes in the past (Singh *et al.*, 2011). Whether this continues into the future has yet to be seen. Adaptation in the agricultural sector occurs through three general processes. Agriculture can either be intensified through improved practice; crop varieties and livestock species can be changed; or cropping intensity and animal husbandry can be reduced.

Intensification of agricultural productivity is an attractive adaptation option as it provides greater returns to farmers, enhancing their capacity and reducing their social vulnerability. A number of researchers suggest that the scope for agricultural intensification (within bio economic limits) is considerable in many poor communities (Chambers & Conway, 1992; Mortimore, 1989; Boserup, 1965). The adoption of agro-forestry, crop rotation, crop diversification and plastic tunnel greenhouses provide opportunities for increasing agricultural output in the mountain regions of Nepal (Devkota, 2010; ICIMOD, 2012).

Adaptation opportunities also stem from the fact that different crops and different livestock species have different environmental requirements. For example, millet requires substantially more water than maize per calorie of food energy produced (ICIMOD, 2012). Likewise, cows and buffaloes have substantially higher water requirements per incremental benefits (either meat or other animal products) than other livestock like goats (Dixit *et al.*, 2009). Substitution of crops and livestock in response to water shortage was recorded by Dixit *et al.* (2009) who investigated local responses to too much and too little water at six sites in the Koshi Basin, Nepal. Approximately half of all farmers surveyed by Dixit *et al.* (2009) reported having changed to less water intensive crops. Nearly one in five households reported diversifying their livestock ownership to include less water intensive species.

Perhaps the least desirable agricultural adaptation strategy is reducing agricultural intensity (Smit & Wandel, 2006). Reducing cropping rates, cropping area and the number of livestock reared are all effective ways of reducing input requirements like water (Dixit *et al.*, 2009). Sale of livestock was reported by as many as 30% of respondents in the investigation of Dixit *et al.* (2009) as a direct response to water shortage. In the most extreme case, lack of required inputs make farming uneconomic and it is abandoned altogether; a situation reported by as many as 13% of respondents in the investigation of Dixit *et al.* (2009).

While changes in water availability may appear to be a dominant factor in crop and livestock changes, Singh *et al.* (2011) point out that other major factors are also responsible. Farmers in the mountain regions of Nepal have been gradually moving away from cereal crops and toward horticulture and other industries as greater connection to markets both increased their ability to sell produce and exposed communities to cheap sources of cereal foods from the world market (Singh *et al.*, 2011). As Gill (2003) points out, this market exposure has brought considerable benefit overall as new opportunities have arisen more quickly than traditional industries have diminished.

4.4.3.3 Livelihood Diversification

A popular undergraduate economics text book by Frank and Bernanke (2007, p.35) begins its second chapter with an illustrative anecdote about comparative advantage featuring a Nepali chef called Birkhaman.

> "Although Birkhaman had virtually no formal education, he was spectacularly resourceful. His primary duties, to prepare food and maintain the kitchen, he performed very well. But he also had other skills. He could thatch a roof, butcher a goat, and repair shoes. An able tin smith and a good carpenter, he could sew and fix a broken alarm clock, as well as plaster walls. And he was a local authority on home remedies. Birkhaman's range of skills was broad even in Nepal, where the least skilled villager could perform a wide range of services that most Americans hire others to perform. Why this difference in skills and employment? One might be tempted to answer that the Nepalese are simply too poor to hire others to perform these services… But as reasonable as the poverty explanation may seem, the reverse is actually the case. The Nepalese do not perform their own services because they are poor; rather, they are poor largely *because* they perform their own services*".*

While this anecdote effectively introduces the concept of comparative advantage in an economic sense, it thoroughly misinterprets the realities of sustainable livelihood strategies in Nepal. Diversification of livelihood strategies across a number of sectors and activities enables intensification of production, small scale economic synergy and reduces social vulnerability to livelihood threats (Chambers & Conway, 1992; Scoones, 1998; Klatzel & Murray, 2009). It is, therefore, *because* poor Nepalese perform wide ranges of services that they are able to prosper in high densities in challenging and dynamic environments.

Livelihood diversification is widely seen as an effective way of reducing social vulnerability. Individuals who pursue multiple livelihood activities are able to spread vulnerabilities across different sectors, time and space and are less vulnerable to any singular hazard as a result (Rasul & Karki, 2007; Scoones, 1998; Chambers & Conway, 1992; Klatzel & Murray, 2009). As Dixit *et al.* (2009, p.21) point out, "A rich farmer or businessperson can be devastated if a flood or drought destroys his sole source of income". According to Scoones (1998), livelihood diversification is a particularly effective strategy if the individual is able to spread activities across multiple sectors in order to reduce the covariance of vulnerability to different hazards.

Chambers and Conway (1992) suggest that diversification of agricultural practice to include intensified home gardening, mixed cropping, agroforestry, aquaculture and cut and carry stall feeding provide labour intensive jobs and can be effective in increasing the sustainable livelihood capacity of a given area of land. Under these conditions, development thinking based on intensification of agricultural inputs or notions of everyone having a singular 'job' is fallacious (Chambers & Conway, 1992).

Diversity of livelihood activities pursued by poor communities is well reflected in the literature. Magor and Orr (1990, in Chambers & Conway, 1992) found that in rural Bangladesh as little as 37% of household income was generated through agriculture directly, while substantially more was generated by employed labour, business and services. Dixit *et al.* (2009) point out the importance of wages from governmental and official jobs and income from small business and trade for households in rural Nepal. Further, Nepal *et al.* (2012) highlight growth in the medicinal and aromatic plant industry in Nepal’s mountain regions which, along with other non-tree forest products, contribute more than NRs 2.5 billion to the national economy. Clearly classifying communities as ‘agricultural’ misrepresents the complexity and diversity of the livelihood strategies which constitute their sustainable livelihood capacities. Livelihood diversification beyond agriculture may represent an attractive and effective way out of poverty for many in the mountain regions of Nepal.

4.4.3.4 Technological Adjustments

Technological developments provide substantial opportunities for reducing social vulnerability among mountain communities in Nepal. Technological opportunities in the rural sector may be particularly promising (ICIMOD, 2012). Approaches like improving or extending irrigation infrastructure, planting trees as shelter belts, using plastic tunnel green-housing and adopting drought resistant strains of seed are all seen as effective ways to reduce agricultural vulnerability in the mountain regions of Nepal (Devkota, 2010; ICIMOD, 2012).

Beyond agricultural changes, a number of options exist for enhanced capture and storage of water as well as runoff smoothing. For example, 13% of respondents in the communities studied by Dixit *et al.* (2009) reported collecting rainwater or using electric pumps to safeguard domestic water supplies. At the community level, Kaltzel and Murray (2009) show that small scale infrastructure such as dams, water tanks and pumping stations have reduced social vulnerabilities in many communities. Bhattacharyya *et al.* (2004) show that water storage at the community level can be more cost effective than large scale dams, making this approach particularly attractive.

Geotechnical options also exist for runoff smoothing and water storage on a seasonal basis. Increased groundwater storage of monsoon precipitation may be achieved by the construction of bunds for disrupting surface flows, increasing land cover, encouraging infiltration from channels and pumping water from aquifers during the dry season (Vaidya, 2009; Singh & Singh, 2002; Keller *et al.*, 2000; Singh *et al.*, 2011). Small scale flow disruption has been seen as highly effective in a demonstration exercise carried out in Andhra Pradesh, India, where this approach increased the duration of spring flow from 75 to 207 days. More advanced options for groundwater storage explored by Keller *et al.* (2000) such as artificial recharge have yet to be implemented but may provide opportunities in the future.

Market and incentive based measures are further technical approaches to reducing social vulnerability. Kumar (2005) details how appropriate pricing of groundwater in northern Gujarat has led farmers to produce much greater crop yields per cubic metre of water input. It appears that market demand for irrigation water is elastic and opportunities for increased water use efficiency often exist (Kumar, 2005). Agrawal (2008) note further opportunities for market based adaptation through cropping and weather related insurance schemes. Mills (2007, p.809) explains that insurance related opportunities are “far from a silver bullet” because, among other problems, some climate sensitive livelihood activities may become effectively uninsurable under climate change. Given their success in developed economies, however, the potential of weather based insurance schemes in developing economies is clear (Mills, 2007).

4.4.4 Coping Strategies

Coping strategies differ from adaptation as a form of response to environmental change. While adaptation implies a long term adjustment, coping strategies are defined by Macchi (2011, p.2) as “short-term actions to ward off immediate risk”. Unlike adaptation, the benefits of coping strategies are often immediately available and their employment has been reported in places where adaptations to climate change are not yet apparent (Dixit *et al.*, 2009). In this section, coping strategies are broken into three broad categories of assets, stores and reserves; borrowing; and migration.

4.4.4.1 Assets Stores & Reserves

Accumulation of assets, stores and reserves during times of plenty for use in times of need is a common and effective coping strategy (Scoones, 1998; Mortimore, 1989; Macchi, 2011). In the right storage conditions, many staple crops keep well. If sufficient reserves of staple foods are kept, these stores can provide sustenance in the event of seasonal crop failure (Mortimore, 1989; Agrawal, 2008). In addition to food stores, farmers are also known to use livestock as a form of coping mechanism. Livestock are a particularly useful currency because they are mobile and able to be either sold or eaten (Bhattacharyya *et al.*, 2004).

4.4.4.2 Borrowing

Borrowing is another effective and commonly employed coping strategy which is pursued through a number of different creditors on a number of different levels. In the mountain communities of Nepal, loans are solicited with varying degrees of formality from family members, friends, village funds and moneylenders (Dixit *et al.*, 2009). Taking loans from money lenders formed part of the coping strategies of respondents in all six communities studied by Dixit *et al.* (2009). This strategy does, however, bring the burden of debt to those who resort to it.

4.4.4.3 Migration

Migration is a long practised coping strategy in mountain communities of Nepal (Gill, 2003; Dixit *et al.*, 2009). According to Gill (2003), there are three major ways in which labour migration exists as a coping strategy. Firstly it reduces the demand on food supplies. Secondly, it increases food supply as migrants return with food. Finally, it provides money to the household. In a review of labour migration in Nepal, all the migration flows from mountain regions studied Gill (2003) were found to be long practised or 'traditional'. Dixit *et al.* (2009) suggest that seasonal migration from mountain regions may have been occurring since the 1800s.

Migration generally occurs from poorer districts to wealthier ones and from higher elevation to lower (Gill, 2003; Macchi, 2010b). Jing and Leduc (2010) point out that both international and domestic labour migration have become increasingly common in recent decades. While this increase has brought benefits as a coping strategy, it has also had a number of detrimental effects. Mass male labour migration has caused labour shortages and increased the domestic and agricultural workloads of women, a process referred to as the 'feminisation' of agriculture (Gill, 2003; Hoermann *et al.*, 2010; Shreshta, 2003). This has been linked to both immiseration of women (Hoermann *et al.*, 2010; Gill, 2003) and reductions in agricultural productivity (Jing & Leduc, 2010). Further, labour migration has been seen to lead to declines in agricultural investment in the mountains (Shreshta, 2003). At its most extreme, labour migration is seen as wholly unsustainable and poses threats of urban overpopulation and structural conflict (Hunzai *et al.*, 2011).

Compounding the negative side effects of migration is the possibility that it may in fact provide only modest benefits (Gill, 2003). Labour migrants must find money to fund their travel and lodging. For this reason migration is undertaken by moderately poor people rather than the very poor. Furthermore, consistent work may be difficult to find and labour migrants are generally poorly paid. This reduces the return on migration as a strategy, particularly if the initial funding came from a high interest loan. The strategy is particularly difficult for female migrants who suffer striking inequality of pay, earning between 10% and 35% less than men for the same type of work (Gill, 2003).

4.4.5 Maladaptation

The adaptation and coping strategies described in the previous two sections are not necessarily wholly positive in nature. In some cases, negative consequences can outweigh benefits in the long run leading to increases in social vulnerability: an occurrence called ‘maladaptation’ (Bandyopadhyay & Gyawali, 1994; Klatzel & Murray, 2009; Macchi, 2011). Maladaptation is a common result of short term coping strategies but it has also been observed in efforts towards adaptation.

Coping strategies commonly exhibit maladaptive properties. For example, the consumption of stores and reserves and sale of assets provide only short term relief and depleting these stocks increases social vulnerability in the long run (Smit & Wandel, 2006; Klatzel & Murray, 2009). Taking out loans, while important in providing opportunities, also creates debt. This can be particularly risky if the loan is taken at high interest (Dixit *et al.*, 2009). Migration, in light of its dubious benefits and substantial side effects, is sometimes viewed as a maladaptation (Tickell, 1990, in Agrawal, 2008). This is often the case when people migrate reactively as a means of survival rather than proactively as a means to prosperity. Mass migrations caused by climatic stress commonly lead to social and political instabilities while flooding destination labour markets and greatly reducing productive capital in communities of origin (Tickell, 1990, in Agrawal, 2008). In light of their negative effects, coping strategies are generally pursued as strategies of last resort. People are often well aware of these drawbacks and only employ coping strategies when they are absolutely necessary.

Adaptation strategies, while targeted at reducing social vulnerability in the long term, often have maladaptive side effects which undermine their effectiveness. As explained by the UNDP (2010, in Maccchi, 2011), maladaptation can often be associated with negative consequences of development and capacity building projects. A prominent example of this is the construction of roads in the Himalayas (Dixit *et al.*, 2009; Klatzel & Murray, 2009). Road construction has been seen to disrupt local hydrology and damage natural springs (Dixit *et al.*, 2009). Furthermore, road construction creates greater demand for water as facilities like modern toilets become more readily attainable (Dixit *et al.*, 2009). Road construction also facilitates changes in land use as new areas are able to be accessed more easily (Dixit *et al.*, 2009). As Messerli *et al.* (2004) point out, change in land use itself can often lead to maladaptation. Intensification of agricultural practice, particularly in headwater catchments, is linked to the depletion of soil nutrients, increases in erosion and pollution of water sources which undermine the natural capital base (Messerli *et al.*, 2004).

These outcomes suggest that strategies like road construction and agricultural intensification may increase certain aspects of social vulnerability. Positive impacts and opportunities, however, commonly outweigh these drawbacks as households can take advantage of unutilised natural capital and are afforded access to livelihood activities which do not rely on water. While maladaptive side effects generally do not outweigh positive outcomes, what this does show is that acknowledgement, understanding and mitigation of these side effects are essential in effective adaptation and development planning.

4.5 Summary

From the literature reviewed in this chapter it is clear that mountain communities in the Himalayas are vulnerable to the potential changes described in Chapter Three, but that they also have considerable ability to respond to these changes. In this chapter, vulnerability was assessed as ‘social vulnerability’ and contextualised against sustainable livelihood capacities with the reference point being the *status quo*. Sustainable livelihood capacities are socially vulnerable to environmental change because of their reliance on ecosystem services. The dependence of agriculture on provisioning ecosystem services, as well as the social reverence for these services and the observed effects of changes or inconsistency in their provision, are evidence of their importance to mountain communities.

Poverty is often absolute in the Himalayas and people frequently struggle to meet basic human requirements. The depth of poverty is, however, known to vary between communities, households and household members. Social vulnerability is known to be closely correlated with poverty and can therefore be expected to be substantial in general, but highly variable at the micro level. This inference is supported by a number of previous investigations.

Himalayan communities have long histories of responding to environmental change and can be considered well adapted to their environments. Whether this holds in the future depends on, among other factors, how successfully these communities respond to environmental changes under climate change. Poor understanding of the likely effects of climate change (both at the local level and the research institutional level) makes it difficult to target adaptation measures. Furthermore, a lack of institutional support, coupled with a bias favouring development on the plains and poor targeting of institutional resources, indicates lost adaptation and capacity building opportunities in mountain regions.

Responses to environmental change are placed in two broad categories: ‘adaptation’ and ‘coping strategies’. In light of scientific uncertainties surrounding the effects of climate change in the region, adaptation should follow ‘no regret’ strategies. Among these are reducing poverty through capacity building; enhancing agriculture through crop strain improvements and intensification; diversifying livelihood practices; and reducing social vulnerability through technological improvements. Coping strategies provide immediate alleviation of social vulnerability and are commonly seen as the use of stores and reserves; borrowing from others; and migration. Attempts at adaptation and the use of coping strategies are not necessarily wholly positive in nature. These responses often have negative side effects. While in many cases this does not negate their overall positive influence, these drawbacks must be considered when appraising coping strategies and adaptation.

The literature reviewed in this chapter provides a basis for investigating social vulnerability in Panglin and Tallo Lorpa. The next chapter describes how social vulnerability and adaptive capacity were investigated in this thesis. Chapter Six then presents the results of this investigation.

Chapter Five

Methodology

5.1 Overview

This chapter describes the methods applied in this investigation within a methodological discussion. The chapter begins by describing the aims of the field research and building a framework for achieving these aims based on definitions. The third section outlines the advantages and drawbacks of using a combination of quantitative and qualitative methods. The ways in which mixed methods are applied in this investigation are subsequently described. Uncertainties present in the data produced are acknowledged before the procession of data analysis is described. Finally, composite indexing is discussed as an introductory form of conceptualisation, and the development of a composite index for water stress vulnerability is described. This chapter aims to ensure methodological rigour using two essential steps highlighted by Hay (2000). The first is through the critical formulation of strategies or methods which ensure credibility. The second is through careful documentation of these methods, as well as their shortfalls, in order to open these methods to scrutiny and criticism.

5.2 Aims and Definitions

In assessing the extent to which the communities of Tallo Lorpa and Panglin are vulnerable to hydrological changes caused by climate change, this thesis uses a framework built on definitions. This approach brings rigidity to the conditions being investigated but leaves their interactions fluid. As outlined in Section 1.2, this thesis investigates the ‘biophysical vulnerability’ of the communities of Panglin and Tallo Lorpa to the hydrological effects of climate change. This overarching concept of biophysical vulnerability is broken down into the concepts of ‘social vulnerability’ and ‘hazard’. The concept of hazard was evaluated as the hydrological effects of climate change reviewed in Chapter Three. The previous chapter reviewed existing literature relating to social vulnerability. The current chapter explains how the social vulnerabilities of the communities of Panglin and Tallo Lorpa were investigated. The next chapter details the results of this investigation.

The converse of biophysical vulnerability is ‘resilience’ which is defined here as the capacity of a community to absorb disturbance while retaining its fundamental structure, function and identity (Combination of definitions taken from Macchi, 2011; Macchi, 2010; Klatzel & Murray, 2009). In the absence of changes in hazard, resilience is enhanced through Adaptation and increasingly effective coping strategies. Adaptation and coping strategies determine social vulnerability and influence biophysical vulnerability, therefore both are investigated in this study.

Biophysical vulnerability means little unless it is contextualised within a range of outcomes. It must be asked ‘what is it that these communities may be vulnerable to?’ As explained in Section 4.2: the sustainable livelihoods of community members are the context against which biophysical vulnerability is measured. In this investigation, sustainable livelihoods are related to place, being the communities of Panglin and Tallo Lorpa. These places currently have the capacity to support a certain number of sustainable livelihoods which can be referred to as the *status quo*. It is the sustainable livelihood capacity of these two places in which vulnerability is contextualised from the reference point of the *status quo*. With these definitions, a decrease in the number of sustainable livelihoods which Panglin or Tallo Lorpa can support would constitute biophysical vulnerability, while no change or an increase in this sustainable livelihood capacity would constitute resilience to the hydrological effects of climate change.

In summary, the field methods described in this chapter are concerned with assessing social vulnerability as a major determinant of the overarching biophysical vulnerability of the communities of Panglin and Tallo Lorpa. Social vulnerability is contingent upon adaptation and coping strategies as well as attributes and assets held by the communities. Biophysical vulnerabilities are investigated in relation to the sustainable livelihood capacities of Panglin and Tallo Lorpa against the benchmark of the *status quo*.

5.3 Mixed Methodology

Social vulnerability in Panglin and Tallo Lorpa was investigated using both qualitative and quantitative research approaches, referred to as a mixed methodology. The use of mixed methodologies has become more common in recent years (Bryman, 2006) and this approach has been successfully applied in the rural mid-mountains of Nepal (Dixit *et al.*, 2009). In a recent review of mixed methodologies applied in 232 social scientific articles, Bryman (2006) compared the rationale for using mixed methodologies with the ways in which they were applied in practice. Interestingly, he found that these two steps did not always correspond, often leading to disparity between the ways in which mixed methodologies were presented and the results which they ended up producing. One possible conclusion reached by Bryman (2006, p.111) was that mixed methodologies "frequently [bring] more to researchers' understanding than they anticipate at the outset". In light of this finding, while efforts were made to rationalise the use of mixed methodologies with reference to their expected outcomes, unexpected insights were welcomed.

The justifications for using mixed methodologies are manifold and often case specific. Qualitatively based investigations can use quantitative data to assist in generalising the responses of a small number of individuals to a larger community (Hay, 2000). Conversely, qualitative insight can complement the findings of quantitative surveys (Hay, 2000). This mixture of techniques is seen to provide both individual and general perspectives while being a useful way to cross check or triangulate results (Hay, 2000). In his review of mixed methodologies, Bryman (2006, p.105-107) classified the rationales for mixed methodologies into 16 individual categories. Ten of these rationales apply directly to this investigation. These are:

(1) "*Triangulation* or greater validity – refers to the traditional view that quantitative and qualitative research might be combined to triangulate findings in order that they may be mutually corroborated*"*.

(2) "*Offset* – refers to the suggestion that the research methods associated with both quantitative and qualitative research have their own strengths and weaknesses so that combining them allows the researcher to offset their weaknesses to draw on the strengths of both*"*.

(3) *"Completeness* – refers to the notion that the researcher can bring together a more comprehensive account of the area of enquiry in which he or she is interested if both quantitative and qualitative research are employed*"*.

(4) *"Process* – quantitative research provides an account of structures in social life but qualitative research provides sense of process*"*.

(5) *"Explanation* – one is used to help explain findings generated by the other*"*.

(6) "*Unexpected results* – refers to the suggestion that quantitative and qualitative research can be fruitfully combined when one generates surprising results that can be understood by employing the other*"*.

(7) *"Credibility* – refers to suggestions that employing both approaches enhances the integrity of findings*"*.

(8) "*Illustration* – refers to the use of qualitative data to illustrate quantitative findings, often referred to as putting 'meat on the bones' of 'dry' quantitative findings*"*.

(9) "*Diversity of views* – this includes two slightly different rationales – namely, combining researchers' and participants' perspectives through quantitative and qualitative research

> respectively, and uncovering relationships between variables through quantitative research while also revealing meanings among research participants through qualitative research".
>
> (10) "*Enhancement* or building upon quantitative/qualitative findings – this entails a reference to making more of or augmenting either quantitative or qualitative findings by gathering data using a qualitative or quantitative research approach".

These rationales show that there is a strong case for integrating qualitative and quantitative approaches in the investigation of social vulnerability in Panglin and Tallo Lorpa. Mixed methodologies are, however, criticised in a number of ways. For example, Bryman (2006) points out that vague justifications for mixing methodologies can lead to data redundancy in which the researcher's, and more importantly the participants' time is wasted. Other arguments suggest that qualitative and quantitative data must be understood with reference to the purposes for which they were collected and therefore cannot be meaningfully aggregated (Brannen, 1992a, p. 13 in Hay, 2000). The former concern can be minimised through careful research design. The issue of incommensurability is avoided in this case by *relating* qualitative and quantitative data rather than attempting to aggregate them. The insights gained from mixed methodology in this case are therefore necessarily qualitative ones. Given the rationale behind using a mixed methodology in this instance, the qualitative nature of insights generated does not negate their utility.

In light of the rationales and criticisms discussed, this investigation used a combination of quantitative household surveys and qualitative interviews, focus group discussions and Participatory Rural Appraisal (PRA) techniques. Efforts were made to avoid data redundancy and repetition by reviewing output from previous field work carried out in Panglin and Tallo Lorpa (described in Chapter Two). Furthermore, qualitative data was only sought when it met one or a number of the rationales provided above. The specific combination of quantitative survey and PRA techniques is advocated by Scoones (1998) as an effective method for investigating sustainable rural livelihoods. The PRA techniques used in this investigation derived, in part, from the sustainable livelihoods approach as described by Macchi (2011). The use of this mixed methodology is therefore both critically designed and justified as well as being targeted toward the assessment of sustainable livelihoods and sustainable livelihood density in rural mountain communities.

Given the sensitive nature of topics like income, a comprehensive ethics assessment was carried out prior to the field investigation. Care was taken to ensure that participants were aware of the intentions of the project and the nature of their involvement. The information form, shown in Appendix One of this thesis, was read to each respondent prior to their involvement. Any questions the participants had about the process were then answered. Prior to each survey the participants were asked to either sign, or give verbal consent for the interpreter to sign the participant consent form shown in Appendix Two. This project gained ethical approval from the University of Otago prior to field research and care was taken to uphold ethical standards throughout the project.

5.4 Quantitative Field Methods

The social vulnerability in Panglin and Tallo Lorpa was assessed quantitatively using household surveys. The household level was considered the appropriate social unit for assessment as this is generally the level at which water is used for things like cooking, cleaning, livestock and irrigation (Ellis, 2000). Of the 35 households in Panglin, 34 were surveyed, while 61 out of the 70 households in Tallo Lorpa were surveyed. These response rates make the survey results valid at the 95% confidence level in both communities. Quantitative surveys are able to identify regularities and patterns of similarity and difference; however they are unable to describe process (Hay, 2000).

It must be acknowledged that the use of questionnaires and quantitative data collection in developing countries has been heavily criticised by a number of leading researchers. Building on a critique by Chambers (1983), Gill (1993) suggests that survey techniques and designs which are modelled on social research in developed countries are inappropriate in developing country contexts. Gill (1993, p.10-12) points out eleven fundamental problems which arise during social surveys in developing countries. In this instance, as Gill (1993, p. 12) points out, the investigation benefits from being small-scale and focussed:

> "At one extreme, the postgraduate student, for example, having a high professional stake in the reliability of the study, having personally designed the questionnaire, trained the enumerators and closely supervised their work in the field, is likely to be able to compensate for many of the inherent defects of questionnaires"

Six of the eleven inherent defects of questionnaires were ameliorated to some degree during the research design and implementation. These are:

1) "The people who design questionnaire surveys in developing countries often do not have specific training in questionnaire design"

In this instance, the surveys were designed by a research student based on templates from an established and respected developing country research institute (ICIMOD) and reviewed by both researchers at this institute and a development studies expert in New Zealand.

2) "If foreigners are involved in questionnaire design, translation is usually unavoidable".

Steps were taken to minimise this problem by using plain, readily translatable language and translating surveys with interpreters before they were undertaken.

3) "Surveys are by now well-known in developed countries and press reports make it clear that information on even very sensitive issues like voting intentions is released only in highly aggregated forms. This is certainly not the case in the rural areas of developing countries".

Great effort was taken at the start of each survey to explain the reasons behind data collection and stress that identity details were not sought and responses were to be analysed at the community level to preserve respondent anonymity.

4) "When complex issues are involved, a great deal of information is required if the study is to be sufficiently comprehensive to be useful… The result is usually a long and cumbersome questionnaire, many of whose questions are sensitive and difficult to ask".

Efforts were made to avoid data redundancy through critical survey design and trimming questions from the survey where possible.

5) "Not understanding the real purpose of the survey, the respondent… tries to please his or her guest by giving what is assumed to be the required answer".

Again, the purpose of the research was explained at the outset of each survey with emphasis on the importance of frank and direct responses. Attempts were also made to ensure that enumerators did not provide leading example answers at any stage.

6) "In developing countries… - particularly those of South Asia, where varying degrees of female exclusion are commonplace – [gender bias] can be a major problem".

In this investigation, efforts were made to survey roughly the same number of women as men. Female exclusion did not seem to affect response rates in this case as similar numbers of men and women responded to surveys in each study community.

The remaining five fundamental problems were more difficult to remedy in this instance. There was little way of checking data reliability through the observation of subsequent behaviour and therefore the data generated cannot be validated. The research was unable to meaningfully assess social trends as it was a snapshot of social condition with no preceding or subsequent survey. Many of the survey subjects were illiterate and were therefore unable to engage with the written survey or check that the data gathered were a true reflection of their responses. This literacy gap in itself contributed to social differences between the enumerator and respondent. This social disjoint between the researcher, interpreters and subjects can be expected to substantially influence attitudes towards the project and responses given. Uncertainties stemming from these problems are further elaborated in Section 5.6 of this chapter.

5.4.1 Participant Selection

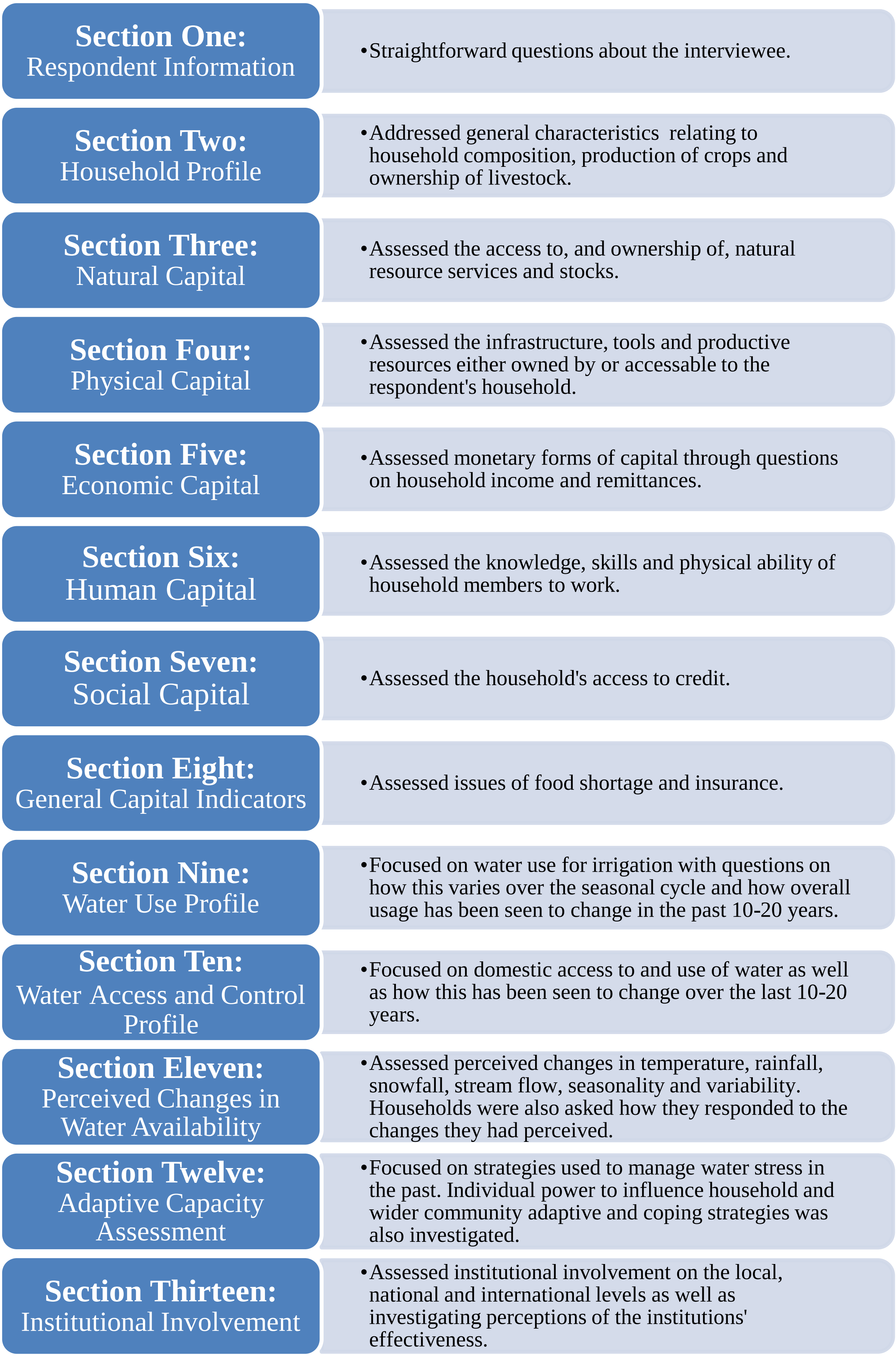
Attempts were made to ensure that participant selection was random in order to enhance the validity of generalising results to the entire community (Hay, 2000). Households were approached for surveying using a patterned sampling method in which one house was surveyed and the house next to it was skipped until every second house in the community was surveyed. The survey team then surveyed every second un-surveyed household until the required confidence level was reached in each community.

While this selection process was random, there were biases introduced in terms of participant availability and response. Households in which there was no one present to answer the survey were skipped. While these may have been returned to in the second round of surveying, the chance that an initially empty house got surveyed was reduced. This availability bias also prevailed within households as the survey was biased towards household members who were more often in the home. In addition, while survey response rates were remarkably high in both communities, there were still some households in which no one was interested in completing the survey. The results were therefore biased toward households in which members were interested in answering the survey. Again, this bias was also present at an intra-household level where individuals who were unwilling to be involved systematically had their observations and opinions overlooked.

The only criterion of the individual respondents was that they had to be at least 16 years of age. This was considered a minimum to have living memory of climatic conditions spanning the last 10 years.

5.4.2 Survey Design

The household surveys used in this investigation were modelled on Vulnerability and Adaptive Capacity Assessment surveys designed by ICIMOD. The resulting survey schedule was made up of 13 sections specifically formulated to investigate vulnerability and adaptive capacity as they relate to water availability. In accordance with the recommendations of Hay (2000), effort was made to ensure the language used in the survey questions was simple, direct and polite. In addition, efforts were made to avoid ambiguity and ensure that the questions were not leading or channelling answers. In light of the recommendations of Macchi (2011), the notion of 'climate change' was not mentioned until the second to last section of the survey so that political bias associated with this concept would be minimised. The survey followed a 'funnel structure' in which simple or general questions were asked first so that the respondents felt comfortable and were not put off by the more challenging or probing questions asked towards the end (Hay, 2000). The full survey schedule is provided in Appendix I and a brief description of its content and sequence is provided in Figure 5.1 below.



Section One: Respondent Information	•Straightforward questions about the interviewee.
Section Two: Household Profile	•Addressed general characteristics relating to household composition, production of crops and ownership of livestock.
Section Three: Natural Capital	•Assessed the access to, and ownership of, natural resource services and stocks.
Section Four: Physical Capital	•Assessed the infrastructure, tools and productive resources either owned by or accessable to the respondent's household.
Section Five: Economic Capital	•Assessed monetary forms of capital through questions on household income and remittances.
Section Six: Human Capital	•Assessed the knowledge, skills and physical ability of household members to work.
Section Seven: Social Capital	•Assessed the household's access to credit.
Section Eight: General Capital Indicators	•Assessed issues of food shortage and insurance.
Section Nine: Water Use Profile	•Focused on water use for irrigation with questions on how this varies over the seasonal cycle and how overall usage has been seen to change in the past 10-20 years.
Section Ten: Water Access and Control Profile	•Focused on domestic access to and use of water as well as how this has been seen to change over the last 10-20 years.
Section Eleven: Perceived Changes in Water Availability	•Assessed perceived changes in temperature, rainfall, snowfall, stream flow, seasonality and variability. Households were also asked how they responded to the changes they had perceived.
Section Twelve: Adaptive Capacity Assessment	•Focused on strategies used to manage water stress in the past. Individual power to influence household and wider community adaptive and coping strategies was also investigated.
Section Thirteen: Institutional Involvement	•Assessed institutional involvement on the local, national and international levels as well as investigating perceptions of the institutions' effectiveness.

Figure 5.1: Flow chart of the household survey design.

The surveys used in this investigation give a detailed, albeit shallow, insight into the composition, livelihood capitals, adaptive strategies and institutional support as well as the current use, perceived changes in, and access to water resources at both the household and community levels. The results provide statistical rigour however lack explanatory power and are, therefore, supplemented by qualitative analysis.

5.5 Qualitative Field Methods

Social vulnerabilities in Panglin and Tallo Lorpa were assessed qualitatively using focus group discussions, key informant interviews and a number of PRA techniques. Three focus group discussions were conducted in Tallo Lorpa, while two were conducted in Panglin. During these discussions, seasonal calendars and livelihood seasonal monitoring calendars were negotiated by the participants. One elderly community member was interviewed at each location and informal observations were made during transect walks during the field work process. These techniques made it possible to investigate the multiple realities which result in multiple manifestations of social vulnerability (Macchi, 2011). In addition it gave insights into the development of identities while empowering and respecting the views of community members (Hay, 2000; Macchi, 2011). Qualitative investigation gave insight into both the underlying processes which interact with social vulnerability, as well as individual experiences of these. These insights deepen the understanding of the multiple experiences of social vulnerability in each community.

5.5.1 Participant Selection

Efforts were made to ensure that qualitative research investigated both male and female perspectives. Hay (2000) likens social reality to an orchestra and notes that poststructural approaches are able to assess each individual instrument by concentrating on its contribution for a period of time. Focusing on individuals who, or groups that would otherwise be dominated by the rest of the orchestra allows for an appreciation of the multiple realities which make up society.

With credence to these multiple realities, focus group discussions were carried out with the local Forestry Group, Water Stewardship Group and Women’s Group in Tallo Lorpa. In Panglin focus group discussions were carried out with the local Women’s Group and a makeshift group of local men with leadership experience.

Key informant interviews were conducted with one elderly member of each community. These interviews were designed to gain a greater understanding of changes in water resources over long periods of time. In Panglin and Tallo Lorpa, the interviewees were both male. Ideally key informant interviews would have been carried out with both men and women in each community. The perceptive histories expressed in the interviews are therefore seen as gender biased and it is acknowledged that women may have had differing perceptive memories.

5.5.2 Qualitative Research Design

The qualitative research design was allowed to be flexible and was developed, in part, from issues or questions that arose from the household survey responses. This dynamic approach is advocated by Hay (2000) as a way of taking advantage of information as it presents itself during research. With this approach, the key informant interview questions focused on changes in water resources over living memory, as well as changes in water use and experiences of community assistance during times of water shortage, in order to deepen the understanding of these issues produced by the household surveys. Again, in designing interview questions, care was taken not to mention the notion of ‘climate change’.

The focus group discussions included a number of interview style questions for the groups. These questions covered similar topics to those used in the key informant interviews with additional questions about water use and institutional involvement. As is common in focus groups, this was found to be a highly propitious method as responses were discussed, negotiated and often fed off one another (Wilkinson, 2004). This has been labelled a ‘synergistic’ result of group discussion (Wilkinson, 2004).

In addition to interview style questions, each focus group was asked to negotiate both a seasonal calendar and a seasonal livelihood monitoring calendar following the framework of Macchi (2011). An example of this, as negotiated by the local Women’s Group in Tallo Lorpa, is given in Figure 5.1. The calendars were drawn up in the local language and care was taken to ensure the meaning of each of the categories was understood by the participants.

Figure 5.2: Seasonal calendar and seasonal livelihood monitoring calendar negotiated by the local community women's group in Tallo Lorpa.

The seasonal calendars (seen on the left of Figure 5.1) were used as a tool to place significant events in a seasonal context (Macchi, 2011). In this instance, timing and intensity or rainfall, snowfall, dry periods, water shortages, floods, food shortages and use of irrigation were assessed. The focus groups were also asked to recall the character of these phenomena ten years previous in order to illustrate perceived changes over time.

The livelihood seasonal monitoring calendars (seen on the right of Figure 5.1) were used to place important livelihood activities within a seasonal context (Macchi, 2011). This included activities such as planting, harvesting and weeding of crops, grazing of livestock and milking of cows. In Tallo Lorpa, the investigated crops were millet, maize, potatoes, onions and summer vegetables. Cropping patterns were not investigated in Panglin as these have been surveyed by previous investigations. Goat grazing areas and seasonal milk production were included in the seasonal livelihood monitoring calendars in each area.

The results of the two calendars are easily merged providing an indication of how climatic phenomena interact with important livelihood activities on a seasonal basis. This provides insight into key periods of seasonal vulnerability as well as an indication of which livelihood activities are most at risk from projected climatic changes (Macchi, 2011).

5.6 Data Uncertainties

The data solicited in this investigation contain a number of uncertainties, which stem from all processes in the research methodology and are broadly categorised in terms of data resolution, subjectivity and reactivity. These three dominant sources of uncertainty are discussed in turn.

Assessing social vulnerability to water stress at the household level introduces uncertainty in terms of data resolution. While the household is a logical level at which to assess water stress vulnerability (as explained in Section 5.4), this level cannot account for intra-household differences in wellbeing and vulnerability. It is understood that some household members, particularly women and children, may be more vulnerable than others (Agarwal, 1997). This disparity extends to social vulnerability and therefore the omission of intra-household research can be seen as a limitation of the data collected in this study.

Subjectivity is seen as an inherent property of social research and may be impossible to eliminate entirely (Gill, 1993; Sarantakos, 2005). It is important that subjectivity is minimised in the research design, and that which persists is openly acknowledged (Hay, 2000). This identification and acknowledgment of subjectivity and uncertainty is termed ‘critical reflexivity’ and requires constant scrutiny of the position of the research team relative to the respondents and vice versa (Hay, 2000).

Subjectivity stems from the fact that the researcher was a 23 year old male, raised in a western culture and relatively unfamiliar with the cultures, practices, beliefs and norms of the research subjects. This introduces subjectivity in the research design, as members of the communities are likely to see parts of the research as unimportant and view omitted topics as crucial to the understanding of water stress vulnerability. The researcher’s positionality also introduces subjectivity in the interpretation of responses, as meanings dependent on social and cultural familiarity are lost.

In addition to the subjectivity introduced by researcher positionality, subject responses may be influenced by the nature of the research process (Gill, 1993). For example, given the huge cultural differences between the researcher and the respondents in this investigation it was, at times, difficult to establish rapport. The credibility of the researcher and the investigation were enhanced through affiliation with ICIMOD. ICIMOD is an established and respected research and learning institution which has conducted previous research in both study communities. This affiliation provided some form of assurance to the respondents that the research was legitimate, professional and ethically sound. The researcher made efforts to learn the basics of Nepali both prior to and during field work; however in the timeframe of the field work, the researcher’s level of understanding remained low. Some amount of familiarity and rapport was gained by living in the communities and being involved in their routines, norms and cultures. The researcher did his best to be open minded, polite, inclusive and receptive and found cultural immersion in each community to be a particularly enlightening and privileged experience. He was, however, acutely aware of his limited depth of social and cultural understanding of these two communities. For example it became apparent that a lack of understanding of religious beliefs and their relationship with the understanding and interpretation of environmental phenomena was a limitation in the research conceptualisation and design, and further understanding of religious belief in each community would have been beneficial. It is acknowledged that further time in, and interaction with, the communities of Panglin and Tallo Lorpa, while not feasible within the scope of this project, would have been beneficial.

The position of the interpreters relative to the respondents must also be acknowledged as an influence on the resulting data (Gill, 1993). The team of three interpreters used in in Tallo Lorpa were all from the local area. Their rapport with the research subjects was excellent as they shared common cultures and norms and often had many common friends. The single interpreter used in Panglin, while from the same district, lived further away from the study community than the interpreters in Tallo Lorpa. Consequently, the interpreter in Panglin had only a small number of local contacts and, while he spoke the local dialect and held similar cultural norms, he was more of an outsider to the Panglin community than the interpreters in Tallo Lorpa were in that community. For this reason, it took more time to build a rapport in Panglin and research progressed more slowly. Both the researcher and the interpreter again stayed in the local community for the duration of the field work and school books and pencils were given to children in the community as a token of good will. Even with these efforts, it must be acknowledged that the social dynamics of data gathering differed between communities and this may be a systematic source of error in the survey data and PRA responses.

It must also be acknowledged that all of the interpreters were male. This goes against the recommendations of Macchi (2011) who suggests that a gender balanced research team is optimal. The interpreters and researcher were aware of the likelihood of reservations in the responses of women and efforts were made to be sensitive to this. It can, however, be assumed that responses would have differed to some degree had the interpreters and researcher been female.

Reactivity presents a further source of error or uncertainty in social research as respondents are known to alter their responses in order to present the version of reality that they want the researcher to hear. This is particularly the case when there are development projects contingent on the outcome of the investigation. In this instance, the fact that the researcher was affiliated with ICIMOD made the assumption of specific development outcomes likely. Effort was therefore made before each survey to inform the respondents that this project was not linked to any specific development outcomes and that the data would be used to enhance understanding rather than to target resources.

5.7 Data Covariance

The data produced by the household surveys were analysed in terms of trends, proportions and modalities at the community level. Beyond this straightforward analysis, household survey data contained a number of broad co-variances. The household survey responses varied with regard to factors like sex, age and relative household wealth, among others. Analysing survey data with respect to these factors can yield important information about inequality, socioeconomic stratification and vulnerability within society as well as indicating divergences of opinion or perception (White & Pettit, 2004; Reitbergen-McCraken & Narayan-Parker, 1998; Macchi, 2011). For some factors, such as age and sex, it is easy to separate or rank the survey data in order to see how they affect outcomes. To do this with regard to relative household wealth is, however, more difficult, and requires careful consideration, reasoning and justification.

There are a number of approaches to household wealth ranking, each with its own advantages, disadvantages, complexities, and research requirements. Wealth ranking can be done both artificially and through participatory means. When done artificially, the most common approach is to survey certain indicators of household wealth and adjust this for household composition (Van Campenhout, 2007; Moser & Felton, 2007; Ravallion, 1992). Historically, income has been the preferred indicator of household wealth for reasons of comparability, cardinality and fungability (Moser & Felton, 2007). Using income as a proxy for wealth, however, has a number of disadvantages, particularly in developing economies (Moser & Felton, 2007). For example, income earned in informal markets, particularly those that are seasonal, can be highly variable through time (Moser & Felton, 2007). Moreover, measuring income does not account for non-monetary exchanges or subsistence activities which were highly prevalent in both of the communities included in this investigation.

Using consumption instead of income as a wealth indicator largely addresses the problems of seasonal variability and oversight of non-monetary transactions (Moser & Felton, 2007). Because of this, consumption replaced income as a standard wealth indicator during the early 1990s (Moser & Felton, 2007). Measuring household consumption and adjusting for household composition has proven to be quick and reasonably accurate (Ravallion, 1992), although there are instances in which it is clearly inappropriate. For example, as Van Campenhout (2007, p.410) points out, a household which saves income rather than spending it would rank low on this conventional wealth ranking when in reality this household may be wealthier than many in its community. There is also commonly variation in the quality of products consumed by a household which is not accounted for in consumption based wealth rankings, yet may further indicate relative wealth (Van Campenhout, 2007). In addition, household consumption is often difficult to recall accurately. Consumption based measures also have trouble valuing bartered goods and tend to overlook work done on things like home improvements (Moser & Felton, 2007).

An alternative approach to wealth ranking which avoids many of the problems of income or consumption based methods is participatory wealth ranking. This involves asking community members what they see as the indicators and dimensions of wealth in their community, then allowing them to rank households according to these (White & Pettit, 2004; Reitbergen-McCraken & Narayan-Parker, 1998). This approach has been shown to produce significantly different rankings to those determined by township and village officials, highlighting the importance of community involvement (Xiaoyun *et al.*, 2001). Participatory wealth ranking has the advantage of allowing communities to define wealth and poverty in the more holistic sense of household well-being (White & Pettit, 2004; Xiaoyun *et al.*, 2001). In this way, well-being can be assessed not just in economic terms but in terms of the factors which are understood to contribute to household vulnerability. This is a clear advantage over traditional wealth ranking methods.

There are, however, a number of disadvantages to participatory wealth ranking. This method relies absolutely on the quality of knowledge local people have about the well-being of others in their community which may be extensive in some cases and tenuous in others (Van Campenhout, 2007; Reitbergen-McCraken & Narayan-Parker, 1998). Furthermore participants may rank households for contrived reasons, particularly where rankings are used to inform development or welfare programmes (Van Campenhout, 2007). Household wealth is also a sensitive topic and participants may feel uncomfortable discussing it openly, particularly in groups of their peers (White & Pettit, 2004; Van Campenhout, 2007). The main disadvantage to participatory wealth ranking in the context of this investigation is that it is a highly involved and time consuming exercise. It is often carried out in isolation as an exercise for targeting development aid (Reitbergen-McCraken & Narayan-Parker, 1998). Best practice requires wealth ranking and discussion with a number of groups in each community in order to triangulate results (Reitbergen-McCraken & Narayan-Parker, 1998; White & Pettit, 2004). As part of a wider project assessing vulnerability and adaptive capacity therefore, this process runs the risk of detracting from the primary focus of the field work.

An alternative to the aforementioned methods is to use a broad range of socioeconomic indicators to construct an artificial wealth ranking which is more encompassing than wealth or consumption based methods, yet less involved than participatory methods. This approach has been widely advocated by development economists in the past decade, and has been shown to produce sound results (Scoones, 1995; Moser & Felton, 2007; Sahn & Stifel, 2003). Indicators can also be drawn from a wide range of socioeconomic data. In light of these advantages, this investigation uses a range of indicators drawn from household survey data to form an artificial wealth ranking for the communities of Panglin and Tallo Lorpa.

A number of studies have looked at the effectiveness of various wealth indicators using extensive participatory wealth ranking as a benchmark (White & Pettit, 2004; Van Campenhout, 2007). These studies have been able to confirm the validity of using certain wealth indicators in certain contexts; however they also show that indicators of wealth are not necessarily intuitive and will differ between communities. For example, while Moser & Felton (2007) found education level to be significantly correlated with household wealth in the community of Guayaquil in Ecuador, this was not the case for communities in the highlands of Tanzania which were studied by Van Campenhout (2007). In addition, while many studies, including Van Campenhout (2007), have found roofing material to be a reliable wealth indicator, Scoones (1995) found poor correlation between these two variables. Examples like these make it clear that, while studies into the efficacy of wealth indicators can provide suggestions of credible indicators, these must be validated in different contexts.

This investigation is, therefore, ultimately informed by the findings of Hunzai *et al.* (2011) who, in an investigation into poverty in the HKH region, appraise determinants of poverty specific to the mountain regions of Nepal. Hunzai *et al.* (2011) used multivariate analysis to assess the informative power of poverty determinants. In light of this analysis, a range of indicators from the household survey responses are chosen to construct an artificial wealth ranking. These indicators were drawn from the three broad categories of household social status; assets and liabilities; and household composition and are as similar as possible to the indicators appraised by Hunzai *et al.* (2011).

The first step in the wealth ranking process involves coding survey results into an un-weighted poverty index. This is done by applying a binary variable to the outcome of each of the selected survey questions with a value of 1 denoting a higher likelihood of household poverty and a value of zero indicating the opposite. The binary outcomes of the selected survey questions are given in Table 5.1. It must be noted that assigning a higher likelihood of poverty to male headed households is unusual, as the opposite is often true worldwide (White & Pettit, 2004; Van Campenhout, 2007). However in this case it provides a further example of context specificity in wealth indicators as Hunzai *et al.* (2011) find female headed households to have a lower likelihood of poverty across the HKH region and in the mountain regions of Nepal specifically.

Table 5.1: Binary values assigned to household poverty indicators in the artificial wealth ranking procedure.

Indicators of Household Social Status	
Dalit = 1	All other castes = 0
Uneducated household head = 1	Educated household head = 0
<50% household literacy = 1	>50% household literacy = 0
Household Assets and Liabilities	
Land ownership < village mean = 1	Land ownership > village mean = 0
Cattle ownership < village mean = 1	Cattle ownership > village mean = 0
Household currently in debt = 1	Household not currently in debt = 0
Household Composition	
Male headed household = 1	Female headed household = 0
Dependency rate > village mean = 1	Dependency rate < village mean = 0

The sum of these binary outcomes for each of the three broad categories is then multiplied by a weighting based on the contribution of this broad category of determinants to poverty in the mountains of Nepal according to Hunzai *et al.* (2011). Using multivariate analysis, Hunzai *et al.* (2011) found indicators of household social status to contribute 35% to the explanation of poverty provided by all indicators in their study combined. This statistic was 26% and 7% for assets/liabilities and household composition respectively. The explanatory powers of each of these broad categories are therefore used as weightings in this investigation such that the sum of binary variables in the household social status category are multiplied by 0.35, the sum of the binary variables in the assets and liabilities category are multiplied by 0.26 and the sum of the binary variables in the household composition category are multiplied by 0.07. The sum of these weighted poverty indicators is then used to rank households according to wealth, where higher values indicate a greater likelihood of poverty and lower values indicate the opposite.

This artificial wealth ranking process is represented mathematically in Equation 5.1:

(Equation 5.1) $$W = ((\sum S)w) + ((\sum A)w) + ((\sum C)w)$$

Where W = Wealth indicator variable; S = Indicators in the category of household social status, A = Indicators in the category of household assets and liabilities; C = indicators in the category of household composition and w = weighting of each respective category.

While an artificial wealth ranking consisting of a broad range of context specific wealth indicators is appropriate for this investigation, there remain a number of limitations to this approach. One commonly mentioned criticism of using wealth indicators instead of peer perception is that wealth indicators provide only a narrow indication of wellbeing (White & Pettit, 2004). There are many dimensions of vulnerability, such as access to credit and diversity of income sources, which are not included in the ranking used in this investigation. In addition to this uncertainty, it is also widely acknowledged that wealth and poverty are transient in nature, such that those people who are poor and thus more vulnerable to water stress now may not be those who are poor and thus socially vulnerable as climate change induced hydrological change proceeds (White & Pettit, 2004). Furthermore, analysing vulnerability at the household level implicitly assumes that every member in a certain household experiences the same level of well-being or vulnerability regardless of age, sex or relationship to the household head. This is unlikely to be the case (Agarwal, 1997; Van Campenhout, 2007; White & Pettit, 2004). Finally, using a broad range of indicators means that the ranking will be ordinal rather than cardinal, positioning households in a rank against others in their community but providing little information about inequality or income stratification (Moser & Felton, 2007). These limitations, while not ideal, are acceptable in the context of this investigation because the artificial wealth ranking is not used as an analytical tool in itself, but simply a means of ordering survey data into broad wealth categories.

5.8 Indexing

Direct assessment of the data gathered in this investigation draws a complex picture of the social vulnerability in Panglin and Tallo Lorpa. This picture risks becoming nebulous if viewed in a disaggregated form. To provide a clearer introductory conceptualisation of social vulnerability in each community, this investigation uses a composite index derived from the Climate Vulnerability Index (CVI (Sullivan & Meigh, 2005)) and the Water Poverty Index (WPI (Sullivan *et al.*, 2003)).

Composite indices are becoming increasingly common as a way to simplify and present complex socioeconomic and environmental relationships and conditions (Booysen, 2002; Sullivan & Meigh, 2005). They have been successfully applied to investigate water poverty in Nepalese river basins (Pandey *et al.*, 2012). Composite indices are useful indicators of development and vulnerability insofar as they are able to integrate a number of individual indicators (Booysen, 2002). This is theoretically beneficial over singular indicators while retaining the simplicity of a single metric (Sullivan & Meigh, 2005; Booysen, 2002; Sullivan *et al.*, 2003). Furthermore, composite indices provide a way to combine qualitative and quantitative data which are otherwise incommensurable (Sullivan & Meigh, 2005; Sullivan *et al.*, 2003). For these reasons composite indices are politically appealing and are commonly used to bridge gaps between social scientific understanding and policy (Jing & Leduc, 2010; Booysen, 2002; Sullivan & Meigh, 2005).

Indexing generally proceeds in four steps: selection of indicators; scaling; weighting; and aggregation (Booysen, 2002). These steps are discussed in turn.

Before describing their methodology, it must be acknowledged that composite indices are widely criticised. For example, Chambers and Conway (1992, p.18) state that:

> "Not surprisingly [sustainable livelihoods] are not easy to measure or estimate; and any attempt to reduce measurement to a single indicator risks doing violence to precisely the complexity and diversity which many rural livelihood manifest – in themselves, in their relationship with the physical environment, and with each other*"*.

Criticisms like this are well founded and widely echoed. They will be discussed further in Section 5.8.8. It is important, however, to bear in mind that the composite index used in this investigation is applied in a limited capacity. It is used to orientate the reader to the broader picture but does not provide the flesh of the argument. This substance is provided by more detailed analysis beyond this introductory indicator.

5.8.1 Selection of Indicators

The first step in composite index development is the selection of components which make up the index. Appropriate measurable variables must then be identified which indicate the value of these components in each community. Selection of index components and indicators is generally based on a combination of theory, pragmatism, intuitive appeal, data availability and empirical analysis (Booysen, 2002). Further important requirements are seen to include simplicity, reliability, validity and comparability (Booysen, 2002). It is fundamentally important that indicator variables represent the component they are supposed to measure and that externalities arising from changes in these indicator variables are considered (McGranahan *et al.*, 1972, in Booysen, 2002). For example, while collecting and selling timber may seem to reduce the social vulnerability of households in this investigation, deforestation associated with this activity is likely to enhance social vulnerability at both the individual household and community levels. Such an activity must not be seen to enhance sustainable livelihoods as they are defined at the start of this chapter.

Ad hoc indicator selection is commonly criticised as being politically contrived. A high profile example is the UNDP's Human Development Index. This index relies heavily on indicators of health and education status and is therefore seen to boost the scores of countries that focus on these sectors of development (Todaro, 1989). It is acknowledged that, in this instance, the way in which social vulnerability was conceptualised contains value judgements of what this concept entails. *Ad hoc* indicator selection is also biased by factors like accessibility and accuracy of data (Booysen, 2002).

Bivariate and multivariate statistical techniques can be used to objectively select indicators through empirical analysis (Babbie, 2010). Bivariate techniques test the strength of correlation between variables and those with the strongest correlations are selected as indicator variables (Babbie, 2010).This relies on the notion that development indicators are highly interdependent and tend to mutually reinforce one another (Babbie, 2010; McGranahan *et al.*, 1972, in Booysen, 2002). Multivariate techniques test the explanatory power of a group of variables and rely on an accurate proxy for the condition being measured. This begs the question: would it not be better to simply use the proxy than a group of variables selected to approximate the proxy? Furthermore, while there is merit in attempting to avoid subjectivity by basing indicator selection on empirical analysis, this requires investigation of a wide range of variables, many of which are rendered obsolete in the process. Empirical analysis is seen as beyond the scope of indicator selection in this instance.

5.8.2 Scaling of Indicators

Scaling of indicators provides the means by which to combine both ordinal and cardinal data with differing units and meanings. This generally occurs through the use of standard scores or Linear Scaling Transformation (LST) methods. Standard scores involve the calculation of z or t values which represent the statistical deviation of the indicator for each individual from the mean of other values of the same indicator (Booysen, 2002). For example, the z-value is calculated by:

$$z = \frac{(Actual\ score - Mean)}{Standard\ Deviation}$$

Linear Scaling Transformation methods commonly seek to define minimum and maximum values for each indicator as points of reference. These limits are then used to form a scale between 1 and 100. For example, the HDI scales life expectancy with a minimum of 25 years and a maximum of 85 years (UNDP, 1996). A country in which life expectancy is 25 would, therefore score zero on this scale whereas a country in which life expectancy is 55 years would score 50 on this scale. Problems arise when indicators have no logical maximum value, for example ownership of assets like goats. Weigel (1986) suggests that using the percentage of the population who meet the criteria in question is a way to scale and account for this.

5.8.3 Weighting of Indicators

In efforts to ensure that composite indices reflect the relative importance of indicators or components, weightings are often applied during aggregation. Conventionally these weights have been set through consultation with experts, however they can also be based on the views of the researcher or tailored to emphasise a political interest (Booysen, 2002). These methods are often labelled as arbitrary (Diener & Suh, 1997). As with scaling efforts, therefore, approaches have been developed in an effort to weight indicators objectively. Again a form of multivariate analysis (called principal component analysis) is used to assess the explanatory power of each indicator and weightings are set based on this. This approach can be criticised because it does not allow the researcher control over the weighting of the components and therefore the index cannot be targeted effectively toward answering a specific research question (Booysen, 2002).

It has been argued that what is important in indicator weighting is that the weightings are openly presented and subject to criticism (Booysen, 2002). Morris (1979) notes that any attempt at weighting indicators can be criticised. In light of this, Babbie (1995) suggests that *not* assigning weights to indicators should be the standard approach. This equal treatment of indicators is seen by Atkinson *et al.* (2003) as appealing in that the indicators used should not have markedly differing importance in the assessment of the condition of interest.

5.8.4 Aggregation of Indicators

Aggregation of indicators can take the form of simple addition or functional combination (Booysen, 2002). The former is relatively straightforward and commonly used. The latter is far more involved, as it requires the functional relationship between variables to be estimated (Booysen, 2002). Functional relationships between indicators like education, income potential, and health are clear, however valuing these relationships can be difficult.

5.8.5 Validation

Validation of composite indices generally involves assessment of correlation between component indicators and overall index scores or assessment of indicators and index scores against external validators (Booysen, 2002). These approaches are called ‘item analysis’ and ‘external validation’ respectively. In item analysis validation, where an indicator is poorly correlated with overall index scores, there is reason to suspect it is not a good indicator of the condition the index is set up to measure and therefore this indicator may be removed from the index (Booysen, 2002). The same logic applies when an indicator is poorly correlated with external validators (Booysen, 2002). External validators can be difficult to select and justify as there are no objective indicators or validators to measure social vulnerability (McGranahan *et al*, 1972, in Booysen, 2002). Indeed the use of external validators seems like somewhat of a circular argument in that the strength of the ability of an index to measure a certain condition is validated by the index's correlation with another indicator used to measure the same condition.

5.8.6 Multidimensional Poverty Indicators

In recent years, composite indices have been developed which assess conditions like poverty in a multidimensional way (Atkinson *et al.,* 2003; Alkire & Foster, 2011). An example of multidimensional indexing called the 'dual cutoff' identification system is presented by Alkire and Foster (2011).This method uses two cutoffs, one for the value of each poverty indicator that constitutes deprivation in that indicator (known as the deprivation cutoffs, zj) and one for when the number of individual indicators in which a person is deprived constitutes poverty (known as the poverty cutoff, k) (Alkire & Foster, 2011). This approach assesses the depth of deprivation of each indicator as well as being able to assess overall poverty across a range of indicators. As Alkire and Foster (2011) point out, the dual cutoff approach is able to identify and prioritise individuals who suffer multiple deprivations. Furthermore, this method can be seen as 'poverty focused' insofar as any increase in achievement of an individual who is above the poverty cutoff leaves the final value unchanged. It is also 'deprivation focused' in that an increase in achievement in any indicator which the subject is not deprived in leaves the final value unchanged. In light of these advantages, the multidimensional dual cutoff approach to indexing can be seen as state of the art. The development of a multidimensional indexing method for the assessment of social vulnerability to water stress would benefit the conceptual rigour of this investigation. Whether it would greatly benefit the index's accuracy is, however, less well known and there are a number of logistical issues in developing such an approach.

While the deprivation cutoffs used in the dual cutoff approach are widely used and understood, poverty cutoffs find less precedence in the literature and are thus more difficult to define (Alkire & Foster, 2011). This is because the poverty cutoff must be defined in a space between indicators, combining a number of differing domains which interact in complex and often nonlinear ways (Alkire & Foster, 2011). Setting this cutoff based on intuitive understanding of actual social vulnerability risks misrepresentation and subjective bias and is seen as an inherent risk of multidimensionality. Moreover, the dual cutoff approach is unable to account for all relevant changes in vulnerability

(Alkire & Foster, 2011). For example, an individual who falls only slightly below the indicator cutoff for only slightly more than the number of dimensions that constitutes poverty and yet scores exceptionally well in all other indicators will be viewed as impoverished. On the contrary, an individual who scores slightly above the individual indicator cutoffs for slightly more than the cutoff number of individual indicators, yet scores exceptionally poorly in the others will *not* be considered impoverished. A hypothetical example of this situation, in which ‘person x’ represents the former example and ‘person y’ the latter, is depicted in Figure 5.2. While it is possible that person y is objectively impoverished relative to person x due to complex interconnections of deprivation, it seems unlikely in this example. Certainly no subjective definition of the poverty cutoff dimension (z) could put forward a strong case for this.

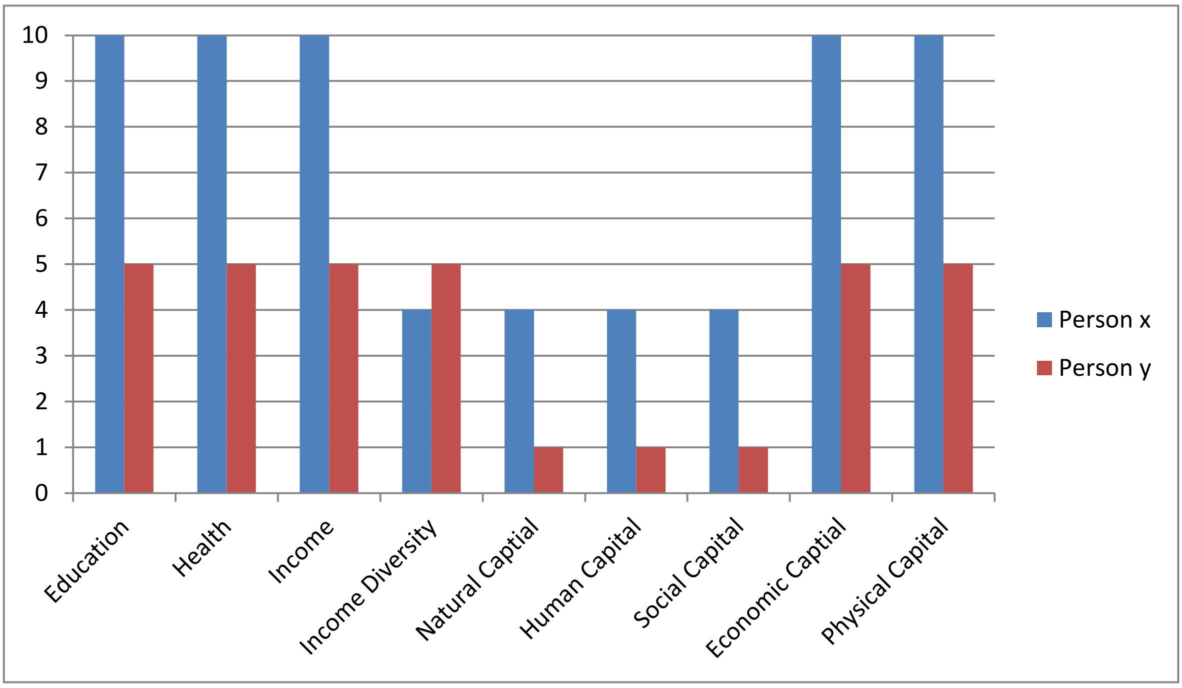


Figure 5.3: Hypothetical example of the insensitivity of the multidimensional ‘dual cutoff’ poverty indexing method. The hypothetical deprivation cutoff (zj) is 5/10 on the x-axis, while the hypothetical poverty cutoff (z) is 4/9 of the individual indicators on the y-axis.

Beyond concerns surrounding conceptual rigour and validity of approaches, indexing methods must be feasible and context appropriate. Morris (1979) suggests that indices should remain simple in their construction in order to aid interpretation. As Booysen (2002) points out, the methods employed in indexing ultimately depend on the scope of the index within the overall study. Studies which explore methodological issues of indexing, such as that of Alkire and Foster (2011), employ relatively complex and involved techniques. Studies like the current one, however, aimed at presenting a simple illustration or conceptual example of poverty or vulnerability, benefit from using simpler methods which are more accessible to the reader (Booysen, 2002).

5.8.7 Index Development and Structure

The composite index developed and used in this investigation (henceforth referred to as the Water Stress Vulnerability Index) integrates aspects of the Climate Vulnerability Index (CVI (Sullivan & Meigh, 2005)) and the Water Poverty Index (WPI (Sullivan *et al.*, 2003)). The CVI and WPI were both developed by participatory means and share a number of components and indicators, but they have differing objectives. The CVI aims to “identify those human populations most at risk from climate change impacts…” (Sullivan & Meigh, 2005, p.70). The WPI “was developed as a holistic tool to measure water stress at the household and community levels…” (Sullivan *et al.*, 2003, p.189). The Water Stress Vulnerability Index integrates both of these foci, therefore elements are taken from both indices. The CVI and WPI are considered to be of most use at the community level (Sullivan & Meigh, 2005; Sullivan *et al.*, 2003) and this is the level at which the Water Stress Vulnerability Index is applied.

Table 5.2 outlines the five components used to approximate water stress vulnerability as well as the individual indicators used to measure these. Each of the five components is used in both the CVI and the WPI. Each variable is noted with the index or indices that it was taken from.

Table 5.2: List of the components and indicators used in the Water Stress Vulnerability Index.

Component	Sub-components/variables
Resource (R)	• Assessment of surface water and groundwater availability (CVI & WPI)
Access (A)	• Access to clean water and sanitation (CVI & WPI) • Reports of conflict over water use (WPI) • Time spent in water collection, including waiting (WPI)
Capacity (C)	• Expenditure on consumer durables or income (CVI & WPI) • Water investment as a % of total fixed capital investment (WPI) • Educational level of the population (CVI) • Percentage of households receiving a pension, remittances or wages (WPI)
Use (U)	• Domestic water consumption rate related to national or other standards (CVI & WPI) • Agricultural water use expressed as a proportion of irrigated land to total land (CVI & WPI)
Environment (E)	• Reports of crop loss (WPI)

Variables used in the Water Stress Vulnerability Index were scaled using the Linear Scaling Transformation method described in Section 5.8.2. In light of the second paragraph of Section 5.8.3, and in the absence of the recommended community consultation regarding the importance of each indicator, no weightings were applied to the indicators in this index. The absence of weightings is common to Pandey *et al.* (2012) who applied the Water Poverty Index to medium sized river basins in Nepal. As applied in the CVI and WPI, the index value is calculated as an average of the component values (Sullivan & Meigh, 2005; Sullivan *et al.*, 2003). The conceptual equation for the Water Stress Vulnerability Index can therefore be written as:

(Equation 5.2) $$Social\,Vulnerability = \frac{R+A+C+U+E}{nc}$$

Where R, A, C, U and E are the average values of variables of the resource, access, capacity, use and environment components respectively and *nc* is the number of components in the index. This results in an index that ranges from 0 to 100 in which 100 represents the highest possible social vulnerability and 0 represents complete resilience to the hydrological effects of climate change. The components are also displayed in a disaggregated form as pentagram diagrams in order to make their individual influence visually clear.

Validation of the variables used in the index was performed by Sullivan and Meigh (2005) and Sullivan *et al.* (2003) using a simple item analysis as described in Section 5.5. The efficacy of these variables within the CVI and WPI has been shown at a number of locations around the globe and at a number of different resolutions (Pandey *et al.*, 2012; Sullivan & Meigh, 2005; Sullivan *et al.*, 2003). These indices have been seen to provide a credible reflection of reality as testified by participants and local experts (Sullivan *et al.*, 2003). While no such ground-truthing is feasible in this study, the performance of the CVI and WPI in practice indicates that the variables used to construct these indices are credible.

5.8.8 Composite Index Uncertainty

It is important to acknowledge that while composite indices are useful within a certain scope, they can be criticised in a number of ways. Uncertainty stems from imperfect or incomplete data collection, subjective weighting of variables, simplification of complex dimensions and site specificity (Booysen, 2002). In a broader sense, the selection of indicators remains arbitrary as our understanding of the dimensions of poverty and vulnerability, and particularly how these dimensions interrelate, is incomplete (Alkire & Foster, 2011). This often results in important indicators being omitted from the index (Booysen, 2002). Moreover, any practical combination of indicators into an index will exist as a gross simplification of reality.

In addition to being uncertain, composite indices are highly subjective because of selections necessary in their construction. Indicators and approaches must be selected from a large number of possibilities and, while this choice can focus these indices, it also renders them political constructs (Booysen, 2002).

Composite indices can be further criticised for producing a lack of critical insight. It is often pointed out that index values cannot be interpreted meaningfully in isolation insofar as they are ordinal rather than cardinal in nature (Booysen, 2002). Furthermore, it is argued that composite index values cannot be meaningfully compared across either time or space because of differences in the relative importance of variables over these dimensions (Veenhoven, 1996). Many indices avoid this problem of incomparability by applying the same methods and weightings over time and space (Estes, 1984, in Booysen, 2002). While this allows comparability of index values, it undermines the indexing method applied in each case as the index is insensitive to the relative salience of indicators in each case. Given these problems, composite indices are perhaps most useful in describing ordinal difference between communities which are not vastly different in terms of the relative importance of individual indicators determined by social, cultural, economic and environmental characteristics. The use of the same methodology for composite indexing in Panglin and Tallo Lorpa, therefore, while not ideal in a strict methodological sense, allows for useful comparison between the two communities.

Finally, indices are often criticised as being obsolete in that they are seen to add little to the understanding or measurement of the conditions they are concerned with. It is often pointed out that indices designed to measure poverty or deprivation reveal little more than a single indicator like *per capita* income does, and the systematic positive correlation between these two measures renders indexing unnecessary (Booysen, 2002). In response to these criticisms, Sullivan *et al.* (2003, p.192) point out that “the purpose [of composite indices] is political rather than statistical”. Index output exists in a limited capacity as a tool to introduce and orientate the reader to a general and simplistic conceptualisation of complex, multifaceted and multidimensional conditions (Booysen, 2002). It is in this capacity that index output is applied in this investigation and this is how it should be used by the reader.

5.9 Summary

The methods outlined in this chapter are applied under a framework built on definitions. This framework positions social vulnerability to water stress under climate change as the focus of field research efforts. With reference to its advantages and drawbacks, a mixed methodological approach was applied in this investigation. Social vulnerability was assessed quantitatively, using household surveys, and qualitatively, using focus group discussions, key informant interviews and participatory rural appraisal techniques. Uncertainties persist both in the data generated and in the degree to which these data can be seen to describe reality. Once these uncertainties were acknowledged, data analysis was described. This took the form of an assessment or raw output, assessments of survey data against sex, age and wealth status and the construction of the Water Stress Vulnerability Index for assessing social vulnerability to water stress under climate change. The methods employed in this chapter are justified with respect to current methodological theory, under the scope and limitations of this project. They are, however, both subject to and open to criticism. The results of this field enquiry are presented in the next chapter.

Chapter Six

Results

6.1 Overview

This chapter presents results from the field investigation of social vulnerability in Panglin and Tallo Lorpa. These results are introduced through the highly simplified lens of the water stress vulnerability index. The links between water and livelihoods are then explored with focus on livelihood activities and agricultural seasonality. With the importance of water established, its availability and use, as well as how these conditions have changed over time, are then discussed. Finally, the ability of households to manage water stress is described through an exploration of capacity, adaptation and coping strategies.

6.2 Water Stress Vulnerability Index

The Water Stress Vulnerability Index provides an introductory overview of social vulnerability to water stress in Panglin and Tallo Lorpa. Because of the limitations and simplifications of this composite index approach, explained in Section 5.8.8, the index is intended to orientate the reader with the results rather than provide detailed insight into their components. Further, the index draws on experience of current water stress and therefore does not account for either how water stress as a hazard may evolve under climate change, or how social vulnerability to water stress may change over time. The first question is addressed in Chapter Three and discussed in Chapter Seven. The second question is discussed in Chapter Seven drawing on insights from Chapter Four and the latter parts of the current chapter.

With these caveats in mind, the Water Stress Vulnerability Index suggests that Panglin and Tallo Lorpa experience remarkably similar levels of overall water stress vulnerability but for remarkably different reasons. Overall index values, as well as the component values from which the index is comprised, are shown in Table 6.1. Higher index or component values indicate greater resilience to water stress and lower values indicate water stress vulnerability. Panglin recorded an overall index value of 59.05 which suggests that it is slightly more vulnerable to current water stress than the community of Tallo Lorpa which recorded an index value of 65.9.

Table 6.1: Water stress vulnerability component and overall index scores for the communities of Panglin and Tallo Lorpa.

Component	Panglin	Tallo Lorpa
Resource	9	74
Access	95	89.5
Capacity	52.25	63
Use	86	37
Environment	53	66
Water Stress Resilience	**59.05**	**65.9**

Differences in the component scores which comprise the overall index scores recorded for each community are shown graphically in Figure 6.1. Based on available stream discharge *per capita*, the community of Panglin has a considerably smaller water resource available to it than the community of Tallo Lorpa. The low ‘Resource’ component score in Panglin substantially increases water stress vulnerability in this community relative to the community of Tallo Lorpa.

Panglin is also slightly more vulnerable than Tallo Lorpa in terms of ‘Capacity’ and ‘Environment’. Community ‘Capacity’ was assessed with respect to income and educational levels combined with the stability of income sources and expenditure on water as a proportion of total expenditure. While households in Panglin had much higher incomes on average than households in Tallo Lorpa, a much larger proportion of this income was spent on maintaining water access infrastructure. In addition, households in Panglin were generally less well educated and earned slightly less income from stable or environmentally insulated sources such as pensions or remittances. ‘Environment’ was assessed by reports of crop loss by local farmers. Reports of crop loss in Panglin were both more common and of greater magnitude than those in Tallo Lorpa. In summary, while the average household in Panglin is wealthier than those in Tallo Lorpa, their income depends heavily on agricultural production in which crop loss is relatively common, and irrigation is relatively costly.

In compensation for vulnerabilities of ‘Resource’, ‘Capacity’ and ‘Environment’, Panglin scored well in components of ‘Use’ and ‘Access’. Water ‘Use’ was assessed with respect to consumption of water for domestic use, and irrigated agricultural land as a proportion of total agricultural land. Panglin scored substantially higher than Tallo Lorpa in both of these criteria, resulting in an overall ‘Use’ score of 86 compared to 37 for Tallo Lorpa.

Both Panglin and Tallo Lorpa scored highly in the 'Access' component of the composite index. This is largely attributable to the public taps which have been constructed in each community and the scarcity of conflict over water resources in each community. In this case, the slightly lower 'Access' score in Tallo Lorpa reflects a slightly higher incidence of conflict over water resources. It can be seen that effective utilisation of the modest water resources available in Panglin largely compensates for other water stress vulnerabilities in the community to the extent that, at present, incidence of conflict over water resources in Panglin is less than that found in Tallo Lorpa.

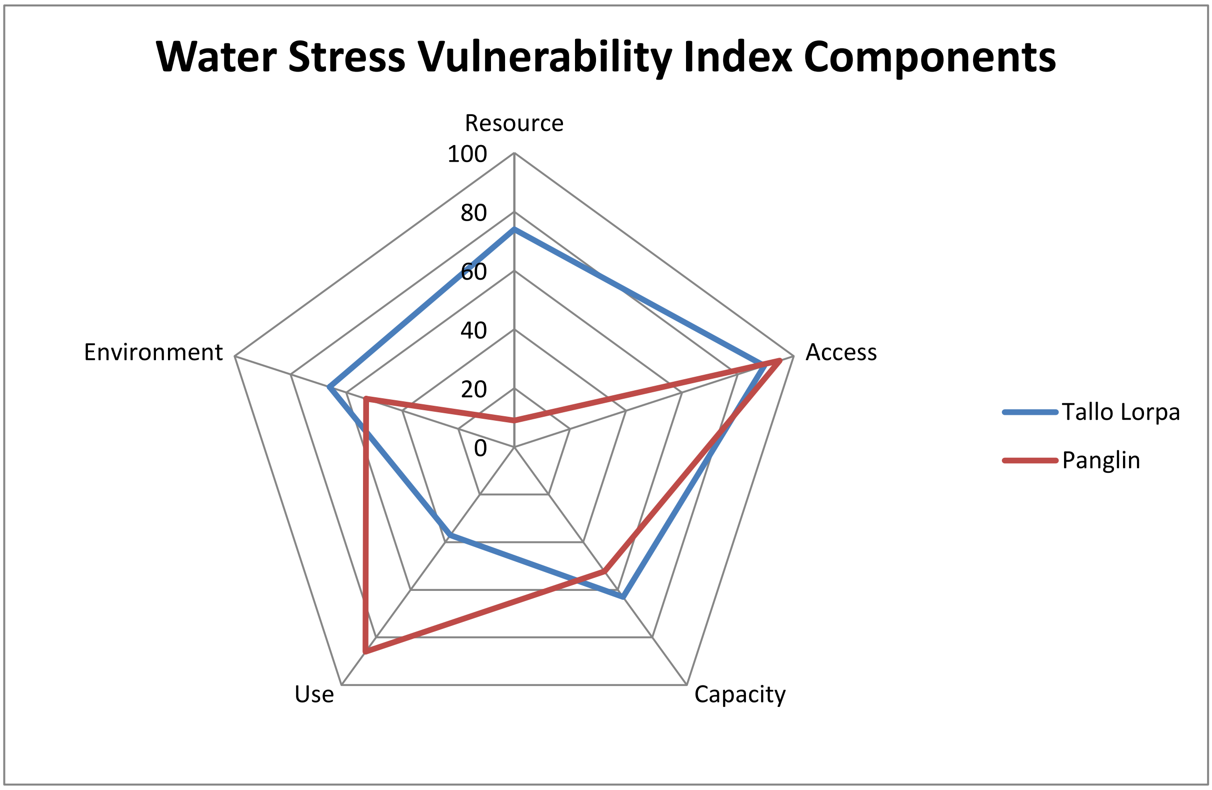


Figure 6.1: Pentagon diagram of Water Stress Vulnerability Index component scores for the communities of Panglin and Tallo Lorpa.

Differences in the component makeup of water stress vulnerabilities between Panglin and Tallo Lorpa are not strictly relevant to overall water stress vulnerability; however in the context of climate change these differences become important. As highlighted in Section 4.3, while social vulnerability is an inherent characteristic of a system and therefore independent of hazard, it remains hazard specific (Brooks, 2003). For example, because of differences in the components of their water stress vulnerabilities, the communities of Panglin and Tallo Lorpa will experience different outcomes depending on whether water stress is driven by a reduction in rainfall or an increase in market prices for piping. As a result, while the Water Stress Vulnerability Index can introduce each community's inherent social vulnerability to water stress at the current time, it is unable to suggest how this may be experienced under climate change. For this to be achieved, understanding of climate change as a hazard, and deeper analysis of how communities respond to this hazard, are essential.

6.3 Environment and Vulnerability

From the coarse understanding given by the water stress vulnerability index, this section describes how water ties in with livelihoods in Panglin and Tallo Lorpa. This is done by first exploring the livelihood activities pursued in order to assess the importance of primary production in each community. The nature of primary production in each community is then examined with reference to seasonality, productivity and the direction in which these have been seen to change. Finally, the link between water and livelihoods is explored directly through respondents' experiences of problems under water stress.

6.3.1 Livelihoods

This section takes a narrower definition of livelihoods than that used in the rest of the thesis. Section 5.2 defines sustainable livelihoods with respect to capabilities and with requirements of sustainability and equity. For the purposes of this section, I will use a definition put forward by the British Department for International Development (DFID, 1999, p.1) which states that "A livelihood comprises the capabilities, assets… and activities required for a means of living". Capabilities and assets are examined in Section 6.6. The current section focuses specifically on the *activities* pursued as a means of living. These activities are essential in understanding social vulnerability and were found to differ considerably both between and within the communities of Panglin and Tallo Lorpa.

Table 6.2 shows the main sources of income in the two study communities. Panglin and Tallo Lorpa are agricultural societies. The most common source of income in both communities was crop and vegetable sales. In Panglin, 79.4% of households sold crops or vegetables. Of these households, the mean reported revenue was NRs. 97,444. In total, crop and vegetable sales moved a total of NRs. 2,631,000 through the village economy, contributing 51.6% of gross community income. In Tallo Lorpa, 95.1% of households sold crops or vegetables, collecting an average income of NRs. 20,647 and moving a total of NRs. 1,197,500 through the village economy which amounts to 35.4% of gross community income.

Participation in, and income generated from, the sale of livestock and livestock products was modest in both communities. Households are often reluctant to sell their livestock. Less than a quarter of households sold livestock or livestock products in Panglin, making a mean reported income of NRs. 40,000 from this activity. In Tallo Lorpa slightly less than half the households sold livestock or livestock products, making a mean reported income of NRs. 20,569. Households in the upper wealth quartiles of both communities earned considerably more from livestock than households in the lower wealth quartiles.

Livelihood activities beyond agriculture were important sources of income in both communities. Non-agricultural livelihood activities were both more commonly pursued and more diverse in Tallo Lorpa than they were in Panglin. In Tallo Lorpa, income was sourced from business, trade, pensions and development aid projects while this was not the case in Panglin. In addition, greater proportions of households generated income through herb sales, paid employment and government schemes in Tallo Lorpa than in Panglin. Herb sales, largely referring to the collection and sale of yarsagumba (*Ophinocordyceps sinensis*), and paid employment were particularly important sources of income in Tallo Lorpa generating almost as much income as agricultural activities between them. Income from remittances was by far the most fruitful source of income in both communities. Only three households received remittances in Panglin and only two in Tallo Lorpa; however they were still an important source of income to the economies because of the large sums of money involved.

Table 6.2: Livelihood activities and sources of income in Panglin and Tallo Lorpa.

Income Source	**Panglin**			**Tallo Lorpa**		
	Number of Beneficiaries	Average Income (NRs.)	Total Income (NRs.)	Number of Beneficiaries	Average Income (NRs.)	Total Income (NRs.)
Crop/vegetable Sales	27	97,444	2,631,000	58	20,647	1,197,500
Livestock Products	8	40,000	320,000	29	20,569	596,500
Herb Sales	3	41,667	125,000	35	26,200	917,000
Paid Employment	6	40,000	240,000	13	44,077	573,000
Tourism	5	45,000	225,000	6	16,333	98,000
Rent/Interest	3	63,333	190,000	1	1,200	1,200
Remittances	3	358,333	1,075,000	2	220,000	440,000
Forest Products	-	-	-	2	12,000	24,000
Business/Trade	-	-	-	2	13,500	27,000
Pension	-	-	-	1	6,000	6,000
Development Aid Projects	-	-	-	19	41,895	796,000
Government Schemes	6	6,583	39,500	26	17,208	447,400

Agriculture is a particularly important livelihood activity in the two study communities because it provides both income and food. Table 6.3 shows where the food consumed by households in Panglin and Tallo Lorpa came from. In both communities, slightly less than half of the food consumed was self-produced. In Panglin, much of the remainder was bought from the market while in Tallo Lorpa, just over half of the remainder was bought from the market.

Table 6.3: Sources of food for household consumption in Panglin and Tallo Lorpa.

Food Source	Percentage of Total Consumption Panglin	Percentage of Total Consumption Tallo Lorpa
Self-Produced	45.47%	48.44%
Bought from Market	44.38%	27.97%
Food Aid from Friends/Relatives	5.47%	4.93%
Subsidised Food from the PDS	0.16%	9.77%
Share Cropping	-	1.84%
Other	4.53%	12.23%

6.3.2 Agriculture

The previous section showed that agriculture is the most important livelihood activity in Panglin and Tallo Lorpa with respect to both income and food provision. As explained in Section 4.2.2, agriculture is also fundamentally dependent on water and therefore potentially vulnerable to changes in water resources under climate change. This section describes the modalities, dependencies and seasonality of agriculture in order to understand how it contributes to social vulnerabilities in Panglin and Tallo Lorpa.

As shown in Table 6.4, Panglin and Tallo Lorpa differed in terms of the type of staple crops cultivated, the amount of staple crops produced and the direction in which productivity of these crops has been seen to change. Wheat, buckwheat and potato were the three most important staple crops in Panglin while in Tallo Lorpa, these were maize, millet and potato. Farmers in Panglin produced almost the same total mass of cereals as those in Tallo Lorpa on around half the area of cultivated land, with around half the number of people and for a population around half the size. This difference in productivity is explained by differences in land quality to be described in Section 6.6.2, and the fact that 99.5% of Panglin's agricultural land is irrigated compared to only 31.65% in Tallo Lorpa.

The productivity of staple crops, especially potato, is seen to have increased in Tallo Lorpa, while in Panglin productivity is seen to have decreased or remained stationary. Respondents in Tallo

Lorpa linked increases in productivity to improvements in farming practice while the decreases perceived in Panglin were attributed to changes in water availability and substitution for other crops (presumably cash crops, given improved access to market). Decreases linked to changes in water availability are part of the reason why Panglin has a lower 'Environment' component score in the water stress vulnerability index than Tallo Lorpa.

Table 6.4: Involvement in, production of and perceived changes in productivity of the three main staple crops grown in Panglin and Tallo Lorpa.

Panglin					
Staple Crop	**Number of Growers**	**Total Production**	**Number Increasing**	**Number Decreasing**	**Number Stationary**
Wheat	25	24,290	5	11	9
Potato	24	34,340	4	9	11
Buckwheat	25	10,070	5	12	8
Tallo Lorpa					
Staple Crop	**Number of Growers**	**Total Production**	**Number Increasing**	**Number Decreasing**	**Number Stationary**
Maize	60	21,750	29	26	5
Potato	49	31,620	37	11	1
Millet	60	12,750	27	25	8

Table 6.5 shows aspects of cash crop production in Panglin and Tallo Lorpa. In terms of the number of growers, garlic was an important cash crop in both communities. Beans, chillies and apples were also important in Panglin, while summer vegetables were also important in Tallo Lorpa. Again productivity was considerably greater in Panglin, where 23 household produced 1,771 Kg of garlic, than it was in Tallo Lorpa where 44 households produced only 861Kg of garlic over the last 12 months.

Productivity of the three most widely grown cash crops in Panglin and Tallo Lorpa are generally reported to have increased in both communities over the last 10 years. In Panglin, respondents cite improved practice as the major reason for increasing cash crop yields. In Tallo Lorpa the main reason put forward for increases in crop yields was 'cash crop'. This is interpreted as increases in attention and effort put into growing these crops because of the increasing ability to sell produce at market.

Table 6.5: Involvement in, production of and perceived changes in productivity of the three main cash crops grown in Panglin and Tallo Lorpa.

Panglin					
Cash Crop	**Number of Growers**	**Total Production**	**Number Increasing**	**Number Decreasing**	**Number Stationary**
Garlic	23	1,771	14	2	7
Beans	20	3,525	9	1	10
Apple	15	36,500	8	1	6
Tallo Lorpa					
Cash Crop	**Number of Growers**	**Total Production**	**Number Increasing**	**Number Decreasing**	**Number Stationary**
Chillies	49	1,285Kg	36	9	4
Garlic	44	861Kg	29	10	5
Summer Vegetables	38	2,759Kg	36	1	1

Livestock, while less important than crops, also provided both income and food for consumption in both Panglin and Tallo Lorpa. Cattle were the most commonly owned livestock in both communities. Goats were the most numerous livestock in both communities with 291 owned by survey respondents' households in Tallo Lorpa and 1,061 owned by survey respondents' households in Panglin. A small number of buffalo are found in Tallo Lorpa while none are found in Panglin. Seven households in Panglin did not own livestock of any kind, while in Tallo Lorpa, only three households were without livestock. In both communities, the households without livestock tended to be poorer than average.

Table 6.6: Livestock ownership in Panglin and Tallo Lorpa.

	Panglin			**Tallo Lorpa**		
Animal	**Number of Owners**	**Average # per Owner**	**Total Number**	**Number of Owners**	**Average # per Owner**	**Total Number**
Cattle	25	5.08	127	58	4.14	240
Buffalo	-	-	-	10	1.8	18
Goat	11	96.45	1,061	26	11.9	291
H/D/M	7	2.57	18	4	2.75	11
Poultry	18	6.17	111	9	3.67	33
Sheep	6	4.43	31	8	12.25	98

As shown in Table 6.7, livestock ownership was strongly correlated with household wealth in both communities. It appears, however, that this correlation is somewhat stronger in Panglin than in Tallo Lorpa. In Panglin, for example, all eight of the households in the upper wealth quartile owned livestock while only half of the households in the lower wealth quartile owned livestock of any kind. Of the 15 households in Tallo Lorpa's lowest wealth quartile, only two households did not own livestock of any kind. Disparity between households in different wealth quartiles with respect to the number of goats, chickens and sheep owned is also greater in Panglin than it is in Tallo Lorpa.

Table 6.7: Livestock ownership of upper and lower quartile households in Panglin and Tallo Lorpa.

	Panglin Upper Quartile	**Panglin Lower Quartile**	**Tallo Lorpa Upper Quartile**	**Tallo Lorpa Lower Quartile**
Goat	395	31	93	27
Poultry	22	14	1	2
Sheep	14	0	7	0

Agricultural seasonality was assessed using seasonal calendars and livelihood seasonal monitoring calendars in both communities. These two calendars were then aggregated to give insight into how the seasonal patterns of water availability and water use influence the seasonal patterns of agriculture in each community.

A seasonal calendar and a livelihood seasonal monitoring calendar for Panglin are shown in Table 6.8. Taken together, these calendars suggest that agricultural patterns are not particularly vulnerable to changes observed in the seasonal availability and use of water. According to respondents, dry periods have reduced substantially during the pre-monsoon and are now confined to the post-monsoon months. Irrigation is reported to occur throughout much of the year with only short periods in the post-monsoon and winter during which it is not done. The months in which there is little irrigation roughly align with the dry periods reported. It appears that irrigation has increased slightly during some months in the last ten years. Perhaps because of the harmony between water availability and water use on a seasonal basis, water shortage was never reported as an issue on the seasonal calendar.

Three staple crops, shaded in light orange and one cash crop, shaded in light green are listed in the livelihood seasonal monitoring calendar. Buckwheat, potato and beans appear to be in reasonable harmony with the seasonal availability and use of water resources in Panglin, being planted at the start of the monsoon, irrigated during the monsoon then harvested in the post monsoon. Barley, however, appears more vulnerable to water supply problems, relying on irrigation during November and December, a known and persistent dry period.

Milk production and goat migration appear to be little affected by the availability and use of water in Panglin; rather it seems that they are both dependent on temperature. Milk production is highest during the warm months of the pre-monsoon, monsoon and post monsoon while dropping off in the winter. The calendar also shows that grazing of goats follows a temperature driven transhumance pattern, with animals allowed to graze at higher altitudes during the monsoon months.

Table6.8: Seasonal calendar and livelihood seasonal monitoring calendar as discussed by the local women's group in Panglin. Responses range between 0 and xxx, with xxx representing the maximum prevalence. Results for cash and staple crops are taken from ICIMOD (2012).

	Apr - May	**May - Jun**	**June - Jul**	**Jul - Aug**	**Aug - Sep**	**Sep - Oct**	**Oct - Nov**	**Nov - Dec**	**Dec - Jan**	**Jan - Feb**	**Feb - Mar**	**Mar - Apr**
Dry Period 2002	xxx	xxx			xx	xx	xxx	xxx				xx
Dry Period 2012					xx	xx	xxx	xxx				
Water Shortage 2002												
Water Shortage 2012												
Food Shortage 2002											xx	xx
Food Shortage 2012												
Irrigation 2002	xxx	xxx		xxx	xxx			xxx			x	xx
Irrigation 2012	xxx	xxx	xx	xxx	xxx			xxx		x	xx	xx
Buckwheat			Planting	Soil Working			Harvesting					
Potato			Planting				Harvesting					
Barley			Harvest				Planting				Soil Working	
Beans			Planting			Harvesting						
Cow's Milk 2012	xx	xxx	xxx	xxx	xxx	xxx	xxx	xx	x	x	x	x
Goat Migration 2012	Graze in public land near community area			Graze at higher altitudes			Graze in public land near community area					

A seasonal calendar and livelihood seasonal monitoring calendar for Tallo Lorpa are shown in Table 6.9. These calendars suggest that the seasonality of agriculture may be vulnerable to the seasonality of water availability and use in Tallo Lorpa. Respondents suggest that the dry period experienced during the late pre-monsoon months of April, May and June has extended slightly to include March and July over the past ten years. This dry period coincides with greatly increased use of irrigation between the months of January and June. Even with heavy usage during dry periods, respondents reported a decline in water shortage during this period. Water shortage was instead increasingly felt during the months of August to November, when no irrigation is reported. This indicates that water shortage is not caused by low availability, but rather by low use of available water resources in Tallo Lorpa.

According to respondents, food shortage is less of a problem than it was ten years ago. The seasonal profile shows that food shortage is more closely correlated with crop seasonality than with the use or availability of water. A short hungry season persists during the pre-monsoon between April and June after the majority of planting has occurred but before crops are ready for harvest.

It can be seen as concerning that the largest emerging period of water shortage occurs in the lead up to the harvest of the community’s three main staple crops, maize, millet and potato. This period of water shortage may also negatively affect the harvest of onions and summer vegetables which occurs at a similar time. Garlic is harvested slightly earlier than the aforementioned crops and directly after a period of intensive irrigation during which water shortage is not mentioned and therefore this crop does not seem at great risk of water shortage.

As is the case in Panglin, milk production and goat migration seem to be seasonally dependent on temperature in Tallo Lorpa. Milk is available between June and November in Tallo Lorpa and goats are allowed to graze the rangeland between June and October.

Table 6.9: Seasonal calendar and livelihood seasonal monitoring calendar for Tallo Lorpa as discussed by the local forestry group. Responses range between 0 and xxx, with xxx representing the maximum prevalence.

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Dry Period 2002	xx	xxx										xx
Dry Period 2012	xxx	xx	x					x			x	xx
Water Shortage 2002	xx	xx			xx	xx	xx				xx	xx
Water Shortage 2012				xx	xx	x	x					
Food Shortage 2002	xxx	xxx				x	xx					xxx
Food Shortage 2012	xx	x										xx
Irrigation 2002	x	x							x	x	xx	x
Irrigation 2012	xxx	xxx							xxx	xxx	xxx	xxx
Millet	Weeding		Transplant		Harvesting		Threshing					Planting
Maize	Weeding					Harvesting		Threshing				Planting
Potato	Weeding					Harvesting			Threshing			Planting
Garlic		Harvesting						Planting				
Onion	Transplant					Harvesting						Transplant
Monsoon Vegetables		Transplant		Harvesting							Planting	
Cow's Milk		Milk Available										
Goat Migration	Stall Feeding	Rangeland Area					Near Rangeland		Around Village			

6.3.3 Livelihood Vulnerabilities to Water Stress

Livelihoods in both communities are highly sensitive to water shortage and evidence of vulnerability to past experiences of water stress was present in both household survey and qualitative data. Agriculture again presents itself as the most vulnerable sector to water shortage and a number of respondents explicitly link water to livelihoods. In Panglin, for example, the elderly key informant pointed out the importance of water to the agricultural sector, saying that "If there is no water, there will be many big problems, water is indispensable for agriculture, what to eat?" The importance of water for agriculture is echoed by the elderly key informant in Tallo Lorpa who explained "Everything is water for us; we cannot live without water… We are farmers; we need irrigation for our land".

When asked what problems members of the community faced during times of water shortage, a member of the men's focus group in Panglin pointed out that "the main problem will be for irrigation. We can anyway manage for drinking purposes but it will be a main problem for irrigation". A member of the women's group in Tallo Lorpa recalled a period in the past where water shortage was an issue and explained that "Our cultivation was destroyed by water shortage… we remember that we had lack of food and our parents had lots of tension feeding us anyways. They brought food from far districts to feed us and make us live". These examples show the importance of water to people's livelihoods in Panglin and Tallo Lorpa.

6.4 Resource and Resource Change

With the importance of seasonally reliable water availability clear, we now examine experiences of water shortage on a seasonal basis and perceived changes in seasonal water availability. Community perception of the nature and origins of these changes and how water availability is expected to change in the future are also explored. While water shortage on an annual and general basis is not hugely apparent in either community, broken down by season and water use sectors, periods of water shortage are clear. There is some suggestion that the seasonality of water availability has changed over the last 10-20 years and strong evidence to suggest increased variability in both communities. Many respondents attribute environmental changes to their gods. Many respondents are also unsure how water availability is likely to change in their areas in the future, and those who do purport to know often contradict one-another.

6.4.1 Current Experience of Water Stress

Local perceptions of water shortage provide useful insight into current water stress. Water shortage is felt if availability does not meet household demands, livestock demands or crop water demands. These shortages often occur in parallel and can be independent of the absolute size of the local water resource if this is unable to be exploited for the purpose for which it is needed.

When assessed from a general perspective on an annual basis, water shortage appears of little concern to respondents in either community. In Panglin, all but one of the respondents believed that they had enough water free of charge throughout the year. A total of 30 of the 34 respondents believed that *everyone* could have access to enough water if it were managed effectively. In Tallo Lorpa, all of the 61 respondents believe they have enough water free of charge throughout the year. Again, slightly fewer (49 out of these 61 respondents) believed that everyone could have access to enough water if it were managed effectively.

When broken down in terms of water use sectors and over months of the year, however, pressure points of water shortage become apparent. On average, households in Panglin face one month per year during which there is not enough water for household needs, while households in Tallo Lorpa face 2.52 months. The timing of water shortage differs between the two communities. As shown in Figure 6.2, water shortage in Panglin is mainly felt over the winter months of January and February, while in Tallo Lorpa the pre-monsoon months of March, April and May are the worst for water shortage.

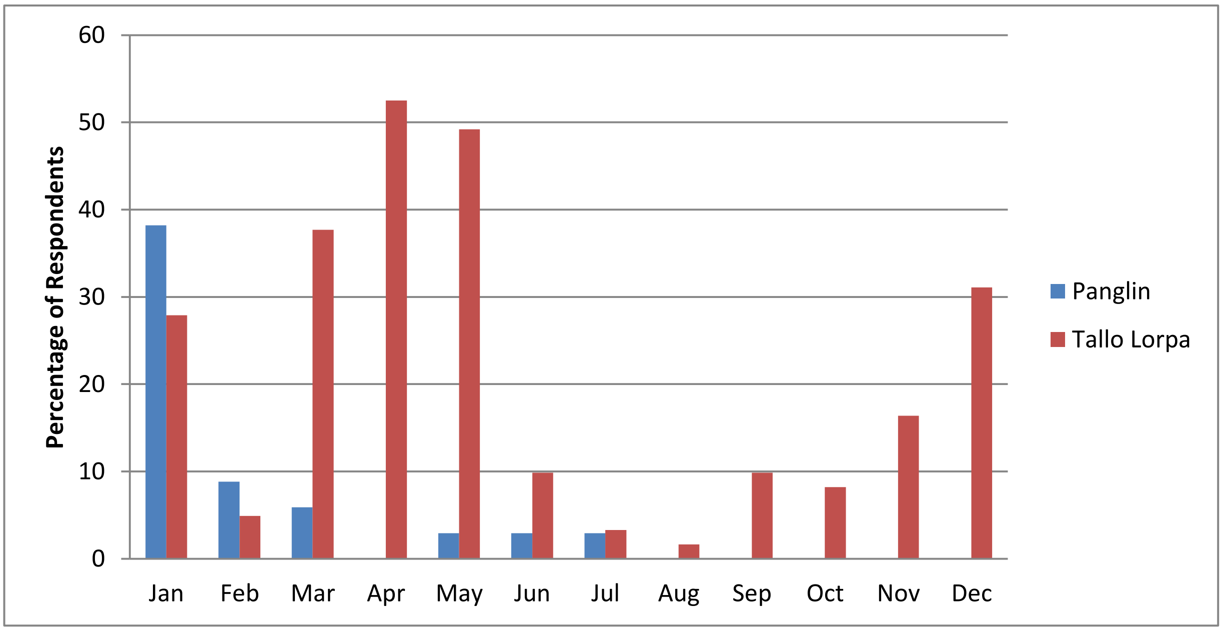


Figure 6.2: Water shortage seasonality shown by the percentage of respondents who reported insufficient household water for each month of the year in Panglin and Tallo Lorpa.

The experience of livestock water shortage varied with wealth in both communities. In Panglin, households in the upper wealth quartile faced an average of 0.75 months in which there was not enough water for their livestock while livestock water shortage was never felt by households in the lower wealth quartile. Similarly, in Tallo Lorpa, households in the upper wealth quartile faced an average of 2.9 months in which there was insufficient water for their livestock while households in the lower wealth quartile faced an average of only 2.1 months in which this was the case. Furthermore, households in the upper wealth quartile of both communities more often reported adverse effects on livestock due to water shortage. These differences may stem from differences in the number and type of livestock owned by wealthier households compared to poorer households. It seems likely that wealthier households are more at risk of livestock water shortages because they own more livestock and therefore require more water.

Both Panglin and Tallo Lorpa had 10 households which experienced insufficient water for their household crops for two months of the year. As shown in Figure 6.3, cropping water shortages were most commonly seen during June and July in both communities. This may indicate the importance of crop type and agricultural seasonality on water stress. The relative frequency of crop water shortage was almost twice as high in Panglin as in Tallo Lorpa.

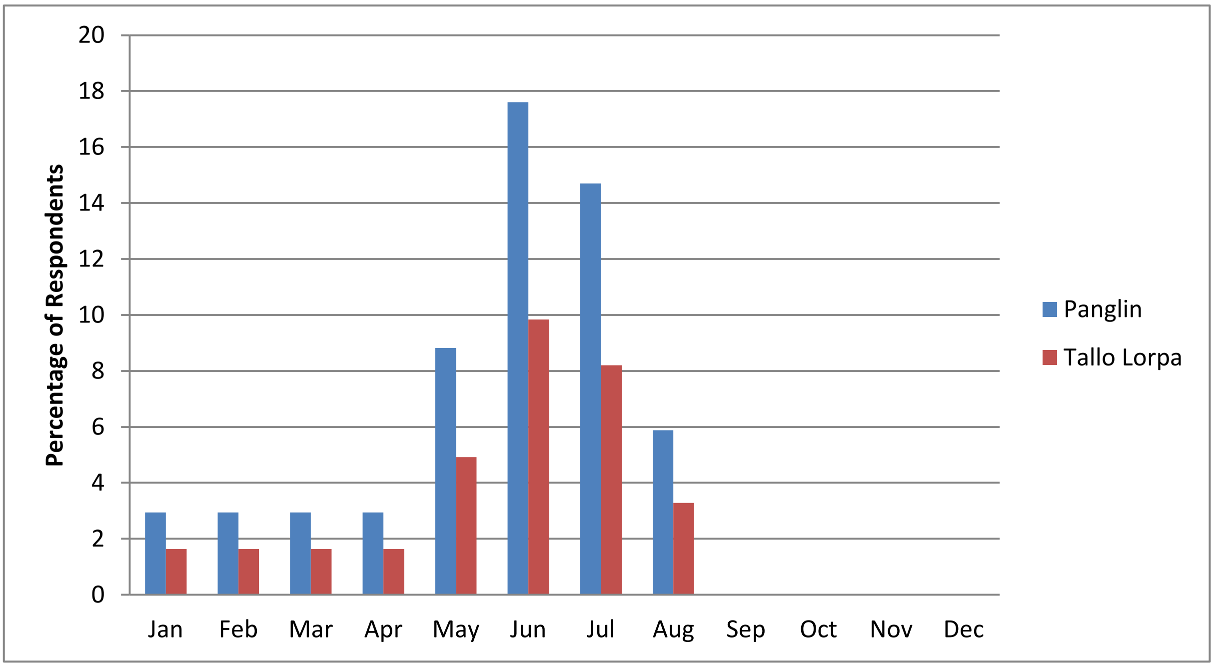


Figure 6.3: Crop water shortage shown by the percentage of respondents who perceived crop water shortage in any given month in Panglin and Tallo Lorpa.

It is interesting to note gender bias in responses as a possible source of error. It is generally found that men's responses to survey questions are more alarmist than those of women (Dixit *et al.*, 2009). Results from this investigation show men perceiving longer periods of both livestock and cropping water shortage while women perceived longer periods of water shortage for household use (Table 6.10). It is possible that respondents report greater water shortage in sectors which they are more engaged with or feel more responsibility for because of a gendered division of household labour.

Table 6.10: Differences in perceived sectorial water shortages between Men and Women.

	Average # of Months Perceived by Men	**Average # of Months Perceived by Women**
Cropping Water Shortage	1	0.26
Livestock Water Shortage	0.56	0.5
Household Water Shortage	0.88	1.18

It is clear from the survey responses that while current water shortage is not a huge concern on annual and general bases, households in both Panglin and Tallo Lorpa experience seasonal and sector specific periods of water shortage. The identification of water shortage during some seasons and in some sectors leads us to the question of how this has changed over time.

6.4.2 Changes in Seasonal Water Availability

Changes in water availability were perceived in a number of different sectors and related to a number of different hydrological processes. Appendix Three provides a detailed account of perceived changes in catchment hydrology in Panglin and Tallo Lorpa and how these changes have affected sectorial water availability. Perceived changes in precipitation, as the most fundamental parameter of water availability, are outlined in the current section.

Changes in seasonal precipitation were perceived by respondents in both communities, while being more common in Tallo Lorpa than in Panglin. In Tallo Lorpa, every single respondent believed that precipitation patterns have changed over the last 10-20 years, while only half of the respondents in Panglin have observed precipitation change in their community. Precipitation changes that respondents in each community have observed are shown in Table 6.11.

There was considerable confusion about the nature and direction of precipitation changes in Panglin. Similar numbers of respondents perceived an annual increase and annual decrease in precipitation. Of the 34 respondents, seven (20.6%) believed that the arrival of the monsoon had advanced. Qualitative evidence consistently suggests that rainfall has become more erratic in the area. One member of the local Women's Group told that "The snowfall and rainfall are untimely. They don't occur when it is needed…" A member of the men's focus group highlighted changes in the timing of precipitation, stating that "In the past, if we expected rain in a particular month the rainfall would occur but now it is not such. Dryness occurs for continuous three to four months and when rainfall starts it is continuous for two to three months. The timing has changed largely*"*. It appears that specific changes are difficult to isolate in Panglin, however change is noticeable in terms of timing and variability.

Increased precipitation variability and changes in seasonality were also perceived in Tallo Lorpa. Of the 61 respondents, 13 (21.3%) believed that the arrival of the monsoon had advanced while 40 (65.6%) saw a decrease in annual precipitation. Perceived decreases in precipitation were echoed by the elderly key informant who states "…rainfall comes unwantedly… Before, rainfall started from March to June. Now God hates us, no rainfall nowadays". Further evidence of precipitation change was given by a member of the forestry group who noted that "Rainfall occurs when we don't need water, but it does not fall when we need and it has destroyed our crops*"*.

Table 6.11: Perceived changes in precipitation over the last 10-20 years and frequency of response.

Precipitation Change	# of Households Observed Panglin	# of Households Observed Tallo Lorpa
Annual Increase	8 (23.5%)	15 (24.6%)
Annual Decrease	7 (20.6%)	40 (65.6%)
Timing advanced	7 (20.6%)	13 (21.3%)
More erratic rainfall	0	12 (19.7%)

It is important to understand how environmental changes are conceptualized by local people. Religious beliefs play a large role in the understanding of environmental phenomena in both Panglin and Tallo Lorpa. A number of respondents suggest that their religious deities have become angered by the actions of the community and that environmental change and disasters are the retribution for their indiscretion. For example, the elderly key informant from Tallo Lorpa explained changes in rainfall he had seen by saying "Now God hates us. No rainfall nowadays*"*. In Panglin, a member of the men's focus group said that:

> "The water level has decreased now maybe because God has become angry with us… forest has been cut down, tractor has been used to build road and explosions are made for road with big sounds. We have been doing bad activities: people collect insects (Yarsagumba) and in the downstream a gold mine is proposed to be built. When the mine

> is dug, it will bring wind with dust. The wind of this year is the worst till now. It comes from the mine. Many people have realised that the mine is responsible [for] all these*”*.

These beliefs about the origins and nature of environmental change are central to understanding how households and communities respond to change, as explained further in Section 6.7.

6.4.3 Respondent Expectations of Change

In addition to observed changes in water availability in the past, respondents were asked how they expected water availability to change in the future under climate change. Only around a quarter of respondents in each community were aware of the concept of climate variability and change (15 of the 61 (24.6%) in Tallo Lorpa and 9 out of the 34 (26.5%) in Panglin). Awareness was somewhat positively correlated with wealth in both communities. In Tallo Lorpa, a higher proportion of the youngest quartile was aware while in Panglin, this was not the case.

Of the small number in Panglin who were aware of climate variability and change, the largest number (still only 3) believed that water availability will decrease in the future. In Tallo Lorpa there appeared to be great confusion about the implications of climate change as 8 respondents believe that water availability will increase, while 6 respondents believed that it will decrease. Moreover, 7 respondents believe that winter water availability will increase while 8 believe it will decrease.

With respect to the importance respondents placed on these expected changes, only 12 of the 34 respondents (35.3%) in Panglin thought that changes in water availability were a greater concern than all other changes in their community. This view was disproportionately held by members of the wealthiest quartile. In Tallo Lorpa, 37 of the 61 respondents (60.7%) see changes in water availability as a greater concern than all other changes they see in their community. This view was disproportionately held by members of the oldest quartile. It is clear that large proportions of both communities do not see changes in water availability as their largest concern.

While change in water availability is an important livelihood forcing, its influence on livelihoods is often indirect. ‘Resource’ is only one component of water stress vulnerability. The influence of changes in the former on the state of the latter is crucially determined by how this resource is used.

6.5 Use of Available Resource

Panglin scored considerably higher than Tallo Lorpa in the ‘Use’ component of the water stress vulnerability index. Finer analysis of this component shows that water usage is both more organised and more prolific in Panglin than it is in Tallo Lorpa. In addition, water usage for irrigation and domestic purposes has generally been seen to have increased over the past 10-20 years in Panglin, while observed irrigation increases are less consistent and of smaller magnitude in Tallo Lorpa.

6.5.1 Water Access

Water resources are governed differently between Panglin and Tallo Lorpa, leading to different constraints on access during times of shortage. In Panglin, irrigation water is stored overnight in two reservoir ponds above the community, shown in Figure 6.5. The water is then released during daytime to through the canal system and is distributed on a rotational basis with every landowner having access for one full day of irrigation water every rotation. As the elderly key informant in Panglin points out: “I cannot say there is no problem of water… there are 25-30 houses in this village… every house gets turn for one day and his next turn comes after 30 days and if between that period there is no water there will be scarcity, there will be less harvest”. This suggests a range of issues related to community based irrigation.

Figure 6.4: Larger of the two storage reservoirs above Panglin village at 9:00am on the 9th of May 2012.

In Tallo Lorpa by contrast, governance of water is informal and community members are not bound by official conventions or constraints. This reflects the greater abundance of water, but can lead to problems of water access during times of shortage. These problems sometimes manifest as conflicts between members of the community over access to water as shown in Table 6.12. Conflict over water resources is considerably more common in Tallo Lorpa than it is in Panglin and, in the absence of formal water control, it appears to play a part in determining water access.

Table 6.12: Reports of conflict over water resources in Panglin and Tallo Lorpa.

Frequency of conflicts over water within community	# of Households Panglin	# of Households Tallo Lorpa
Never	22	17
Rarely	3	5
Sometimes	9	36
Often	0	2

The existence of these conflicts suggests that access to water is limited at times. As is the case in Panglin, therefore, water use does not directly reflect the water ‘Resource’. The use of water in each community is socially determined.

6.5.2 Water Use

Panglin scored considerably higher than Tallo Lorpa in the ‘Use’ category of the water stress vulnerability index because of a much greater capacity to exploit available water resources. The major divergence in water use between communities came from irrigation. On an intra-community level, differences in water use between different wealth quartiles were dramatic, indicating different water stress contributions and vulnerabilities.

In Panglin, the average reported domestic use of water (108L) was substantially larger than that used for household livestock (44.8L). Unsurprisingly, average water use for household livestock was much greater in the upper wealth quartile (58.1L) than in the lower wealth quartile (37.5L). Water use for household purposes did not vary greatly between wealth quartiles.

In Tallo Lorpa, remarkably similar average amounts of water were used per day for domestic purposes and household livestock (70.2L and 70.6L respectively). While proportional use of water in these two sectors differs substantially between Panglin and Tallo Lorpa, taken together the average use of water for household purposes and livestock needs is reasonably similar (145.5L and 140.8L for Panglin and Tallo Lorpa respectively).

The major divergence in water use between Panglin and Tallo Lorpa came from differences in irrigation. In Panglin, 99.5% of agricultural land is irrigated compared to only 31.7% in Tallo Lorpa. Irrigation occurs year round in Panglin. The mean of respondent estimates of seasonal irrigation use suggests that an average of 11,745L is used per household during the monsoon, 11,927L during the post monsoon, 2,095L during the winter and 10,563L during the pre monsoon. All of this irrigation water was applied using flood irrigation with water from the irrigation canals.

Irrigation was generally confined to the pre monsoon in Tallo Lorpa. Again taking the mean of respondent estimates suggests that the average usage in this season was 3,104L, which is less than a third of that used per household in Panglin during the pre monsoon. Irrigation water in Tallo Lorpa is transported through a combination of pipes and irrigation canals. On an annual basis, households in the upper wealth quartile used substantially more irrigation water (5,343L) than households in the lower wealth quartile (747L). This represents a 616.2% greater share of irrigation water which was used on a 171.4% larger irrigated land area held by the upper wealth quartile relative to the lower wealth quartile.

6.6 Community and Household Capacity

With an understanding of water resource availability as well as appreciation of how this resource is utilised and for what purposes it is most important, we now move to describe community and household capacities. Social vulnerability to water stress is determined by the ability that communities and individual households have to withstand and manage water shortages. Specifically this is determined by adaptation and coping strategies, which are explored in Section 6.7, but on a more fundamental level it depends on the skills, possessions and attributes that constitute capacity. This section describes capacity through an exploration of demographics, income, food security, natural capital, physical capital, human capital and instances of social discrimination in Panglin and Tallo Lorpa.

6.6.1 Community Statistics

The communities of Panglin and Tallo Lorpa differ greatly in terms of population, income and food security. As shown in Table 6.13, the population of Panglin is less than half that of Tallo Lorpa. While there is little difference in the gender ratio between communities, Panglin seems to have a substantially older citizenry than Tallo Lorpa. This inference is supported by the average age of respondents which was 51.2 years in Panglin and only 34.1 years in Tallo Lorpa. The high average age of respondents in Panglin may be due to out-migration of young people in search of opportunities in Jomsom or Pokhara. For the young people of Tallo Lorpa, opportunities in Jumla are more limited and major cities like Pokhara and Nepalgunj are difficult to reach, therefore more may remain in the village.

Table 6.13: Population, gender and age statistics for Panglin and Tallo Lorpa.

Panglin							
Males age 0-15	14	Males age 16-49	42	Males age 50+	19	**Total male**	**75**
Females age 0-15	11	Females age 16-49	40	Females age 50+	22	**Total female**	**73**
Total	25 (16%)	Total	82 (55%)	Total	41 (28%)	**Total**	**148**
Tallo Lorpa							
Males age 0-15	71	Males age 16-49	87	Males age 50+	23	**Total male**	**181**
Females age 0-15	70	Females age 16-49	86	Females age 50+	21	**Total female**	**177**
Total	141 (39%)	Total	173 (48%)	Total	44 (12%)	**Total**	**358**

The average annual household income in Panglin was NRs. 154,346 which is nearly three times that for Tallo Lorpa which was NRs. 57,271. This income split is even more dramatic when assessed *per capita* because the average household size was greater in Tallo Lorpa (5.58 people) than it was in Panglin (4.47 people). Based on gross income *per capita*, people in Panglin are, on average, 3.65 times wealthier than people in Tallo Lorpa.

Income inequality is much greater in Panglin than it is in Tallo Lorpa to the extent that even though Panglin is a much wealthier community than Tallo Lorpa overall, the lowest wealth quartiles in both communities have similar expected incomes. In Panglin, the total income of the surveyed households was NRs. 5,094,000. The four highest earning households collected 61% of this income while the four lowest earning households collected only 1% of this income. The average income for the upper wealth quartile was NRs. 179,625 while the average income for the lower wealth quartile was only NRs. 40,875. In Tallo Lorpa, the total income of the surveyed households was NRs. 3,379,000. The average income for the upper wealth quartile was NRs. 60,800, while the average income for the lower wealth quartile was NRs. 39,600.

Income was strongly negatively correlated with age and strongly positively correlated with household size in Panglin. The average age of respondents in Panglin's lowest wealth quartile was 65 years and the average household size for this quartile was 2.3 people. In Tallo Lorpa, income was only slightly negatively correlated with age and there was little correlation between income and household size.

Food sufficiency was a big issue in Tallo Lorpa with 50 out of the 61 households surveyed (82%) experiencing some period of food shortage with a community mode of 6 months as shown in Figure 6.5. Interestingly, households in Tallo Lorpa's upper wealth quartile faced a slightly longer average period of food shortage (4.7 months) than households in the lower wealth quartile (4.1

months). This perhaps reflects the seasonal oscillation of plenty and want that characterises subsistence agriculture as well as the tenuous economic position of even wealthy members of the Tallo Lorpa community.

Food shortage was far less common in Panglin where only five households (14.7%) faced periods in which there was not enough food for their families. Four of these households (11.8%) experienced food shortage for only one month of the year while one household experienced it for two months of the year. Food shortage in Panglin appeared to be more closely correlated to household wealth, with no households in the upper wealth quartile facing food shortage while the house facing two months of food shortage was the poorest household in the community.

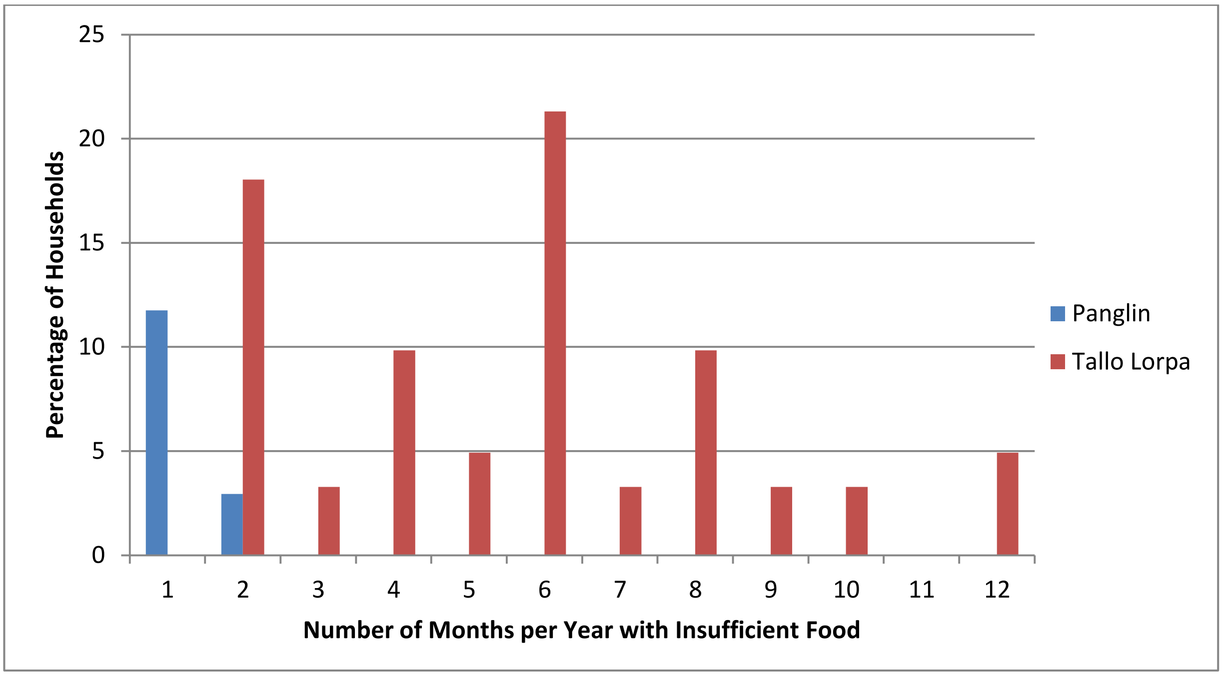


Figure 6.5: Food shortage in Panglin and Tallo Lorpa, as shown by the number of months in which households do not have enough food for family needs.

Household food shortage affected household food consumption as shown in Table 6.14. In Panglin, food consumption was reduced due to food shortage in only six households (17.6%). Five of these households (14.7%) reported having to reduce meal sizes or frequency once or twice a year while one (2.9%) reported having to do this approximately once a month. Food shortage was more common in the lower wealth quartile.

In Tallo Lorpa, many of the households which reported food shortage did not report having to reduce consumption. There were, however, still some households which had to reduce meal frequency and size and a smaller number of households which faced full days with no food to eat. Chronic food shortage was again more common in poorer households with three households

(4.9%) in the lowest wealth quartile facing full days with no food to eat and one (1.6%) experiencing this approximately once every two weeks.

Table 6.14: Chronic food shortage in Panglin and Tallo Lorpa, as shown by reductions in food consumption during the last 12 months.

Number of times a family member had smaller portions or fewer meals.	**Number of Households Panglin**	**Number of Households Tallo Lorpa**
Never	26 (76.5%)	37 (60.7%)
Once or twice	5 (14.7%)	9 (14.8%)
Once a month	1 (2.9%)	3 (4.9%)
A few times a month	0	9 (14.8%)
Every Day	0	3 (4.9%)
Number of full days with no food to eat in the last 12 months.	**Number of Households Panglin**	**Number of Households Tallo Lorpa**
Never	30 (88.2%)	50 (82%)
Once or twice	0	6 (9.8%)
Approximately every 2 weeks	0	1 (1.6%)

Linked with food sufficiency, and providing an interesting example of vulnerability, is household experience of feed shortage for livestock. Livestock fodder shortage was more common in Tallo Lorpa than in Panglin, as shown in Figure 6.6. What is interesting is that in both communities, fodder shortage was far more common among upper wealth quartile households than lower wealth quartile households. This reflects the greater ownership of livestock in the upper wealth quartile and suggests that, while wealthier households may not be more vulnerable in an absolute sense, they may be more *sensitive* to water shortage than households in the lower wealth quartile.

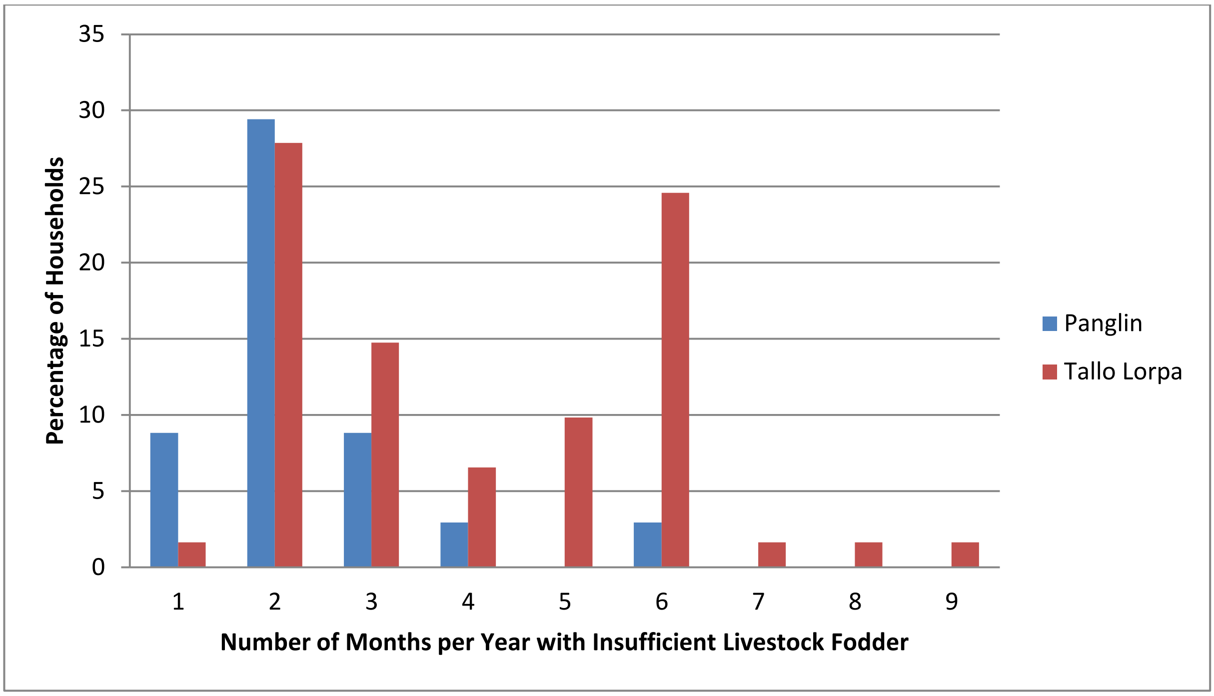


Figure 6.6: Livestock fodder shortage in Panglin and Tallo Lorpa.

6.6.2 Natural Capital

Differences in natural capital between Panglin and Tallo Lorpa are most obvious in terms of land quality rather than land quantity, while differences between households within each community are clear with respect to both quality and quantity. The total area of cultivated land reported by respondents in Panglin was 19.78ha (Table 6.15). Divided between 31 landowners this is equal to an average landholding of 0.67 Ha. The 60 landowners in Tallo Lorpa cultivate a reported total of 35.7 Ha, making an average of 0.59ha of agricultural land per household. Taking into account the smaller household size in Panglin, average *per capita* land ownership is only moderately larger in this community than in Tallo Lorpa.

Table 6.15: Land ownership in Panglin and Tallo Lorpa.

	Panglin	**Tallo Lorpa**
Total Agricultural Land	18.78 Ha.	35.7 Ha.
Number of Landowners	31 (91.2%)	60 (98.4%)
Average Household Landholding	0.67 Ha.	0.59 Ha.

The major difference in natural capital between Panglin and Tallo Lorpa was the quality of agricultural land available. While there is little difference in soil classification between Panglin and Tallo Lorpa (with the vast majority of soil in both areas being classified as loamy), large differences are seen in terms of relief. In Panglin, 98% of the cultivated land is flat, while in Tallo Lorpa, only 37% of cultivated land is flat (Table 6.16). Of the remaining agricultural land in Tallo

Lorpa, 25% was gently sloping, 23.8% was steep and 13.3% was terraced. The difference in productivity between the flat irrigated land of Panglin and the relatively steep and predominantly rain fed land of Tallo Lorpa largely explains why Panglin produces more food from only slightly more than half the cultivated land area.

Table 6.16: Agricultural land relief profiles in Panglin and Tallo Lorpa.

	Panglin	**Tallo Lorpa**
Flat land total	17.4 Ha. (98%)	13.05 Ha. (37%)
Gently Sloping	0.05 Ha. (0.3%)	8.8 Ha. (24.9%)
Steep	0.31 Ha. (1.7%)	8.4 Ha. (23.8%)
Terraced	0	5.05 Ha. (13.31%)

While 60 out of the 61 households in Tallo Lorpa own agricultural land, ownership of flat land was found to be unequal. Unsurprisingly, wealthier households tended to own more flat land while poorer households held more marginal steep land. On average, households in the lower wealth quartile reported owning 0.14ha of steep land, compared to 0.088ha owned by households in the upper wealth quartile. This proportional ownership of steep land is made more extreme by the fact that households in the lower wealth quartile own 36.1% less land than households in the upper wealth quartile. Poorer households therefore own both less land and steeper land than richer household in Tallo Lorpa.

In Panglin, three out of the 34 households surveyed were landless. Inequality amongst households which did own land was less than that found in Tallo Lorpa. Households in the lower wealth quartile owned 21.7% less land than those in the upper wealth quartile. With the vast majority of agricultural land being flat, land ownership can be seen as substantially more equal in Panglin than it is in Tallo Lorpa.

6.6.3 Physical Capital

Indicators of physical capital, in contrast to those of natural capital, suggest that households in Tallo Lorpa are better off than those in Panglin. Almost all households (60 of 61 (98.4%)) in Tallo Lorpa owned their own houses while this was the case for only 17 out of the 35 respondents (48.6%) in Panglin. Home ownership was considerably more common among wealthier households in Panglin.

The average monthly expected rent value for households in Tallo Lorpa was NRs. 1,419. In Panglin, the average monthly expected rent value was only slightly more than half that for Tallo Lorpa, at NRs. 746. Rent value increased markedly with household wealth in Tallo Lorpa while this was not necessarily the case in Panglin. It is possible that this indicates a lack of demand for housing in Panglin.

Oxen or horses were used for working agricultural land by all 60 landowners in Tallo Lorpa. Of these households, 81.7% owned the ox or horse while the remaining 18.3% rented or borrowed the animal(s). In Panglin only 81.5% of landowners used oxen or horses to work their land and of those who did, only 62.8% owned the animals while the remaining 31.8% had to rent or borrow them.

While these indicators cover only a small portion of the repertoire of physical capital households can be expected to own, they are considered to be the most important ones in this instance. By this measurement, Tallo Lorpa seems better endowed with physical capital than Panglin.

6.6.4 Human Capital

Human capital is defined here as skills, traits or conditions which improve individual productive capacity (adapted from Moser and Felton (2007)) and is assessed with respect to health, literacy and education. Frequency of illness, as shown in Table 6.17, was much higher in Tallo Lorpa than Panglin. The modal incidence of serious illness rendering household members unable to work was once a month in Tallo Lorpa. Of particular relevance are the six households (9.8%) in which serious illness prevents a household member from productive work a few times a week and the three households (4.9%) which see this every single day. There were slightly higher rates of illness amongst lower wealth quartile households.

In Panglin by contrast, half of the respondents reported never experiencing serious illness in their households while the next largest grouping experienced it only once or twice a year. Only one household (2.9%) reported serious illness occurring a few times a week and none had to suffer this every day. Again, slightly higher rates of illness occurred in poorer households.

Table 6.17: Frequency of serious illness which prevents patient from working in the last 12 months.

Frequency of Illness	Number Affected Panglin	Number Affected Tallo Lorpa
Never	17 (50%)	3 (4.9%)
Once or twice	7 (20.6%)	12 (19.7%)
Once a month	3 (8.8%)	25 (41%)
A few times a month	3 (8.8%)	7 (11.5%)
Once a week	2 (5.9%)	5 (8.2%)
A few times a week	1 (2.9%)	6 (9.8%)
Every Day	0	3 (4.9%)

Head of house literacy rates were higher in Tallo Lorpa (47.5%) than they were in Panglin (41.1%). Tallo Lorpa also had fewer households in which no one could read or write a letter (5 out of 61 households (8.2%)) than Panglin (6 out of 34 households (17.6%)). Household literacy rates were strongly positively correlated with wealth with an average of 57.9% literacy in the upper wealth quartile in Panglin compared with 14.6% in the lower wealth quartile and an average of 62.8% literacy in the upper wealth quartile compared to 23.3% in the lower wealth quartile in Tallo Lorpa. In both communities literacy rates were approximately twice as high among males as they were among females.

Educational levels were also generally higher in Tallo Lorpa than in Panglin, as shown in Table 6.18. Again these educational levels were strongly positively correlated with household wealth with none of the households in the lower wealth quartiles of either community having an educated household head.

Table 6.18: Highest completed level of education for each respondent's head of household.

Education Level	# of Households Panglin	# of Households Tallo Lorpa
Class 1-5	10 (29.4%)	10 (16.4%)
Class 5-8	3 (8.8%)	10 (16.4%)
Class 9-11	1 (2.9%)	8 (13.1%)

In summary, while frequency of illness is substantially lower in Panglin than Tallo Lorpa, levels of education and literacy are higher in Tallo Lorpa than Panglin. This makes it difficult to differentiate the two communities in terms of overall human capital.

6.6.5 Social Discrimination

Linked closely with inequality, and vital to the understanding of community and household capacity, is the experience of social discrimination. Social discrimination occurs based on a number of biases and can undermine the capacity of households and individuals, increasing their social vulnerabilities (Macchi, 2011). In this investigation, social discrimination was assessed through respondent experiences of discrimination at water management decision making fora. By this measure, social discrimination was felt more widely in Panglin than it was in Tallo Lorpa and the groups experiencing this discrimination differed between communities.

Table 6.19 shows respondents' experiences of discrimination felt when taking part in water management decision making. In Panglin, six respondents (17.7%) faced discrimination on the basis of gender while 11 (32.4%) respondents faced discrimination on the basis of social status. In Tallo Lorpa, only one respondent (1.6%) faced discrimination on the basis of gender while five respondents (8.2%) faced discrimination on the basis of age.

Table 6.19: Respondents' experience of discrimination felt when taking part in water management decision making.

Discrimination faced on the basis of:	# of Households Panglin	# of Households Tallo Lorpa
Caste	1 (2.9%)	3 (4.9%)
Class	1 (2.9%)	4 (6.6%)
Gender	6 (17.7%)	1 (1.6%)
Age	4 (11.7%)	5 (8.2%)
Social Status	11 (32.4%)	3 (4.9%)
Difficulty attending decision making forums	3 (8.8%)	4 (6.6%)

Religion was not formally surveyed but it is a further basis for discrimination which appears to have a substantial influence on household capacity in Panglin and Tallo Lorpa. In Panglin, 30 out of the 34 households surveyed were Buddhist. All of the households in the upper wealth quartile were Buddhist while two of the eight respondents in the lower wealth quartile were Hindu and one was Christian. Of the 61 respondents in Tallo Lorpa, 60 were Hindu and one was Christian. The Christian respondent was in the lowest wealth quartile.

Caste also appears to garner substantial discrimination in both communities. Of the 34 respondents in Panglin, 32 were Hill Janajaties, one was Brahman/Chetri and one was Dalit. The Brahman/Chetri was in the lowest wealth quartile and the Dalit household was the poorest household in the community. Of the 61 respondents in Tallo Lorpa, 60 were Brahman/Chetri and one was Dalit. The one Dalit in Tallo Lorpa was also the poorest household in the community.

6.6.6 Summary of Community and Household Capacity

With respect to capacity, it is difficult to differentiate between Panglin and Tallo Lorpa because each community has differing strengths and weaknesses of capital. Panglin is a much wealthier community than Tallo Lorpa in terms of income and access to arable flat land, however in Tallo Lorpa, home ownership, the usage and ownership of working livestock, levels of education and literacy are higher and social discrimination is less common.

On an intra-community level, it is clear that household capacity is highly unequal. This is seen in Panglin particularly with respect to household income and in Tallo Lorpa particularly with respect to ownership of productive agricultural land. In both communities, poorer households show lower rates of education and literacy, higher rates of serious illness and more commonly experience social discrimination. The lack of capacity that these poorer households exhibit make them particularly vulnerable to environmental stress.

6.7 Adaptation and Coping Strategies

From an understanding of the skills, possessions and attributes that constitute capacity, we move to investigate the specifics of resilience. Resilience, as it is defined in Section 5.2, is the converse of biophysical vulnerability, and it can be enhanced by reducing social vulnerability through adaptation. Adaptation is defined by Klatzel and Murray (2009, p.7) as “A process of adjusting to changes in variables that influence human well-being and survival”. Adaptation is distinct from coping strategies, which are defined by Macchi (2011, P.4) as “short-term actions to ward off immediate risk, rather than to adjust to continuous or permanent threats or changes”. Both adaptation and coping strategies are important for managing periods of water stress and both approaches are seen in efforts to reduce water use during dry periods in Panglin and Tallo Lorpa.

6.7.1 Adaptation

To assess household and community adaptation to water stress, respondents were asked what adjustments they have made in response to changes they had observed in their environment (outlined in Section 6.4). Table 6.20 shows the most common responses in each community. Adjustment in response to observed changes was far more common in Tallo Lorpa than it was in

Panglin. Half of the respondents in Panglin reported having done nothing to adapt to environmental changes while the most common response (introducing new crop varieties) was pursued by less than a third of respondents. The main reason respondents in Panglin gave for inaction was that the environmental changes were too erratic to respond.

Responses to observed change in Tallo Lorpa were common and diverse relative to those in Panglin. Of the 61 respondents, 27 (44.3%) reported giving up planting certain types of crops while 26 (42.6%) introduced new crop varieties in order to adapt to observed environmental changes. Other agricultural adjustments including changing grazing practices and giving up rearing certain types of livestock were also popular. It is interesting to note that in Tallo Lorpa, twice the number of households had invested in household irrigation infrastructure (16) than had invested in community irrigation infrastructure (8). In Panglin, this situation was reversed with five households having invested in community irrigation infrastructure in response to environmental change while only two households invested in private irrigation infrastructure.

Table 6.20: Adaptation measures taken in response to environmental changes observed by respondents in both Panglin and Tallo Lorpa.

Reaction to Changes	# of Households Employed Panglin	# of Households Employed Tallo Lorpa
Given up planting certain types of crops	2 (5.9%)	27 (44.3%)
Introduced new crop varieties	10 (29.4%)	26 (42.6%)
Given up rearing certain types of livestock	1 (2.9%)	16 (26.2%)
Introduced new types of livestock	1 (2.9%)	8 (13.1%)
Changed grazing practices	2 (5.9%)	21 (34.4%)
Changed farming practices	1 (2.9%)	14 (23%)
Migrated for work	-	6 (9.8%)
Abandoned farming	-	10 (16.4%)
Household invested in new irrigation infrastructure	2 (5.9%)	16 (26.2%)
Community invested in new irrigation infrastructure	5 (14.7%)	8 (13.1%)
Have done nothing	17 (50%)	2 (3.3%)

Focus group and interview respondents suggested a number of other ways in which adaptation is believed to occur. In Panglin, worship is generally seen as a means to adapt to environmental changes. For example, a member of the men’s focus group explains that “The water in the pond might decrease so a ‘Lama’ has built an idol god near the pond”. In addition to this, there is a general belief that if water availability becomes a serious problem, mechanical pumps could be used to draw water from the main Kali Gandaki River below the village. The elderly key informant uses the small community of Tiri on the other side of, and much closer to, the Kali Gandaki River as an example of pumped irrigation working. He does, however, point out problems with this strategy, saying that "The machines may not work always….and when flood comes in the Ganga, it may sweep the machine with it*".*

In Tallo Lorpa, respondents highlighted improved connection to markets and forest conservation as realized and potential adaptations respectively. The elderly key informant highlighted the utility of improved access to market, saying "Before we use our goats and donkeys to carry food from far away town. But it's easy to find food nearby our village, after wheels came in Jumla". Clearly improved access to markets insulates the community members from extremes of deprivation and helps to diversify risks of crop failure and famine. In addition to this, the local Forestry Group works to safeguard or enhance the hydrological utility of the Ghatte Khola watershed by conserving forests and planting new trees. As a member of the Forestry Group explains: "…our group works on preserving forests and vegetation around which would save our water sources, we tell people not to cut young trees and plants… we know if the forest is conserved well it would increase water sources , cattle [would] get good water*".* Again it appears that means of adaptation are more substantive in Tallo Lorpa, consisting of hydro-biological and economic changes, and more speculative in Panglin relying on faith and the possibility of technological improvements.

6.7.2 Water Saving Strategies

Households in both Panglin and Tallo Lorpa used water saving technologies and implemented water saving strategies to reduce their water use during times of shortage. Efforts to reduce water use were far greater in Tallo Lorpa than in Panglin which reflects the relative frequency of water shortage in these communities, described in Section 6.6. Wealthier households in both communities were able to take advantage of water saving technologies such as micro irrigation while poorer households had to pursue less desirable water saving strategies such as reducing household cleaning, sanitation and drinking water use.

Water saving technologies, including micro irrigation, mulching and Multiple Use water Systems (MUS), were surveyed in both communities. In Panglin, only one household reported using any of these three technologies. Respondents did, however, point out that improving irrigation infrastructure was an important form of water saving technology and 28 of the 34 respondents (82.4%) followed this approach. This commonly took the form of cementing irrigation canals to reduce leakage and increasing water storage capacity.

Table 6.21 shows the prevalence of water saving technologies in Tallo Lorpa. MUS along with mulching and micro irrigation were commonly used in this community, with slightly greater use among upper wealth quartile households than lower wealth quartile households. A member of the local water group demonstrated the interest of community members in such technologies, saying that micro irrigation is "quite effective [and] we would like to know more ideas and implement strategies… we believe such ideas would help us to reduce wastages and help us in dry periods in the future". When pressed on their effectiveness, however, they key informant in Tallo Lorpa explained "if [strong] drought situation it will not be sufficient. [Micro irrigation] would be [sufficient] if low drought but if high drought situation how can it be sufficient?"

Table 6.21: Adoption of water saving technologies in Tallo Lorpa.

Water Efficient Technology	# of Households Employed	Upper Wealth Quartile	Lower Wealth Quartile
Micro Irrigation	39	12	8
Mulching	39	9	8
MUS	24	6	6

Table 6.22 shows water saving strategies employed by community members during periods of water shortage. Respondents were asked to estimate the amount of water each strategy saved their household per week, however they often found this difficult to do. As a result, water savings estimates are taken from a small number of respondents in Tallo Lorpa only, and the results should be seen as a vague indication of effectiveness in this community and should not be applied to households in Panglin.

In Panglin, community investment in new irrigation infrastructure was the most commonly adopted water saving strategy, however more than twice as many households reported having done nothing. A member of the local Women's Group explained that worship is a common way of preventing water shortage in Panglin: "After we worship the water level in the canal increases". Only three of the 34 respondents (8.8%) in Panglin did not believe that the strategies the community followed to conserve water would be sufficient during dry periods in the future.

In Tallo Lorpa by contrast, water saving strategies were commonly employed and only four of the 61 respondents (6.6%) reported having done nothing to save water during dry periods. Commonly used strategies included giving up certain types of crops, investing in new irrigation infrastructure, reducing household drinking water and reducing household water for cleaning. A member of the local Water Group also suggested that the community "need[s] to plant forests and increase the number of trees to save the water sources". Households in the lower wealth quartile were somewhat more inclined to reduce water for drinking, cleaning and sanitation than those in the upper wealth quartile.

The most effective water saving strategy was investing in new community irrigation infrastructure which is said to reduce household water demand by 200L a week on average. A member of the local Women's Group explained that "*…we are making our tanks stock enough all the time. We hope we would not face water shortage in the future*". Another member of the local Women's Group explained the importance of worship in Tallo Lorpa, saying "*…we went to our God taking him a goat and ribbon for blessing our water we hope God will give sufficient water in the future. We all people pray to God*". Despite the numerous water saving strategies and faith, 27 of the 61 respondents (44.3%) do not believe that this will be sufficient to avoid water shortage during dry periods in the future. This view was disproportionately held by older members of the community.

Table 6.22: Water saving strategies employed in Panglin and Tallo Lorpa. Average savings for each strategy were taken from a small number of respondents in Tallo Lorpa only and should be interpreted as such.

Water Saving Strategy	# of Households Panglin	# of Households Tallo Lorpa	Average Savings
Given up planting certain types of crops	3 (8.8%)	24 (39.3%)	73.4L
Introduced new crop varieties	4 (11.8%)	17 (27.9%)	120L
Sold livestock	2 (5.9%)	4 (6.6%)	40L
Slaughtered Livestock	-	4 (6.6%)	80L
Changed Farming practices	4 (11.8%)	2 (3.3%)	
Farmland was left fallow	-	2 (3.3%)	
Sold Farmland	1 (2.9%)	1 (1.6%)	
Abandoned Farming	-	4 (6.6%)	
Household invested in irrigation infrastructure	4 (11.8%)	21 (34.4%)	58.2L
Community invested in irrigation infrastructure	7 (20.6%)	11 (18%)	200L
Reduced household drinking water	2 (5.9%)	33 (54.1%)	31L
Reduced household water for cleaning	3 (8.8%)	47 (77%)	39.6L
Reduced household water for sanitation	3 (8.8%)	24 (39.3%)	46.8L
Have done nothing	17 (50%)	4 (6.6%)	

6.7.3 Coping Strategies

Coping strategies differed substantially both between and within the communities. Coping strategies that were commonly employed during times of water shortage in Panglin are shown in

Table 6.23. Popular strategies included borrowing money from relatives, spending savings on food and sending family members to live outside of the community. Of the 34 respondents, 12 (35.3%) said that sending family members to live outside of their community was the first strategy they employ during times of water shortage, while 28 of the 34 respondents (82.4%) said that reducing meals was the third strategy they employ during times of water shortage. One of the respondents believes "we will never face water shortage, we keep our God happy". Another said that they would "follow what the God says – no other ideas". Half of the respondents in both the upper and lower wealth quartiles relied on borrowing money during times or water shortage.

Table 6.23: Coping strategies commonly employed during periods of water shortage in Panglin.

Strategy employed during times of water shortage	# of Households
Relied on less expensive foods	4 (11.8%)
Borrowed from bank	4 (11.8%)
Borrowed from relatives	10 (29.4%)
Spent savings on food	11 (32.4%)
HH members sought wage employment	5 (14.7%)
Displaced outside community	18 (52.9%)
Reduce meals	28 (82.4%)

Coping strategies that were commonly employed during times of water shortage in Tallo Lorpa are shown in Table 6.24. The most popular coping strategies included buying food on credit, spending household savings on food, collecting wild food and changing farming practices. Out of the 61 respondents, 12 (19.7%) said that spending savings on food was the first strategy they employed during times of water shortage, while 11 of the 61 respondents (18%) said that their first response would be to walk to the river to carry water to where it is needed. Eight of those in the upper wealth quartile relied on borrowing money during times of water shortage while all 15 of those in the lower wealth quartile relied on borrowing money during times of water shortage.

Table 6.24: Coping strategies commonly employed during periods of water shortage in Tallo Lorpa.

Strategy employed during times of water shortage	# of Households
Bought food on credit	12 (19.7%)
Borrowed from money lender	6 (9.8%)
Borrowed from relatives	9 (14.8%)
Spent savings on food	16 (26.2%)
Collected wild food	8 (13.1%)
Sold firewood/NTFP	6 (9.8%)
Slaughtered livestock	5 (8.2%)
Non-working household members started to work	7 (11.5%)
Changed farming practices	8 (13.1%)

Table 6.25 shows household indebtedness in Panglin and Tallo Lorpa. Households relied on borrowing money during times of water shortage in both communities, although this strategy was far more common in Tallo Lorpa than in Panglin. More than half of the households in Tallo Lorpa were in some degree of debt, with 12 households (19.7%) in 'a lot' of debt. Only five (14.7%) of the households in Panglin were in any sort of debt with three of these describing this debt as 'little'. Indebtedness was correlated with wealth in Tallo Lorpa with eight upper wealth quartile households borrowing money during periods of water shortage and all 15 lower quartile households borrowing money during these periods.

Table 6.25: Household indebtedness in Panglin and Tallo Lorpa.

	# of Households Panglin	**# of Households Tallo Lorpa**
Household not in debt	29 (85.3%)	24 (39.3%)
Household in a little debt	3 (8.8%)	19 (31.1%)
Household in moderate debt	1 (2.9%)	6 (9.8%)
Household in a lot of debt	1 (2.9%)	12 (19.7%)

6.7.4 Community Support

Challenges to individual livelihoods are both internally and externally defined. While household adaptation and coping strategies are important, community support and institutional involvement also have considerable influence. Table 6.26 shows people and institutions from which respondents commonly received assistance during previous periods of water shortage. In Panglin, commonly cited assistance came from family, friends and the local government. In Tallo Lorpa, more than four fifths of respondents reported having received assistance form people of the community while more than half of respondents had received assistance from family and local NGOs. The figures in Table 6.27 show that community assistance is less commonly received by households in Panglin than households in Tallo Lorpa.

Table 6.26: Sources of community support received by respondents in Panglin and Tallo Lorpa.

Assisted during periods of water shortage	**# of Households Panglin**	**# of Households Tallo Lorpa**
Family	14 (41.2%)	35 (57.4%)
Friends	14 (41.2%)	12 (19.6%)
People of the Community	-	50 (82%)
Local Government	13 (38.2%)	11 (18%)
Local NGO	7 (20.6%)	35 (57.4%)

Interview and focus group responses seem to echo the strength of community support seen in quantitative responses from Tallo Lorpa relative to those from Panglin. In Panglin, community support was given on the condition of personal surplus. For example, a member of the local Women's Group explains that "if someone has excess of water and other asks him to provide some then he gives". A member of the men's focus group explains that the community does not otherwise provide welfare for those in need, saying "If he is relative then he might get help otherwise not. If any organization comes that is another case but no help from individual level".

In Tallo Lorpa, by contrast, community support is a prominent source of social welfare. A member of the local Forestry group believed that community members "would rather die but help others in need. If [they] help others, god will help [them]". A member of the Water Stewardship Group said that "We help everyone in need. Villagers are like our family. Villagers are all like family members". The elderly key informant explains that this social responsibility is borne from experiences of hardship by saying "…because sometimes the trouble is also for us, so we share our trouble we help each other. We should watch their face and they will watch our face too". This community support and kinship also extended to other communities, as a member of the local Women's Group explains: "Once Gothichaur Village had fire… at that time we all took our pots with water and helped to extinguish the fire. And we collected some money from our side and food too, and helped them in need at fire time…"

On a personal level, I was also hugely privileged to experience the kindness and support of the people of Tallo Lorpa, being warmly received and invited into many homes for Tibetan tea, millet wine and food. The attitude of a member of the local Forestry Group that "we don't like eating alone, we share everything, we would help anyone" certainly holds true in my experience as I was consistently humbled by the generosity and selflessness of community members.

6.7.5 Institutional Involvement

Institutions, from the community level to the international level, were seen to provide assistance to households in both communities. A member of the local Women's Group in Tallo Lorpa explains the importance of institutional involvement during periods of water stress, recalling that "due to erratic rainfall our potato was damaged, and also maize was destroyed, our household crops [were not enough] to consume for whole year, but we depend on aid which comes from various projects".

Table 6.27 shows the number of household beneficiaries as well as the average effectiveness (scored between a minimum of one and a maximum of five by respondents) of various development and aid institutions. At the local level, households in Panglin most commonly received support from local government and the local community support group with an average effectiveness of 2.5 out of a possible five and four out of a possible five respectively. Panglin's elderly key informant explains that assistance from local government depends upon community organisation, pointing out that "…if [we] develop… consensus then we might get help from government bodies, otherwise going just now and seeking help for immediate purpose might not help".

In Tallo Lorpa, local level support most frequently came from the local Women's Group with an average effectiveness of 2.9 out of five. A member of Tallo Lorpa's Water Stewardship Group explains that support is "[extended] to the needy people, and sometimes [they] would [provide more] help to more needy people; some people would need more".

Nepali NGOs were the only reported national institutions assisting households in either community. Of the 34 households in Panglin, 16 (47.1%) received support from Nepali NGOs with an average effectiveness of 2.2 out of a possible five. Support from this level was given disproportionately to households in the upper wealth quartile. Of the 61 households in Tallo Lorpa, 35 (57.4%) had received support from Nepali NGOs, with an average effectiveness of 3.3 out of five. Again, these organisations more commonly assisted those in the upper wealth quartile than those in the lower wealth quartile.

Assistance from the international level came from international organisations in Panglin. The ten households (29.4%) which received support from this level gave this support 1.9 out of a possible five for effectiveness. International organisations assisted 15 of the 61 households (26.4%) in Tallo Lorpa. This support was more effectively targeted at poorer households than that of Nepali NGOs and received a rating of 2.3 out of five for effectiveness. A member of the local Women's Group recalled the assistance her household received in the past, saying that "The World Food Program provided us seeds and plants, it is quite memorable and we had lot of support during food shortage".

Table 6.27: Number of beneficiary households and average effectiveness of local, national and international support institutions.

Support Organisation	# of Households Received Panglin	Average Effectiveness Panglin	# of Households Received Tallo Lorpa	Average Effectiveness Tallo Lorpa
Community Support Group	20 (58.8%)	4	14 (23%)	0.64
Local Women's Group	1 (2.9%)	-	17 (27.9%)	2.88
Farmers' Association	-	-	14 (23%)	2.5
Local Government	24 (70.6%)	2.46	15 (24.6%)	2.53
Nepali NGOs	16 (47.1%)	2.21	35 (57.4%)	3.29
International Organisations	-	-	15 (26.4%)	2.33
International NGOs	10 (29.4%)	1.9	2 (3.3%)	2.5

6.8 Summary of Results

Full investigation of the results of field research echo the findings of the water stress vulnerability index, suggesting that Panglin and Tallo Lorpa exhibit remarkably similar levels of overall water stress vulnerability but for remarkably different reasons. Water resources were found to be critical to livelihoods in both Panglin and Tallo Lorpa through the prominence of agriculture in each community. Dependence on water for livelihood activities was found to be greater in Panglin, where the vast majority of income was earned through irrigated agriculture, than it was in Tallo Lorpa, where irrigation was less common and non-agricultural livelihood activities were more common and more diverse.

Agricultural productivity was much greater in Panglin than Tallo Lorpa because of higher land quality and more extensive irrigation. Comparison of agricultural seasonality against changes observed in hydrological seasonality suggests that the former is not particularly vulnerable to the latter in Panglin. In Tallo Lorpa, by contrast, seasonal dry periods were found to align with seasonal peaks in water demand, leading to reports of increasing water shortage during the post monsoon. Irrigation was not reported during these periods of water shortage, suggesting that water shortage occurs because of a lack of rainfall rather than an absolute shortage of water in the catchment.

The community of Panglin scored poorly in the 'Resource' component of the index, reflecting the low absolute amount of water available *per capita* in the Panglin watershed relative to the Ghatte Khola watershed. While water resource availability was generally seen to have become more erratic over the last 10-20 years in Panglin, decreases in water availability throughout much of the annual cycle were perceived over this time period in Tallo Lorpa, suggesting that the available water ‘Resource’ has been eroding in this community.

Panglin largely compensated for its low ‘Resource’ score in the index with a substantially higher ‘Use’ score than Tallo Lorpa. Results of the field research show that water usage is both more organised and more prolific in Panglin than it is in Tallo Lorpa. The components of ‘Resource’ and ‘Use’ are combined in respondents’ experiences of water shortage. This was found to be less common and less severe in Panglin than in Tallo Lorpa, emphasising the importance of water ‘Use’ over ‘Resource’ availability in the current climate.

Reports of the negative impacts of water shortage were common in both the qualitative and quantitative responses from both communities. Findings relating to capacity show that, while it is difficult to differentiate between the two communities because of different strengths and weaknesses of capital, substantial intra-community inequality existed in both communities. Poorer households in both communities showed lower rates of education and literacy, higher rates of serious illness and more commonly experience social discrimination. These households show particularly high social vulnerabilities.

Specific responses to environmental change in the form of adaptation and coping strategies were reported in both communities. Adjustments in response to observed changes were far more common in Tallo Lorpa than they were in Panglin. In addition, responses to environmental change appeared to be more substantive in Tallo Lorpa and more speculative in Panglin. Efforts made to reduce water use during dry periods were far greater in Tallo Lorpa than in Panglin. Coping strategies employed differed greatly between the two communities reflecting differences in the socioeconomic conditions and differing impacts of water shortage. Wealthier households in both communities were able to take advantage of more desirable technological adjustments, while poorer households relied on less desirable changes like reducing household drinking, cleaning and sanitation water.

Institutional support during periods of water shortage was identified in both communities. Community level support was substantially more prevalent in Tallo Lorpa than it was in Panglin. National level support from Nepali NGOs was received in both communities; however this support did not consistently reach the poorer households in either community. Assistance from the international level was also reported in both communities. This assistance more effectively targeted poorer households in each society, although recipients suggested that it was not very effective.

With this understanding of social vulnerability in Panglin and Tallo Lorpa, we now move to discuss these findings in relation to the hazard identified in Chapter Three.

Chapter Seven

Discussion

7.1 Overview

This chapter discusses the findings of the field investigation into social vulnerability as they relate to expected changes in water availability as a hazard. The discussion aims to answer two research questions:

1) How vulnerable are the communities of Panglin and Tallo Lorpa to water stress caused by climate change *ceteris paribus*?
2) Will water shortage under climate change constrain population in Panglin and/or Tallo Lorpa or does this depend on adaptation?

The first question is addressed through a discussion of which people and which livelihood sectors are vulnerable to changes in water availability. Expected changes are then compared with water use, agricultural activities and previous experiences of water shortage on a seasonal basis. The key drivers of biophysical vulnerability in each community are then explored.

The second question is addressed through a discussion of the adaptation opportunities available to each community. These include internally driven opportunities as well as external opportunities which may bring substantial benefits. Adaptation opportunities are then compared with the vulnerability identified in the previous sections. Beyond this, a number of major constraints on adaptation are explored. The contest throughout is whether the Malthusian implications outlined in Chapter One are justified or whether Boserup’s implications, detailed in Section 7.5, are more accurate in this case.

7.2 Framework

Before discussing the results of this investigation, it is important to clarify their position within the framework of enquiry. Hydrological change caused by climate change is the basis of this thesis. Hydrological change is defined as a ‘hazard’ and is assessed in Chapter Three. The results presented in the previous chapter describe aspects of social vulnerability in Panglin and Tallo

Lorpa. This investigation follows the definitions of Brooks (2003) which describe biophysical vulnerability as a function of social vulnerability and hazard. Here, we seek to assess the biophysical vulnerability of the communities of Panglin and Tallo Lorpa to water stress under climate change.

Biophysical vulnerability is measured against sustainable livelihood capacities from the reference point of the *status quo*. A decrease in the number of sustainable livelihoods which Panglin and Tallo Lorpa can support would constitute biophysical vulnerability, while no change or an increase in this capacity would constitute resilience to the hydrological effects of climate change. The former outcome would constitute a sort of Malthusian crisis while the latter outcome would point to the determining influence of people, as suggested by Boserup (1965).

This analysis is an artificial one in that it allows for change in hazard under climate change and community adaptation to this hazard, however it ignores a number of other important forcings like population growth, globalisation and technological innovation. The analysis can be seen as a theoretical regression analysis in which hazard and social vulnerability are the independent variables and biophysical vulnerability is the dependent variable *ceteris paribus*.

The research questions are answered using a stepwise approach. Hazard is treated as the only independent variable in the following section (7.3). This section assesses biophysical vulnerability if hydrological change under climate change were to occur instantaneously with no chance for adaptation (social vulnerability remains static). Section 7.5 allows for change in social vulnerability through adaptation, and thus introduces a second independent variable to the theoretical regression. This section assesses the playoff between increasing hazard under climate change and decreasing social vulnerability through adaptation to determine the validity of Malthus's interpretation against that of Boserup in Panglin and Tallo Lorpa.

7.3 Current Biophysical Vulnerability

This section assesses the biophysical vulnerability of the communities of Panglin and Tallo Lorpa to water stress under climate change. It begins by discussing which people within each society are most socially vulnerable to water stress under climate change at the current time. Vulnerable livelihood sectors are then identified. Finally, understanding of these pressure points of social vulnerability is reconciled with projected changes in hazard under climate change in order to identify pressure points of biophysical vulnerability.

7.3.1 Vulnerable People

Social vulnerability varies greatly between communities, households and household members. As explained in Section 4.3.1, differences in poverty between people indicate differences in social vulnerability (Hunzai *et al.*, 2011; Macchi, 2011). In Nepal, poverty is known to correlate with factors such as caste (Jing & Leduc, 2010), household dependence ratio, access to basic facilities and social status (Hunzai *et al.*, 2011). Using Chambers and Conway's (1992) example of 'production thinking', it is clear that focusing on *community* capacity is fallacious because vulnerability is often the result of unequal access to resources rather than overall deficiency of resources.

Inequality was considerable in both Panglin and Tallo Lorpa. In Panglin, for example, the four highest earning households amassed 61% of the community's gross annual income while the four lowest earning households collected only 1% of this income. While income was somewhat more equal in Tallo Lorpa, ownership of productive land was not. Land owned by households in Tallo Lorpa's lowest wealth quartile was less extensive and considerably more marginal than that owned by wealthier households. In both communities, poorer households show lower levels of education, lower rates of literacy, higher rates of serious illness and more commonly experience social discrimination.

Differences in household capacity mean that social vulnerability varies considerably within each study community. Interestingly, differences in social vulnerability do not translate directly to differences in biophysical vulnerability. In both communities, wealthier households consistently experienced more severe effects from previous water shortages, largely through the effects these shortages had on livestock. Wealthier households reported longer periods of inadequate water for their livestock and more commonly reported negative effects on livestock condition. This is perhaps unsurprising given that wealthier households tend to own both more livestock and larger, more resource-intensive species. It does, however, suggest the interesting notion that wealthier households are the first to suffer from water stress.

This situation provides an example of hazard specificity in social vulnerability assessment, as explained in Section 4.3.2. In this instance, wealthier households are more sensitive to the early effects of water stress because of the large numbers of livestock they own. This would not be the case if the hazard in question was increases in market prices for rice which would logically affect poorer households more quickly than wealthier ones.

The threat that the early effects of water shortage pose to the livelihoods of wealthy people is relative rather than absolute. In most cases, livestock are kept in conjunction with other income generating activities and it is unlikely that stress on these animals will undermine the sustainability of their owners' livelihoods. With the focus of this investigation on sustainable livelihood capacity in the study communities, therefore, this sensitivity does not in itself constitute biophysical vulnerability. The sensitivity of wealthy households can be seen, rather, as an early signal of water shortage as a problem.

Biophysical vulnerability is likely to depend on the *degree* of water shortage. While wealthier households show the first signs of stress, poorer people, as a result of their lower capacities, are likely to be most at risk from more severe water shortages. The sustainable livelihoods of these poorer people are most in jeopardy under hydrological change. It is the success or failure of these people that will determine sustainable livelihood capacities of Panglin and Tallo Lorpa. Poorer households, therefore, remain the focus of this discussion on biophysical vulnerability.

7.3.2 Vulnerable Sectors

As explained in Section 6.3.1, agriculture is the most important livelihood activity in Panglin and Tallo Lorpa with respect to both income and food provision. Agriculture is also highly sensitive to climatic conditions as explained in Section 4.2.1. The importance of water to agricultural productivity was highlighted by the elderly key informant in Panglin who pointed out: "water is indispensable for agriculture, what to eat?" Similar sentiments highlighting the sensitivity of agriculture to water availability were common among respondents in both Panglin and Tallo Lorpa.

Crucially, agriculture depends on climatic seasonality. A number of studies cite perceived changes in agricultural seasonality in the Himalayas, as explained in Section 4.2.1 (Allen, 2011, in Singh *et al.*, 2011; Vedwan & Rhoades, 2001; Chaudhary *et al.*, 2011, in Nepal *et al.*, 2012). Similar changes were perceived by some respondents in Panglin and Tallo Lorpa, as noted in Section 6.4.2. Of the 34 respondents in Panglin, seven (20.6%) reported that the timing of monsoon precipitation had advanced while 13 of the 61 respondents (21.3%) in Tallo Lorpa believed this to be the case. In Panglin, water is short during the winter months of January and February while in Tallo Lorpa, water shortage is common during the pre-monsoon in March, April and May. Water shortage for cropping was seen to occur during the pre-monsoon and monsoon months in both Panglin and Tallo Lorpa, indicating the importance of ecosystem provisioning of water during these seasons.

Agriculture is the most important livelihood activity in Panglin and Tallo Lorpa. Agriculture is sensitive to water availability, particularly over seasonal timescales. Seasonal water availability is expected to change under climate change. Agricultural seasonality therefore exists as the dominant pressure point of biophysical vulnerability in Panglin and Tallo Lorpa.

7.3.3 Biophysical Vulnerability of Agriculture

Biophysical vulnerability is assessed here by comparing agricultural seasonality with expected seasonal changes in water availability. Table 7.1 shows expected seasonal changes in water availability against crop water stress, experiences of water shortage, irrigation demand and major crop growth cycles in Panglin. These results show that currently, crop water shortages are concentrated during the monsoon when buckwheat, potatoes and beans are growing. Expected increases in monsoon precipitation in Panglin may alleviate these water shortages to some degree in the future. In the previous chapter, Table 6.8 suggests that agriculture in Panglin was not particularly vulnerable to *observed* changes in seasonal water availability. Table 7.1 suggests that many of Panglin’s crops may in fact *benefit* from expected increases in water availability during the monsoon under climate change.

A number of negative impacts are, however, also expected. At the current time, crop water shortages and general water shortages are reported during the pre-monsoon; a period during which irrigation demand is high, precipitation is low and barley is growing. Expected decreases in water availability during this season may exacerbate both crop and general water shortage. This threatens the viability of crops like barley which rely on irrigation during the pre-monsoon.

Dryness during the pre-monsoon increases the importance of the timely arrival of the monsoon rains. The early monsoon is a period of high irrigation demand during which cropping water shortages are commonly observed and a number of major crops are planted. If monsoon rains were to be delayed, as has been perceived by local people at a number of sites in the region (Malla, 2008, in Nepal *et al.*, 2012; Allen, 2011, in Singh, 2011; Vedwan & Rhoades, 2001), the impact on agricultural production could be severe.

Table 6.1: Expected seasonal changes in water availability against crop water stress, experiences of water shortage, irrigation demand and major crop growth cycles in Panglin. Water shortage and crop water stress are displayed as the percentage of respondents who observed these conditions in each individual month. The results for irrigation demand were negotiated by the Women's Group and the focus group of local men and range between 0 and xxx, with xxx representing the highest demand.

Panglin	Pre-Monsoon			Monsoon			Post-Monsoon		Winter			
	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb
Best Guess Changes in Water Availability	Substantial decreases in water availability			Likely increases offset to some degree by increased evapotranspiration			Uncertain (increased soil moisture vs. increased evapotranspiration)		Uncertain (decreases in precipitation vs. increases in snowmelt runoff)			
Crop Water Stress	2.9%	2.9%	8.8%	17.6%	14.7%	5.9%						
Water Shortage	5.9%		2.9%	2.9%	2.9%						38.2%	41.2%
Irrigation Demand	xx	xxx	xxx	xx	xxx	xxx			xxx		x	xx
Buckwheat				Crop Growing								
Potato				Crop Growing								
Barley	Crop Growing							Crop Growing				
Beans				Crop Growing								

Table 7.2 shows expected seasonal changes in water availability against crop water stress, experiences of water shortage, irrigation demand, and major crop growth cycles in Tallo Lorpa. Crop water shortages are again most commonly reported during the monsoon. General water shortages are, however, primarily found during the pre-monsoon; a period during which many major crops are growing. Irrigation demand is also high during the pre-monsoon, reflecting the low rainfall totals in this season. Considerable decreases in water availability are expected during the pre-monsoon which may necessitate the expansion of irrigation in the community while reducing the amount of water available for this. Water shortages for domestic uses, sanitation, household livestock, and energy may also increase during the pre-monsoon. Again it is interesting to note that perceived changes in water availability under the *current* climate pose threats to agricultural productivity in Tallo Lorpa as shown in Table 6.9 of the previous chapter. Table 7.2 suggests that expected changes in seasonal water availability *further* threaten agricultural productivity in this community.

Assuming that crops are not damaged by water shortages during the pre-monsoon, increases in monsoon precipitation will relieve water shortages during the monsoon proper. All of the crops shown in Table 7.2 extend their growing season into the monsoon, and irrigation is still heavily used during the early monsoon. The agricultural importance of this period again means that delays in the arrival of monsoon rains could lead to severe crop losses, particularly following a dry pre-monsoon.

Table 6.2: Expected seasonal changes in water availability against crop water stress, experiences of water shortage, irrigation demand and major crop growth cycles in Tallo Lorpa. Water shortage and crop water stress are displayed as the percentage of respondents who observed these conditions in each individual month. The results for irrigation demand were negotiated by the local Women's Group, Forestry Group and Water Stewardship Group and range between 0 and xxx, with xxx representing the highest demand.

Tallo Lorpa	Pre-Monsoon			Monsoon			Post-Monsoon		Winter			
	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb
Best Guess Changes in Water Availability	Substantial decreases in water availability			Likely increases offset to some degree by increased evapotranspiration			Uncertain (increased soil moisture vs. increased evapotranspiration)		Possible decreases (considerable decreases in precipitation vs. increases in snowmelt runoff)			
Crop Water Stress	1.6%	1.6%	4.9%	9.8%	8.2%	3.3%						
Water Shortage	37.8%	52.5%	49.2%	9.8%	3.3%	1.6%	9.8%	8.2%	16.7%	31.1%	27.7%	4.9%
Irrigation Demand	xxx	xxx	xxx	xxx							xxx	xxx
Millet		Crop Growing										
Maize		Crop Growing										
Potato		Crop Growing										
Garlic	Crop Growing										Crop Growing	
Onion		Crop Growing										
Summer Vegetable	Crop Growing											

In summary, expected changes in water availability under climate change pose a greater threat to agriculture in Tallo Lorpa than in Panglin. Vulnerability largely stems from expected decreases in pre-monsoon water availability in both communities. The negative effect this has on agriculture will be greatly magnified if the monsoon rains are delayed. Biophysical vulnerability is therefore seen in the agricultural productivity of both Panglin and Tallo Lorpa, while being greater in the latter than the former. In light of the importance of agriculture in setting the sustainable livelihood capacities of these communities, Tallo Lorpa seems to be more vulnerable than Panglin to water stress under climate change.

7.4 Key Drivers of Biophysical Vulnerability

Having established when and where biophysical vulnerability occurs, we now move to ask why it occurs. This section discusses water availability and water use as contributors to biophysical vulnerability in Panglin and Tallo Lorpa. The notion that land availability exists as another underlying driver of biophysical vulnerability is also explored.

7.4.1 Water Availability as a Constraint

Absolute lack of water is the most fundamental parameter of water stress vulnerability. Agriculture in Tallo Lorpa does not appear to suffer from a lack of water flowing through the Ghatte Khola. The discharge of the Ghatte Khola is far greater than agricultural water demand throughout the seasonal cycle and the vast majority of catchment runoff flows into the Tila River below.

In Panglin by contrast, almost all of the available surface water is captured and used in the community's irrigation network. As explained in Section 2.5.2, surface flow in the Pan Khola is diverted through two storage ponds which capture inflow overnight and then flush water through the irrigation network to crops during the day. This irrigation network covers 99.5% of agricultural land in Panglin. Problems of water shortage must, therefore, stem from inefficient allocation or absolute shortage rather than inadequate distribution infrastructure.

Qualitative evidence of ineffective allocation is provided by the elderly key informant who explains that: "… every house gets [irrigation water] for one day and his next turn comes after 30 days and if between that period there is no water there will be scarcity*...*". Further highlighting ineffective allocation, 30 out of the 34 respondents in Panglin believed that everyone could have enough water throughout the year if it were managed effectively, despite the high frequency of water shortage identified in Figure 7.1.

While allocation appears to be the underlying cause of water shortage at the present time, the alternative explanation, absolute deficiency of available surface water, is likely to be more problematic in the future. This is particularly true during the pre-monsoon when runoff is expected to decrease substantially as the climate changes. While improvements in allocation efficiency have potential to ameliorate this deficiency to some degree, there is no guarantee this will occur. Absolute water availability, therefore, exists as a substantial contributor to biophysical vulnerability in Panglin.

7.4.2 Water Use as a Constraint

Notwithstanding the situation in Panglin, an absolute lack of available surface water is rare in the Himalayas. Often the main contributor to water stress is an inability to use water that is available. As Shah (2006) points out, water poverty generally shows little correlation with water availability. Bandyopadhyay and Gyawali (1994) explain that Himalayan people often find it difficult to divert and transport water to crops on steep or varying terrain. Effective use of water resources proved to be more of a challenge in Tallo Lorpa than in Panglin.

Available water resources are largely utilised in Panglin. By contrast, in Tallo Lorpa only 31.7% of agricultural land is irrigated, despite frequent experiences of crop water shortage and high absolute water availability. The importance of water use in determining water shortage is highlighted in Table 6.9 of the previous chapter. It shows that during the pre-monsoon when dry periods have been increasing, water shortages have decreased largely due to increased irrigation during these months. During the months of August to November, when water shortages were increasingly reported, irrigation did not occur. This suggests that water shortage was not caused by dry conditions, but by low usage of available water in Tallo Lorpa. As Shah (2006, p.3,414) points out, water poverty could perhaps be more properly labelled ‘water access poverty’. The primary importance of water ‘use’ in determining water shortage is reflected in a number of medium sized river basins in Nepal through the work of Pandey *et al.* (2012). Low use of available water is seen as the main contributor to biophysical vulnerability in Tallo Lorpa.

7.4.3 Land Availability as a Constraint

In addition to absolute deficiency and the inability to use available water, a lack of arable land appears to be a further key contributor to biophysical vulnerability. This notion was stressed by Kumar and Singh (2005) who deconstructed the concept of ‘virtual water’ trade. In theory, regional trade of water intensive products (virtual water) from humid countries to arid ones can increase water use efficiency (Suweis *et al.*, 2013; Dekens & Eriksson, 2009). Indeed, the amount of virtual water traded worldwide exceeds that used for drinking and domestic purposes by a factor of ten (Tamea *et al.*, 2013). As Kumar and Singh (2005) point out however, there is no correlation between the relative water availability within countries and their trade of virtual water. Rather, trade in virtual water correlates most strongly with total cropped area. The authors suggest that the amount of arable land is the key factor in the ability of an area to produce virtual water products. Furthermore the authors explain that people have historically settled in larger numbers where water resources are plentiful, often leading to reduced arable land *per capita* in these areas.

It appears that in Panglin and Tallo Lorpa, differences in the area of arable land available contribute to differences in productivity, and ultimately, to differences in biophysical vulnerability. As explained in Section 2.4.1.3, Panglin lies in one of the most sparsely populated districts in Nepal and has an abundance of flat land, which, given nutrients and irrigation, could be used productively. By contrast, Tallo Lorpa lies in a densely populated district and there is only 2.25ha of flat land in the entire Ghatte Khola watershed. Around Tallo Lorpa, agriculture is extended on to steeper, more marginal land. As Gill (1993) notes, a number of researchers have seen an overextension and consequent withdrawal of cultivation from steeper marginal lands in Nepal because land degradation and marginality render it uneconomic. There appears to be little scope for expansion of cultivated land in Tallo Lorpa. A shortage of arable land in this community therefore constrains the production of virtual water from the water resources available. Although water is plentiful in Tallo Lorpa, a shortage of arable land results in food insecurity and necessitates the import of virtual water products at cost to the community. The inverse of this situation is true in Panglin.

The dynamics of virtual water trade (or more accurately in this case, virtual land trade) on a global basis were analysed by Suweis *et al.* (2013). The authors suggest that as population increases worldwide, virtual water exporting countries will reduce their supply to the market because of a need to feed their own populations. Simultaneously, populations in virtual water importing countries will be allowed to grow beyond their environmental means because of unsustainably high virtual water trade. As a result, decrease in the market supply of virtual water products coupled with increased demand will lead to worldwide shortage. If these suggestions are accurate, they may also apply at the local level. In this instance, one might expect substantial increases in market prices for virtual water products in local markets. Over the medium to long term, this may prove to be an important contributor to biophysical vulnerability in Tallo Lorpa while being less so in Panglin. Suweis *et al.* (2013, p.4233) conclude their analysis with a tempered Malthusian undertone, stating "Unless new freshwater resources become available or investments for a more water-efficient agriculture are made, these populations will have to decrease". We now explore the caveats that the authors refer to.

7.5 Adaptive Capacity

With an understanding of the current state and key drivers of biophysical vulnerability in Panglin and Tallo Lorpa, we now address the potential for reducing this vulnerability through adaptation. The nature of the relationship between agri-environmental development and sustainable livelihood capacities was explored by Thomas Malthus who, writing at the turn of the 19th century, suggested that population growth fundamentally depends on agricultural growth. Within the framework of this investigation, Malthus's theory suggests that at any one time in Panglin and Tallo Lorpa, agricultural productivity determines the sustainable livelihood capacities of these communities (Malthus, 1798). This interpretation was challenged in 1965 by Ester Boserup, who suggested the causal connection is in fact the other way around. Under Boserup's interpretation, the population of Panglin and Tallo Lorpa would determine the agricultural productivity of the surrounding land: sustainable livelihood capacity is the independent variable on which agricultural productivity in the area depends.

Boserup (1965) based her interpretation on extensive findings that show increasingly productive cultivation systems emerging as a result of increasing population density. She holds that as population increases, agricultural practice intensifies, making use of additional labour inputs to compensate for reductions in fallow. In the words of Boserup (1965, p.177):

> "By the gradual change from systems where each cultivated plot is matched by twenty similar plots under fallow to systems where no fallow is necessary, the population within a given area can double several times without having to face either starvation or lack of employment opportunities in agriculture".

Boserup's interpretation of the relationship between population and productivity is more positive than that of Malthus. This section, informed by the contest of ideas between Malthus and Boserup, allows for change in social vulnerability through adaptation. Social vulnerability is therefore introduced as a second independent variable to the theoretical regression. Through this approach, the two main causal determinants of biophysical vulnerability are compared. Will changes in water availability determine the sustainable livelihood capacities of Panglin and Tallo Lorpa or will these communities determine their own prosperity through adaptation? The previous two sections describe the possibility of the former. This section explores the possibility of the latter.

7.5.1 Current Adaptive Capacity

The adaptive capacities of Panglin and Tallo Lorpa describe the potential for these communities to reduce their social vulnerabilities. Should this potential be greater than the influence that changes in water availability are likely to have on sustainable livelihood capacities, Malthus's interpretation can be rejected. Adaptive capacity is assessed here with respect to agricultural adjustments, technological developments and livelihood diversification.

7.5.1.1 Agricultural Adjustments

The potential for reducing social vulnerabilities through agricultural adjustments is considerable in both Panglin and Tallo Lorpa. Specific agricultural opportunities, however, differ between these communities. Agricultural adjustments are assessed here using the three broad categories of crop and livestock change; intensification; and extensification.

As explained in Section 4.4.3.2, agricultural input demand can be reduced by changing crop strain, crop type or livestock species. There is considerable scope for the introduction of new crops and changes in livestock in both communities. Recommendations of the HIMALI project in Tallo Lorpa encourage mixed cropping and planting of fruit trees like walnuts which are more resistant to water shortage than cereal crops (ICIMOD, 2012). These opportunities are being actively pursued in Tallo Lorpa where 27.9% of households reported having introduced new crop varieties, while 39.3% reported abandoning certain types of crop. The planting of fruit trees is also encouraged in Panglin, where apple yields are expected to increase relative to lower altitude sites because of temperature increases (ICIMOD, 2012). Fewer households, however, pursued these approaches in Panglin, with 11.8% of households having introduced new crop varieties and only 8.8% having abandoned other types of crop.

It is also suggested that cattle be replaced by species like goats and buffaloes to relieve grazing pressure (ICIMOD, 2012). The selling of livestock was, however, uncommon at the time of research; reported by only 5.9% of households in Panglin and 6.6% of households in Tallo Lorpa.

Opportunities for intensification of agriculture are also considerable in both Panglin and Tallo Lorpa, though greater in the latter than the former. Opportunities for intensification through labour intensive working and management of agricultural land is seen to be considerable in many developing communities (Chambers & Conway, 1992; Boserup, 1965). Opportunities for intensification common to both communities include mixed fruit tree cropping, plastic tunnel greenhousing and composting (ICIMOD, 2012; Khanal *et al.*, 2011). Additional opportunities in Tallo Lorpa include further terracing of steep land, maintenance of drainage and risers, and planting of terrace edging (ICIMOD, 2012). Irrigation could also be extended to previously rain-fed plots in Tallo Lorpa (ICIMOD, 2012).

Opportunities for agricultural extensification exist in Panglin. As explained in Section 2.4.1.2, only 3% of the Panglin watershed is cultivated leaving large areas of slightly sloping land uncultivated. With the addition of sufficient compost, irrigation and labour, this land could be used productively if it were needed. In Tallo Lorpa by contrast, expansion of cultivation pushes on to very steep land and the re-working and intensification of existing agricultural land is a much more favourable option.

7.5.1.2 Technological Developments

Technological developments in the capture, storage and efficient use of water present further opportunities for adaptation. Improvements in the capture and storage of water are possible on a range of scales in both communities. In Panglin for example, the capture of water from the Pan Khola has been seen as incomplete (ICIMOD, 2012). As the draft development plan explains, while the current diversions capture much of the surface flow, subsurface flow in this channel is considerable – enough to return the stream to its pre-diversion flow only 100m downstream from where it is tapped (ICIMOD, 2012). Plans are therefore being developed to construct a gabion check dam to disrupt and capture some of this subsurface flow.

Small scale capture of rainwater for domestic purposes is possible in both communities and has been seen to be cost effective in other parts of the HKH region, as explained in Section 4.4.3.4 (Dixit *et al.*, 2009; Klatzel & Murray, 2009). Rainwater capture techniques are likely to be particularly effective in Tallo Lorpa, where the construction of eyebrow pits, contour terraces and trenches are suggested as a way to relieve water stress on un-irrigated land (ICIMOD, 2012). Agricultural rainwater harvesting is also seen to improve large scale groundwater storage by increasing infiltration (Vaidya, 2009; Singh & Singh, 2002). Increased groundwater storage can smooth runoff on a seasonal basis, increasing spring discharge over long periods (Keller *et al.*, 2000; Vaidya, 2009; ICIMOD, 2012) and could also be achieved by the construction of bunds, small scale flow disruption, and increasing land and forest cover in the Pan Khola and Ghatte Khola catchments (ICIMOD, 2012).

Water use efficiency could be substantially improved in both communities. In Panglin, plans are underway to reduce seepage from the water storage ponds and replace the canals with a piped irrigation system to reduce transmission losses (ICIMOD, 2012). The use of sprinklers, drip irrigation and pitcher irrigation is recommended to improve water use efficiency in both communities (ICIMOD, 2012). In Tallo Lorpa, 63.9% of households reported introducing micro-irrigation, and respondents were generally interested in further water saving strategies. Adoption of micro-irrigation was not apparent in Panglin. Beyond physical water saving strategies, market-based incentives such as pricing water volumetrically may further improve water use efficiency and could be implemented in Panglin and Tallo Lorpa based on existing developing community examples (Kumar, 2005).

7.5.1.3 Livelihood Diversification

Livelihood diversification is another way to enhance resilience and increase sustainable livelihood capacities in Panglin and Tallo Lorpa. As explained in Section 4.4.3.3, spreading livelihood activities across different activities and production sectors is an effective way of reducing social vulnerability to individual hazards. Furthermore, Boserup (1965) suggests that intensification of agriculture requires higher labour input, thereby increasing both agricultural productivity and agricultural labour employment. Chambers and Conway (1992) explain that diversification of livelihoods through increases in labour employment leads to small scale economic synergy brought about by recirculation of income. In holding with the theories of Chambers and Conway (1992), non-agricultural income was greater and income sources were more diverse in Tallo Lorpa, where farm holdings are smaller, than in Panglin where farm holdings are larger. There is, therefore, likely to be considerable scope for livelihood diversification in Panglin, and with this, scope for increases in sustainable livelihood capacity.

7.5.2 External Opportunities

Section 7.5.1 explored opportunities for adaptation which are immediate, accessible and able to be implemented by the communities of Panglin and Tallo Lorpa. The current section explores opportunities which are external to the communities in question but have the potential to bring substantive benefits to these communities. The three major opportunities explored are value chain development, payment for ecosystem services and reduced emissions from deforestation and degradation.

7.5.2.1 Value Chain Development

Value chains are essentially pathways of processing or marketing through which raw goods or services gain value. Because of their unique environments, mountain communities produce and provide a wide variety of niche products and services such as medicinal and aromatic plants, non-timber forest products, honeybee products and mountain tourism (Chaudhary *et al.*, 2011; Hoermann *et al.*, 2010b). Mountain communities are, however, seen to have little stake in current value chains and often receive only a small proportion of the final value of mountain products (Chaudhary *et al.*, 2011; Hoermann *et al.*, 2010b). Consequently there is a large scope for value chain development in mountain communities. According to Hoermann *et al.* (2010b), attempts at value chain development in the HKH region have suffered from a lack of contextualisation to mountain specificities. The authors call for an unconventional approach which incorporates multiple goods and services to generate ‘economies of scope’ rather than developing singular products using economies of scale. Mountain specific value chain development is being rigorously investigated by ICIMOD and a generic framework has recently been developed to this end (Hoermann *et al.*, 2010b). Value chain development may become a significant tool in poverty reduction and may act to reduce social vulnerabilities in Panglin and Tallo Lorpa.

7.5.2.2 Payment for Ecosystem Services

Payment for Ecosystem Services (PES) presents a further opportunity which may benefit mountain communities in the future. Mountain regions provide a multitude of ecosystem services to external communities, however markets often fail to recognise the value of these services or the environments from which they derive (Rasul & Karki, 2007; Eriksson *et al.*, 2009). PES schemes act to price the positive externalities and incentivise sound environmental stewardship through *quid pro quo* payments from external beneficiaries of ecosystem services (Kronenberg & Hubacek, 2013; Jianchu *et al.*, 2007). Implemented properly, PES schemes can address both environmental issues and poverty (Kronenberg & Hubacek, 2013; Singh *et al.*, 2011).

In the Kulekhani catchment in central Nepal, for example, communities are receiving payments from the Kulekhani-1 hydropower project for maintaining forest cover around their settlements in an attempt to reduce siltation of the reservoir (Karky & Joshi, 2009). These payments have been channelled through the district development committee to development projects in the area (Karky & Joshi, 2009). While only a small number of PES schemes have been explored in the Himalayas, the potential for others is gaining increasing attention (Eriksson *et al.*, 2009; Singh *et al.*, 2011).

Such schemes have the potential to benefit the communities of Panglin and Tallo Lorpa whilst also protecting environmental and aesthetic values in their areas.

While PES schemes appear promising, they may have a number of drawbacks. Kronenberg and Hubacek (2013) suggest that, in similar vein to the ‘resource curse’ highlighted by Sachs and Waner (1995), economies that accrue large payments for ecosystem services may suffer from local economic distortion; a phenomenon they call the ‘ecosystem services curse’. The authors point to the work of Karsenty (2004; 2007) which suggests that payment to maintain certain ecological functions may lead communities into a static poverty trap in which disincentives for change limit development opportunities relating to these ecosystem services. Furthermore, protection of land or retirement of land from productive use may inflate local land and commodity prices (Kronenberg & Hubacek, 2013). Instances of large scale rent-seeking and dilution of benefits due to local people, unequal bargaining power between funders and local communities and volatility in payments are also widely reported (Kronenberg & Hubacek, 2013). The potential for mutually beneficial PES schemes therefore depends on a strong institutional context and the careful design of safeguards against the drawbacks discussed.

7.5.2.3 Reduced Emissions from Deforestation and Degradation

Reduced Emissions from Deforestation and Degradation in developing countries (REDD or REDD+) is an approach to reducing greenhouse gas emissions developed under the United Nations Framework Convention on Climate Change (UNFCCC). It is essentially a global scale PES scheme aimed at climate change mitigation through payments for reducing emissions from ecosystems in developing countries (Singh *et al.*, 2011). Like other PES schemes, where implemented properly REDD has the potential to bring both environmental and development benefits (Singh *et al.*, 2011; Nepal *et al.*, 2012). According to the IPCC (2007a), mountain regions contain 28% of the world’s forests and therefore have considerable scope for REDD projects (Macchi, 2010b). ICIMOD has been working on a demonstration REDD project in Nepal, and expansion of REDD projects throughout the region is expected (Singh *et al.*, 2011). If carefully implemented, REDD projects could provide substantial benefits to the communities of Panglin and Tallo Lorpa.

At the current time, however, REDD projects are both controversial and rudimentary. Among other problems, it is unclear what standards REDD projects will be held to and many observers are concerned about projects ignoring the rights of indigenous forest users (Anonymous, 2011). Furthermore, based on the analysis of the Munden Project (Chicago), Petherick (2011) points out that market demand fell two orders of magnitude short of that needed to finance the forest protection objectives of REDD in 2011. While it is possible that the private sector could make up for this shortfall in demand, there is little chance of this happening organically and the centralised market structure of REDD is inappropriate in any case (Petheric, 2011). Fundamentally, REDD carbon credits suffer from a lack of fungibility and the market is at risk of demand side monopoly, which concentrates power with buyers and consequently undervalues forest protection under REDD (Petheric, 2011). The benefits that REDD may bring to the communities of Panglin and Tallo Lorpa therefore depend on careful design and implementation on a number of levels which, while not infeasible, is far from guaranteed.

7.5.3 Was Malthus Right?

It is clear that the adaptation opportunities currently available to the communities of Panglin and Tallo Lorpa are numerous and substantial. A number of immediate, accessible and internally achievable adaptation opportunities are available in Panglin and Tallo Lorpa. Agricultural adjustments provide a number of means by which production could be increased and other means by which input requirements could be decreased in both communities. Technological developments could further reduce water requirements by improving water use efficiency while greatly increasing the capture and storage of water in both watersheds. Further opportunities exist, in Panglin in particular, through the diversification of livelihoods leading to small scale economic synergy.

Beyond these self-determined opportunities, a number of external yet promising opportunities exist. The development of mountain-specific value chains may enhance the product value share that communities receive for mountain goods and services. PES schemes have the potential to assist both development and environmental conservation if carefully designed and implemented in a strong institutional context. REDD projects, again if carefully implemented, may further incentivise conservation while providing financial support for more sustainable means of development.

This section has demonstrated that the potential for adaptation, development and reductions in social vulnerability in Panglin and Tallo Lorpa is large. These potential reductions appear to outweigh the influence of changes in water availability as a hazard by a considerable margin in both communities. For example in a hypothetical Panglin or Tallo Lorpa, where all of the opportunities described above were carefully implemented to their best effect, it is hard to imagine reductions in pre-monsoon water availability reducing the number of sustainable livelihoods that either place could support. Even in the extreme scenario of drying during the post-monsoon, winter and pre-monsoon followed by delays in the arrival of the monsoon rains, the potential for reducing social vulnerability through adaptation comfortably offsets this hazard. Malthus's causality under this investigation's framework, in which water resource changes determine sustainable livelihood capacities, is therefore rejected.

In light of the scope for adaptation in both study communities, Boserup's causality in which populations determine the productivity and potential of their environment is accepted in theory. Whether this theory translates to reality, however, depends on the constraints that these communities face in realising the adaptation opportunities available to them. It is these constraints that we now discuss.

7.6 Constraints on Adaptation

The opportunities described in the previous section are tempered by a number of constraints. These constraints determine how successfully opportunities are realised and as such determine real world outcomes. The main constraints in this case are seen to be the beliefs and awareness of community members; inadequacies in the institutional context; and poverty.

7.6.1 Beliefs and Awareness as Constraints

Beliefs and awareness are key determinants of adaptation. To reiterate Macchi's (2011, p.9) point: "only informed individuals are able to implement planned adaptation strategies". Communities must first be aware of the changes they are responding to. Their responses are then moderated by their beliefs about the origins of environmental change and how best to respond (Vedwan & Rhoades, 2001). The effort expended on adapting then depends on the priority people assign to this.

The results of this investigation show a general lack of awareness of the implications of climate change in both Panglin and Tallo Lorpa. Only around a quarter of respondents in each community were aware of the concept of climate change. Perhaps unsurprisingly, given the scientific uncertainties outlined in Chapter Three, there was great confusion about the implications of climate change amongst those aware of the concept. There was also general confusion about *perceived* changes in climate in each community. For example, in Panglin the main reason given for not responding to observed changes in climate was that these were simply too erratic to respond to.

In addition to confusion about what changes to expect, beliefs about the origins of these changes, and how best to respond to them, were diverse. Many respondents in both communities saw environmental changes as acts of retribution by their gods. For example, the key informant in Tallo Lorpa stated “Now God hates us. No rainfall nowadays”. Similarly, a survey respondent in Panglin claimed “we will never face water shortage, we keep our God happy”. These beliefs often dictate worship as the appropriate response. For example, a member of the men’s focus group explains that “The water in the pond might decrease so a Lama has built an idol God near the pond”. The results of the field investigation suggest that responses to environmental change were generally more substantive in Tallo Lorpa, consisting of hydro-biological and economic changes, and more speculative in Panglin, relying on faith and the possibility of technological improvements. The community of Tallo Lorpa may therefore be more inclined to pursue the adaptations described in Section 7.5.

Responses to environmental change also hinge on the degree to which people are *concerned* by these changes. In Panglin only three of the 34 survey respondents believed that their coping strategies and adaptations would be insufficient to manage dry periods in the future. In Tallo Lorpa, the number of respondents who believed this was higher, at 27, but still less than half of the 61 respondents. In Panglin, 35.3% of respondents saw management of water resources as their community’s biggest concern for the future, while in Tallo Lorpa this statistic was 60.7%. It is clear that for large proportions of both communities, adapting to water shortage under climate change is not a great priority. This is not to say that it should necessarily be a priority. Community members are seen to respond to many pressing concerns like meeting rent or interest payments, paying for healthcare or providing food, which are likely to dominate climate change at any one time. It does, however, provide a further constraint on the realisation of adaptive capacity to water resource changes.

7.6.2 Institutional Context as a Constraint

As explained in Section 4.4.2, institutional support is often lacking in mountain regions and that which does exist tends to be poorly designed for mountain communities or ineffectively targeted. The need for institutional support is clear in both communities. For example, in Tallo Lorpa, where investment in new irrigation infrastructure was seen to be the most effective water saving strategy available, the traditional irrigation networks have deteriorated in recent years reflecting ineffective community organisation.

In both communities, institutional support was found to come from local government, Nepali NGOs, international NGOs and international organisations. Support from local government was perceived as only moderately effective by recipients, receiving an average rating of 2.5 out of five in both communities. Recipients of this support, however, came disproportionately from wealthier households. While support from international NGOs and international organisations was found to more accurately target assistance towards poorer households, it was not seen as particularly effective by recipients: receiving average ratings of 1.9 and 2.5 out of five in Panglin and Tallo Lorpa respectively. The poor effectiveness rating garnered by international institutions suggests that their projects may be poorly suited to the mountain contexts in Panglin and Tallo Lorpa. This inference, along with observed mis-targeting of the needy reflects common institutional shortfalls described in Chapter Four. These shortfalls are likely to limit the ability of households in Panglin and Tallo Lorpa to seize the opportunities available to them.

7.6.3 Poverty as a Constraint

Even in an effective institutional environment and with sound awareness of likely changes and how best to respond, adaptation can be constrained by poverty. As Pandey *et al.* (2012) explained, social vulnerability to water stress is often strongly correlated with poverty. Shah (2006) found GDP to be the strongest indicator of water access poverty in India. Poverty was seen as a major barrier to adaptation by Jing and Leduc (2010) and Macchi (2011). As explained in Section 7.3.1, while wealthier households in both study communities were found to be more sensitive to water shortages, poorer households are more vulnerable to severe water stress as a result of their limited capacities.

There was little to differentiate the communities of Panglin and Tallo Lorpa in terms of wealth because of different strengths and weaknesses of capital. Substantial inequality within each community was, however, clear. Poorer households in particular may struggle to grasp or implement adaptation opportunities, particularly ones requiring capital inputs. For example, dividing the average lower quartile household incomes by the average household size in each community suggests that people in this quartile live off just 25 rupees a day in Panglin and just 19.4 rupees a day in Tallo Lorpa (equivalent to less than 30 US cents a day in each case). People in this situation cannot buy drip irrigation equipment or sprinklers. Indeed, it is likely that these people have little capacity to consider adaptation approaches beyond their day-to-day survival. For these people in particular, poverty exists as a substantial constraint on adaptation, rendering many of the adaptation opportunities discussed meaningless.

7.6.4 Was Boserup Right?

As explained at the end of the previous section, Boserup's direction of causality is correct in this instance. The opportunities available to Panglin and Tallo Lorpa *will* determine the sustainable livelihood capacities of these two places. These opportunities are, however, hindered by a number of critical constraints.

Confusion about the nature of environmental changes, coupled with divergent views on their causes, complicate adaptation. In Panglin in particular, managing changes in water resources was not seen as a priority and responses commonly hinged on worship. Where conventional adaptation was pursued, a weak and ill-targeted institutional context provided only moderately effective support. Poverty provides a further constraint to adaptation in Panglin and Tallo Lorpa which places many strategies beyond people's reach.

These constraints appear to be considerable relative to the adaptation opportunities available in Panglin and Tallo Lorpa. It is by no means certain that these communities will be able to overcome these constraints to implement their adaptation opportunities and prosper. We cannot, therefore, accept Boserup's implications unreservedly. There remains a contingent possibility that the implications of Malthus - which would see forced out-migration or starvation as a result of water stress under climate change - will eventuate. The defining factor will be the success with which constraints on adaptation are overcome. Fundamentally, this depends on awareness and education, strengthening of the institutional environment and reduction of poverty in the two communities.

7.7 Uncertainties

The findings of this investigation rest on the interpretation of fallible empirical evidence. While efforts were made through the methods used to minimise uncertainty, some was unavoidable and must be acknowledged. This section discusses uncertainty stemming from official statistics, informant recollection and survey techniques.

Census data were used in Chapter Two to introduce social and demographic aspects of the study communities. Census data in Nepal have, however, been criticised for being unreliable, inaccurate, piecemeal, exaggerated and untimely (Gill, 1993). Gill (1993) highlights these points by comparing a Nepalese Cadastral Survey with an overlapping Agricultural Census. The author found the area of cultivated land reported to be almost four times higher in the Cadastral Survey than in the Agricultural Census; a discrepancy he blames on opposing incentives for exaggeration and underreporting. While this may be an extreme case, the probability of substantial inaccuracies in the census data used in this investigation is acknowledged.

The quality of the data collected during field work hinges on the ability of the subjects to recall complex conditions or phenomena like climate, water usage and income. Respondents were often asked to recall conditions and phenomena as they existed 10 years ago and compare them with the current situation. Uncertainty is an obvious pitfall of this approach which may contribute systematic error as some phenomena, like snowfall, have different recollection salience than others like temperature (Vedwan & Rhoades, 2001).

Despite these problems, it is suggested that rural people in developing countries have at least two distinct recollection advantages. Firstly, as Gill (1993) points out, literate people are able to record information by writing and research information by reading and as a consequence their memories tend to atrophy. Illiterate respondents must remember information that they use and therefore tend to have an impressive ability to recall conditions and phenomena. Secondly, as Chambers (1983) explains, rural people in developing countries commonly use a wider range of senses and indicators to assess and describe things than those used by scientists. As a result, these people can more finely delineate conditions and phenomena than, for example, an automatic weather station could. While these advantages do not eliminate the uncertainties explained above, they do go some way to freeing the results from unreasonable doubt.

Finally, surveys conducted in developing countries are often criticised as unreliable. Chambers (1983, p.53-54) in his section on ‘survey slavery’ describes situations where

> “Exhausted researchers ... stare at print-outs and tables. Under pressure for ‘findings’, they take figures as facts. They have neither time nor inclination to reflect that these are aggregates of what has emerged from fallible programming of fallible punching of fallible coding of responses which are what investigators wrote down as their interpretation of their instructions as to how they were to write down what they believed respondents said to them, which was only what respondents were prepared to say to them in reply to the investigators’ rendering of their understanding of a question and the respondent’s understanding of the way they asked it; always assuming that an interview took place at all and that the answers were not more congenially compiled under a tree or in a teashop or bar, without the tiresome complication of a respondent”.

While I, along with my interpreters, spent plenty of time in teashops and bars, I assure the reader household surveys were not the topic of conversation. All reasonable efforts were made to ensure accuracy of recording and consistency of understanding throughout the survey procedure. The likelihood of differing interpretation of questions and contrived or incomplete responses during the field work is, however, acknowledged. I concede that the data produced are fallible and exist only as interpretations of reality.

Notwithstanding these uncertainties, the data generated are as credible as was feasible. As explained in Chapter Five, the methods employed in data collection and analysis are justifiable with respect to current methodological theory under the scope and limitations of this project. Caution was taken to discuss these results within their limitations; therefore the findings of this thesis are presented with confidence.

7.8 Wider Implications

This research, by its nature, is case specific. The two main foci of the investigation, namely hydro-climatological conditions and community adaptive capacity, are highly idiosyncratic. The specific projections for hydrological change and the analysis of adaptive capacities should not, therefore, be applied outside the two study sites. In the colourful words of Bandyopadhyay and Gyawali (1994, p.14), extrapolation of hydrological findings within the Himalayan region would be a “gigantic reductionist folly”.

Rather than elucidating a rule, this investigation presents an *example* of water stress vulnerability under climate change. Moreover, this example is a sector specific one, as it only considers a narrow range of variables and does not account for changes influenced by forces like globalisation or population growth. The specific findings of this investigation can inform other investigations as to the possibility of similar circumstances, but care must be taken to acknowledge the case-specific circumstances of this study.

On a general level this investigation shows that viewing water stress under climate change using Malthus’s causality is inappropriate in Panglin and Tallo Lorpa. Given the extent to which adaptive capacity dominates hazard in this instance, there is reason to suspect that this finding has broader applicability. While further research is needed to gauge this broader applicability, this investigation alone shows that the use of Malthusian environmental determinism to explain the impacts of climate change on people is likely to be inaccurate. A more accurate, and indeed a more positive interpretation places adaptive capacity, and more specifically the constraints on its realisation, as the determining factors. Future studies and interventions would benefit from being cognizant of this alternative causality and considering it when deciding where to focus their efforts.

7.9 Summary

This discussion answered the two research questions set out in Chapter One. The first question was:

1) How vulnerable are the communities of Panglin and Tallo Lorpa to water stress caused by climate change *ceteris paribus*?

Careful analysis of the results showed that while wealthy households in both study communities were most sensitive to changes in water availability, it is the livelihoods of poorer people which are most in jeopardy from these changes. Agriculture is the most important livelihood activity in both communities and also the sector most vulnerable to hydrological change. In the absence of adaptation, expected decreases in pre-monsoon water availability suggest biophysical vulnerability in both communities. This vulnerability is greater in Tallo Lorpa than in Panglin because decreasing water availability is expected during a period of high crop water demand. Both communities are particularly vulnerable to delays in the arrival of monsoon rains which have been seen to occur in other areas of Nepal.

Biophysical vulnerability is seen to derive from three fundamental constraints. In Panglin, an absolute lack of available surface water may contribute to water shortages in the future. While surplus water is available in Tallo Lorpa, an inability to use this resource effectively contributes to biophysical vulnerability in this community. A lack of arable land also limits productivity in Tallo Lorpa.

With biophysical vulnerability to hydrological change identified in both communities, the analysis then introduced changes in social vulnerability through adaptation. The second research question was:

2) Will water shortage under climate change constrain population in Panglin and/or Tallo Lorpa or does this depend on adaptation?

It is clear that both communities have many substantial opportunities to adapt to changes in water availability. Agricultural adjustments, technological developments and livelihood diversification are immediate, accessible and internally achievable adaptation opportunities. Value chain development, PES and REDD are further opportunities external to the communities themselves, but poised to bring substantive adaptation benefits.

Taken together, the adaptation opportunities available in Panglin and Tallo Lorpa appear to vastly outweigh changes in water availability under climate change. In terms of causality, therefore, it is the effective realisation of adaptive capacity that determines sustainable livelihood capacity in Panglin and Tallo Lorpa. A number of constraints, however, impede the realisation of adaptive capacity in each community.

The three main constraints to adaptation identified in this investigation were the beliefs and awareness of community members; inadequacy in the institutional context; and poverty. These constraints appear considerable relative to the opportunities they apply to. It is possible that these constraints will negate the potential increases in sustainable livelihood capacity afforded by adaptation opportunities. While we can reject Malthus's causality, therefore, there is no guarantee that the implications of his argument will not eventuate. It remains possible that sustainable livelihood capacities will diminish in Panglin and Tallo Lorpa as changes in water availability under climate change proceed. This would not occur because of narrowing environmental limits on population in the areas, as Malthus would suggest. Rather, it would result from an inability of the communities in question to make use of the adaptation opportunities available to them. Whether the communities of Panglin and Tallo Lorpa flourish or falter, therefore, depends on the development of environmental understanding, the strengthening of the institutions that surround them and the relief of the poverty constraining them.

Chapter Eight

Conclusion

8.1 Thesis Objectives

This thesis approached water stress vulnerability using the framework of definitions proposed by Brooks (2003). Hazard was taken as the potential for water shortage under climate change and was assessed in Chapter Three to form projections for water resource changes in Panglin and Tallo Lorpa. Social vulnerability was investigated in both study communities using mixed qualitative and quantitative techniques and informed by a review of the literature on social vulnerability and adaptive capacity. The influence of hazard on biophysical vulnerability with social vulnerability held static was assessed in the first half of Chapter Seven to answer the first research question:

1) How vulnerable are the communities of Panglin and Tallo Lorpa to water stress caused by climate change *ceteris paribus*?

The second half of Chapter Seven allowed for decreases in social vulnerability through adaptation, introducing social vulnerability as a second independent variable. This allowed for comparison of increasing hazard under climate change against diminishing social vulnerability through adaptation and development. The second research question therefore asked:

2) Will water shortage under climate change constrain population in Panglin and/or Tallo Lorpa or does this depend on adaptation?

Finally, factors constraining the realisation of adaptive capacity in Panglin and Tallo Lorpa were explored.

8.2 Summary of Main Findings

Changes in water availability were identified as a hazard in both Panglin and Tallo Lorpa. Water resource availability is expected to increase during the monsoon and decrease during the pre-monsoon in both communities. The direction of change in the post-monsoon depends on the contest between increased groundwater discharge following the wetter monsoon and increased evapotranspiration under warmer temperatures. The direction of change over winter months depends on the contest between decreasing precipitation and increasing rainfall proportions and snowmelt rates under warmer temperatures.

Social scientific analysis revealed intra-community inequality and agricultural seasonality as pressure points of social vulnerability in Panglin and Tallo Lorpa. While wealthy households in both communities are most sensitive to changes in water availability, poorer households, due to their limited capacities, are most vulnerable to them. Agriculture is the most important livelihood sector in both communities and is vulnerable to changes in water availability, particularly on a seasonal basis.

In response to the first research question, both communities in their current state of social vulnerability show biophysical vulnerability to water stress caused by climate change. This current biophysical vulnerability is greater in Tallo Lorpa than in Panglin because anticipated decreases in seasonal water availability coincide with periods of high crop water demand in this community. Both communities are highly vulnerable to delays in monsoon rainfall. Biophysical vulnerability was seen to stem from an absolute lack of available surface water in Panglin while stemming from incomplete use of available water and a lack of arable land in Tallo Lorpa.

Whether biophysical vulnerability caused by water shortage constrains population in the future depends on the ability of the people of Panglin and Tallo Lorpa to adapt. In both communities, potential reductions in social vulnerability through adaptation clearly outweigh increasing hazard under climate change. Opportunities immediately available to, and internally achievable for, both communities include agricultural adjustments, technological developments and livelihood diversification. Opportunities external to these communities but offering substantive benefits include value chain development, PES and REDD. The potential of each of these opportunities is substantial and their aggregate potential outweighs the negative effects of expected changes in water availability. In response to the second research question therefore, water shortage under climate change will *not* constrain population in either community; rather, the implementation of adaptation opportunities is the determining factor.

Realisation of the opportunities available in Panglin and Tallo Lorpa is, however, inhibited in a number of ways. Beliefs about what changes to expect, the origins and importance of these changes and how best to respond, greatly impede the realisation of opportunities, particularly in Panglin. Weak and ill-targeted institutional support coupled with persistent poverty place adaptation opportunities beyond the reach of many households in both communities. These constraints limit the opportunities available in both communities and are likely to determine real-world outcomes for sustainable livelihood capacities. Therefore neither changes in water availability under climate change nor opportunities for adaptation determine sustainable livelihood capacities in the two study communities. Rather, it is the communities’ ability to realise and appropriate benefits from the opportunities that exist. This ability fundamentally relies on the understanding and communication of hazards; the strengthening and proper targeting of institutional support; and the reduction of poverty in these communities.

These findings suggest that the Malthusian terms often used to describe the human effects of climate change in the Himalayas are spurious. Scholarship referring to the integration of physical and social climate change impacts must proceed with more caution. This integration often exists as either an important justification or finding of research and care should be taken to ensure the causal connection is the right way around.

Rather than negating the importance of research into, and work to address, the human impacts of climate change, these findings emphasise the need for such effort. Improvements in understanding, knowledge and support are in fact the defining factor in the equation. Fatalist Malthusian views in which communities like Panglin and Tallo Lorpa are at the mercy of climate change are misplaced. Climate change introduces a hazard but it is the social infrastructure of these communities that will determine their futures. It is the responsibility of the members of these communities, the researchers investigating them and the institutions with which they interact to ensure that this future is a propitious one.

8.3 Need for Further Research

The findings of this investigation point to a number of areas where further research is needed. To advance this enquiry in Panglin and Tallo Lorpa, the next logical step would be to investigate the magnitude of adaptation opportunities against adaptation constraints. This would require in-depth anthropological research into community beliefs, awareness and attitudes to change, coupled with a comprehensive assessment of the institutional context within which these communities exist and careful economic modelling of development.

The interdisciplinary framework built on definitions of hazard, social vulnerability and biophysical vulnerability produced interesting and useful insights in this case. As Sullivan and Meigh (2005) point out however, the costs of producing these assessments need to be weighed against the cost of implementing development and adaptation programmes in their absence. Cost makes it infeasible to repeat such an investigation in every vulnerable community, and yet the idiosyncratic nature of environmental, social, cultural and economic conditions in each community limits the wider applicability of singular studies. Effort should therefore be put into refining and streamlining this method of assessment and understanding the diversity of outcomes by applying this framework to a wide range of communities.

It would be particularly interesting to see whether this framework could provide more quantitative comparisons of hazard, social vulnerabilities and adaptation constraints in regions with more comprehensive and reliable hydrological projections and social data. Were these parameters able to be quantitatively estimated, the framework would provide a means for systematic vulnerability assessment. This could improve prioritisation of climate change adaptation support.

References

Agarwal, B. (1997). "Bargaining" and Gender Relations: Within and Beyond the Household. *Feminist Economics, 3*(1), 1-51.

Agrawal, A. (2008). Role of Local Institutions in Adaptation to Climate Change: *Social Dimensions of Climate Change*. Washington DC: World Bank.

Agrawala, S., Raksakulthai, V., Aalst, M. v., Larsen, P., Smith, J., and Reynolds, J. (2003). Development and Climate Change in Nepal: Focus on Water Resources and Hydropower. Paris: Organisation for Economic Co-operation and Development.

Alkire, S., and Foster, J. (2011). Counting and multidimensional poverty measurement. *Journal of Public Economics, 95*(7–8), 476-487.

Andermann, C., Longevergne, L., Bonnet, S., Crave, A., Davy, P., and Gloaguen, R. (2012). Impact of transient groundwater storage on the discharge of Himalayan rivers. *Nature Geoscience, 5,* 127-132.

Anders, A. M., Roe, G. H., Hallet, B., Montgomery, D. R., Finnegan, N. J., and Putkonen, J. (2006). Spatial patterns of precipitation and topography in the Himalaya. In S. D. Willett, N. Houvis, M. T. Brandon & D. M. Fisher (Eds.), *Tectonics, Climate and Landscape Evolution*. U.S.A: The Geographical Society of America, pp. 39-55.

Andréasson, J., Bergström, S., Carlsson, B., Graham, L. P., and Lindström, G. (2004). Hydrological Change - Climate Change Impact Simulations for Sweden. *AMBIO: A Journal of the Human Environment, 33*, 228-234.

Anonymous. (2011). Seeing REDD. *Nature, 472*(7344), 390-390.

APN. (2003). Global climate change impact assessment for Himalayan mountain regions: Resource management and sustainable development, Final Report. Kathmandu: Asia Pacific Network for Global Change Research (APN).

Arnell, N. W. (1999). Climate change and global water resources. *Global Environmental Change, 9, Supplement 1*(0), S31-S49.

Arnell, N. W. (2003). Effects of IPCC SRES emissions scenarios on river runoff: a global perspective. *Hydrology and Earth System Sciences, 7,* 619-641.

Associated Press. (2013). UN chief warns that nearly half the world could face a scarcity of water by 2030, *The Washington Post*. Retrieved from: http://www.washingtonpost.com/world/un-chief-warns-that-nearly-half-the-world-could-face-a-scarcity-of-water-by-2030/2013/03/22/1e4aee1a-933a-11e2-8e33-9cc6c739d012_story.html.

Atkinson, A. B. (2003). Multidimensional Deprivation: Contrasting Social Welfare and Counting Approaches. *The Journal of Economic Inequality, 1*(1), 51-65.

Babbie, E. R. (2010). *The practice of social research*. Belmont, Calif: Wadsworth Cengage.

Badola, R., Hussain, S. A., Mishra, B. K., Konthoujam, B., Thapliyal, S., and Dhakate, P. M. (2010). An assessment of ecosystem services of Corbett Tiger Reserve, India. *The Environmentalist, 30*(4), 320-329.

Bandyopadhyay, J., and Gyawali, D. (1994). Himalayan Water Resources: Ecological and Political Aspects of Management. *Mountain Research and Development, 14*(1), 1-24.

Banjade, M., and Timsina, N. (2005). Impact of Armed Conflict in Community Forestry of Nepal, *ETFRN News*, pp. 43-44.

Barnett, T. P., Adams, J. C., and Lettenmaier, D. P. (2005). Potential impacts of a warming climate on water availability in snow-dominated regions. . *Nature, 438*, 303-310.

Bates, B. C., Kundzewicz, Z. W., Wu, S., and Palutikof, J. P. (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat (pp. 201 pp.). Geneva.

Beniston, M. (2003). Climatic Change in Mountain Regions: A Review of Possible Impacts. *Climatic Change, 59*(1), 5-31.

Beven, K. J. (2000). *Rainfall Runoff Modelling: The Primer*. Chichester: Wiley.

Bhattacharyya, K., Azizi, P. M., Shobair, S. S., and Mohsini, M. Y. (2004). Drought impacts and potential for their mitigation in southern and western Afghanistan (Working Paper 91). Colombo: International Water Management Institute.

Boe, J., Terray, L., Martin, E., and Habets, F. (2009). Projected changes in components of the hydrological cycle in French river basins during the 21st century. *Water Resources Research, 45*(8)35-49.

BÖHner, J., and Lehmkuhl, F. (2005). Environmental change modelling for Central and High Asia: Pleistocene, present and future scenarios. *Boreas, 34*(2), 220-231.

Bookhagen, B. (2012). Himalayan Groundwater. *Nature Geoscience, 5*, 97-98.

Booysen, F. (2002). An Overview and Evaluation of Composite Indices of Development. *Social Indicators Research, 59*(2), 115-151.

Boserup, E. (1965). *The conditions of agricultural growth: the economics of agrarian change under population pressure*. Chicago: Aldine.

Bradley, R. S., Diaz, H. F., Eischeid, J. K., Jones, P. D., Kelly, P. M., and Goodess, C. M. (1987). Precipitation Fluctuations over Northern Hemisphere Land Areas since the Mid-19th Century. *Science, 237*(4811), 171-175.

Brooks, N. (2003). Vulnerability, risk and adaptation: A conceptual framework. University of East Anglia: Tyndall Centre for Climate Change Research.

Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative Research, 6*(1), 97-113.

Butts, M. B., Payne, J. T., Kristensen, M., and Madsen, H. (2004). An evaluation of the impact of model structure on hydrological modelling uncertainty for streamflow simulation. *Journal of Hydrology, 298*, 242-266.

CBS (2003). District Level Indicators of Nepal for Monitoring Overall Development. Kathmandu, Nepal: His Majesty's Government National Planning Commission Secretariat.

Chalise, S. R., and Khanal, N. R. (2001). An introduction to climate, hydrology and landslide hazards in the Hindu Kush-Himalayan region. In L. Tianchi, S. R. Chalise & B. N. Upreti (Eds.), *Landslide hazard mitigation in the Hindu Kush-Himalayas.* (pp. 51-62). Kathmandu: ICIMOD.

Chambers, R. (1983). *Rural development: putting the last first*. New York: Longman.

Chambers, R., and Conway, G. (1992). sustainable rural livelihoods: practical concepts for the 21st century *IDS Discussion Paper 269*. Brighton: IDS.

Chen, T. C., and Weng, S. P. (1999). Interannual and interseasonal variations in monsoon depressions and their westward-propagating predecessors. *Monthly Weather Review, 127*, 1005-1020.

Clark, M. P., Hreinsson, E. O., Mattinez, G., Tait, A., Slater, A., Hendrix, I., and Woods, R. (2009). Simulations of seasonal snow for the South Island, New Zealand. *Journal of Hydrology (NZ), 48*, 41-58.

Dai, A., Fung, I. Y., and Del Genio, A. D. (1997). Surface Observed Global Land Precipitation Variations during 1900–88. *Journal of Climate, 10*(11), 2943-2962.

Dai, A., Trenberth, K. E., and GQian, T. T. (2004). A global dataset for Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. *Journal of Hydrometeorology, 5,* 1117-1130.

Davies, H., and Prudhomme, C. (2009). Assessing uncertainties in climate change impact analyses on the river flow regimes in the UK. Part 1: Baseline climate. *Climatic Change, 93*, 177-195.

Dekens, J., and Eriksson, M. (2009). Adapting to Climate-induced Water Stress and Hazards in the Hindu Kush-Himalayas *Water Storage - A strategy for climate change adaptation in the Himalayas*. Kathmandu: International Centre for Integrated Mountain Development (ICIMOD).

Devkota, L. P. (2010). Developing Daily Climate Scenarios for Environmental Impact Studies at Jumla and Mustang, Nepal. *High Mountain Agribusiness and Livelihood Improvement (HIMALI) Project Preparation Technical Assistance (PPTA) 7298 - NEPAL*. Kathmandu: ICIMOD.

DFID. (1999). Sustainable livelihoods guidance sheets. Retrieved 10/1/2013, from www.eldis.org/vfile/upload/1/document/0901/section1.pdf

Diener, E., and Suh, E. (1997). Measuring quality of life: economic, social, and subjective indicators. *Social Indicators Research, 40*(1), 189-216.

Dixit, A., Upadhya, M., Dixit, K., Pokhrel, A., and Rai, D. R. (2009). Living with Water Stress in the Hills of the Koshi Basin, Nepal. Kathmandu: ICIMOD.

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford: Oxford University Press.

Eriksson, M., Fang, J., and Dekens, J. (2008). How does climate change affect human health in the Hindu Kush-Himalaya region? *Regional Health Forum, 12*(1), 10-15.

Eriksson, M., Jianchu, X., Shrestha, A. B., Vaidya, R. A., Nepal, S., and Sandstorm, K. (2009). The Changing Himalayas: Impact of Climate Change on Water Resources and Livelihoods in the Greater Himalayas. Kathmandu: ICIMOD.

Frank, R. H., and Bernanke, B. S. (2007). *Principles of Economics* (Third Edition). New York, USA: McGraw-Hill.

Garg, A., Shukla, P. R., and Kapshe, M. (2007). From climate change impacts to adaptation: A development perspective for India. *Natural Resources Forum, 31*(2), 132-141.

Georgievskii, V. Y., Ezhov, A. V., Shalygin, A. L., Shiklomanov, A. I., and Shiklomanov, A. L. (1996). Assessment of the Effect of Possible Climate Changes on Hydrological Regime and Water Resources of the Rivers in the Former USSR. *Russian Meteorology and Hydrology, 11*, 67-74.

Gill, G. J. (1993). O.K., the Data's Lousy, But It's All We've Got (Being a Critique of Conventional Methods) *Gatekeeper Series*. London: International Institute for Environment and Development (IIED).

Gill, G. J. (2003). Seasonal Labour Migration in Rural Nepal: A Preliminary Overview. In *ODI Livelihood Options study* (Working Paper 218). London, UK: Overseas Development Institute.

Giorgi, F., Hurrell, J. W., Marinucci, M. R., and Beniston, M. (1997). Elevation dependency of the surface climate change signal: A model study. *Journal of Climate, 10*, 288-296.

Gosain, A. K., Shrestha, A. B., and Rao, S. (2010). Modelling climate change impacts on the hydrology of the Eastern Himalayas *Climate change impact and vulnerability in the Eastern Himalayas - Technical report 4*. Kathmandu: ICIMOD.

Groisman, P. Y., Knight, R. W., Karl, T. R., Easterling, D. R., Sun, B., and Lawrimore, J. H. (2004). Contemporary Changes of the Hydrological Cycle over the Contiguous United States: Trends Derived from In Situ Observations. *Journal of Hydrometeorology, 5*(1), 64-85.

Gurung, D. R., Amarnath, G., Khun, S. A., Shrestha, B., and Kulkarni, A. V. (2011). Snow-cover mapping and monitoring in the Hindu Kush-Himalayas. Kathmandu: ICIMOD.

Hay, I. (2000). *Qualitative Research Methods in Human Geography*. Oxford: Oxford University Press.

Hoermann, B., Banerjee, S., and Kollmair, M. (2010a). Labour migration for development in the Western Hindu Kush-Himalayas: Understanding a livelihood strategy in the context of socioeconomic and environmental change. Kathmandu, Nepal: ICIMOD.

Hoermann, B., Choudhary, D., Choudhary, D., and Kollmair, M. (2010b). Integrated Value Chain Development as a Tool for Poverty Alleviation in Rural Mountain Areas. Kathmandu: International Centre for Integrated Mountain Development.

Huddleston, B., Ataman, E., and d'Ostiani, L. F. (2003). Towards a GIS-based analysis of mountain environments and populations *Environment and Natural Resources Working Paper* (No. 10). Rome, Italy.

Hunzai, K., Gerlitz, J., and Hoermann, B. (2011). Understanding mountain poverty in the Hindu Kush-Himalayas: Regional report for Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. Kathmandu: ICIMOD.

ICIMOD. (2012). Highland Mountain Agribusiness and Livelihood Improvement: Final Report. Kathmandu: ICIMOD.

Immerzeel, W., van Beek, L., and Bierkens, M., (2010). Climate Change Will Affect the Asian Water Towers. *Science, 328*(5984), 1382-1385.

Immerzeel, W., van Beek, L., Konz, M., Shrestha, A., and Bierkens, M. (2012). Hydrological response to climate change in a glacierized catchment in the Himalayas. *Climatic Change, 110*(3), 721-736.

Immerzeel, W. W., Droogers, P., de Jong, S. M., and Bierkens, M. F. P. (2009). Large-scale monitoring of snow cover and runoff simulation in Himalayan river basins using remote sensing. *Remote Sensing of Environment*, *113*(1), 40-49.

IPCC. (2007a). Climate Change 2007: The Physical Scientific Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In S. Solomon, D. Quin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller (Eds.). Cambridge and New York: Intergovernmental Panel on Climate Change.

IPCC. (2007b). Climate Change 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P. J. v. d. Linden & C. E. Hanson (Eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Jianchu, X., Shrestha, A., Vaidya, R., Eriksson, M., and Hewitt, K. (2007). The Melting Himalayas: Regional Challenges and Local Impacts of Climate Change on Mountain Ecosystems and Livelihoods. Kathmandu: ICIMOD.

Jing, F., and Leduc, B. (2010). Potential threats from climate change to human wellbeing in the Eastern Himalayan region *Climate change impact and vulnerability in the Eastern Himalayas*. Kathmandu: ICIMOD.

Karky, B. S., and Joshi, L. (2009). Payment for environmental services: An approach to enhancing water storage capacity. (Newsletter 56: 31-33). Kathmandu: ICIMOD.

Kaser, G., Großhauser, M., and Marzeion, B. (2010). Contribution potential of glaciers to water availability in different climate regimes. *Proceedings of the National Academy of Sciences*, *107*(47), 20223-20227.

Kehrwald, N. M., Thompson, L. G., Tandong, Y., Mosley-Thompson, E., Schotterer, U., Alfimov, V., and Davis, M. E. (2008). Mass loss on Himalayan glacier endangers water resources. *Geophysical Research Letters, 35*(22), 22503-22505.

Keller, A., Sakthivadivel, R., and Seckler, D. (2000). Water Scarcity and the Role of Storage in Development. Colombo, Sri Lanka: International Water Management Institute.

Khalid, M. A., and Kaushik, G. (2008). *Food security in mountains: Challenges and sustainable strategies*. Kathmandu: ICIMOD.

Khanal, U., Thapa, K., Thapa, K. B., and Limbu, J. (2011). Assess pilot communities perception of climate change in Mustang District for operationalizing Climate Change Adaptation (CCA) Oriented Participatory Action Research (PAR) for High Mountain Agribusiness and Livelihood Improvement (HIMALI). Annual technical report submitted to ICIMOD. Pokhara, Nepal: Local Initiatives for Biodiversity, Research and Development (LI-BIRD).

Kingston, D. G., and Taylor, R. G. (2010). Sources of uncertainty in climate change impacts on river discharge and groundwater in a headwater catchment of the Upper Nile Basin, Uganda. *Hydrological Earth System Sciences, 14*(7), 1297-1308.

Klatzel, F., and Murray, A. B. (2009). Local Responses to Too Much and Too Little Water in the Greater Himalayan Region. Kathmandu, Nepal: ICIMOD.

Konz, M., Uhlenbrook, S., Braun, L., Shrestha, A., and Demuth, S. (2007). Implementation of a process-based catchment model in a poorly gauged, highly glacierized Himalayan headwater. *Hydrology and Earth System Sciences, 11*(4), 1323-1339.

Kronenberg, J., and Hubacek, K. (2013). Could Payments for Ecosystem Services Create an "Ecosystem Service Curse"? *Ecology and Society, 18*(1).

Kumar, M. D. (2005). Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: analysis from Western India. *Energy Policy, 33*(1), 39-51.

Kumar, D. M., and Singh, O. P. (2005). Virtual Water in Global Food and Water Policy making: Is There a Need for Rethinking? *Water Resources Management, 19*, 759-798.

Lama, A. K. (2010). *Vulnerability of Nature Based Tourism to Climate Change: Stakeholders' Perceptions of and Responses to Climate Change in the Lower Mustang Region of the Annapurna Conservation Area.* Master of Parks, Recreation and Tourism Management, Lincon University.

Lang, T. J., and Barros, A. P. (2002). An Investigation of the Onsets of the 1999 and 2000 Monsoons in Central Nepal. *Monthly Weather Review, 130*(5), 1299-1316.

Macchi, M. (2010a). Rural Livelihoods and Adaptation to Climate Change in the Himalayas. Kathmandu: ICIMOD.

Macchi, M. (2010b). Mountains of the World - Ecosystem Services in a Time of Global Climate Change. Kathmandu, Nepal: ICIMOD.

Macchi, M. (2011). Framework for community-based climate vulnerability and capacity assessment in mountain areas. Kathmandu: ICIMOD.

Maharana, I., Rai, S. C., and Sharma, E. (2000). Environmental economics of the Khangchendzonga National Park in the Sikkim Himalaya, India. *GeoJournal, 50*(4), 329-337.

Malthus, T. R. (1798). *An Essay on the Principle of Population as it affects the Future Improvement of Society*. London: J. Johnson.

Matsuo, K., and Heki, K. (2010). Time-variable ice loss in Asian high mountains from satellite gravimetry. *Earth and Planetary Science Letters, 290*(1–2), 30-36.

Mavi, H. S., and Tupper, G. J. (2004). *Agrometeorology: principles and applications of climate studies in agriculture*. New York: Food Products Press.

MEA. (2005). Ecosystems and Human Wellbeing: a Framework for Assessment. Washington DC, USA: Millennium Ecosystem Assessment.

Meehl, G. A. (1994). Coupled land-ocean-atmosphere process and South Asian monsoon variability. *Science, 226*, 263-266.

Merz, J., Nakarmi, G., Shrestha, S., Shrestha, B., AShah, P. B., and Weingartner, R. (2002). Water Demand and Supply Survey. Kathmandu: ICIMOD.

Messerli, B., Viviroli, D., and Weingartner, R. (2004). Mountains of the World: Vulnerable Water Towers for the 21st Century. *Ambio, Spec No 13*(6), 29-34.

Mills, E. (2007). Synergisms between climate change mitigation and adaptation: an insurance perspective. *Mitigation and Adaptation Strategies for Global Change*, *12*(5), 809-842.

Mortimore, M. (1989). *Adapting to drought: farmers, famines, and desertification in West Africa*. Cambridge: Cambridge University Press.

Moser, C., and Felton, A. (2007). The Construction of an Asset Index Measuring Asset Accumulation in Ecuador *CPRC* (Vol. Working Paper 87). Washington DC: The Brookings Institution.

NASA. (2002). Visible Earth: a catalogue of NASA images and animations of our home planet Retrieved 4/4/2013, from http://visibleearth.nasa.gov/view.php?id=63013

NCVST. (2009). Vulnerability through the Eyes of Vulnerable: Climate Change Induced Uncertainties and Nepal's Development Predicaments. Kathmandu: Institute for Social and Environmental Transition-Nepal (ISET-N).

Nemani, R. R., Keeling, C. D., Hashimoto, H., Jolly, W. M., Piper, S. C., Tucker, C. J., and Running, S. W. (2003). Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999. *Science, 300*(5625), 1560-1563.

Nepal, G., Devkota, D. C., and Bhattarai, T. N. (2012). Mountain environment and climate change in Nepal *Country Report for the International Conference of Mountain Countries and Climate Change*. Kathmandu: Government of Nepal Ministry of Environment.

Nirmal, B. K., Shreshta, R., Acharya, S., and Ansari, A. (2009). Maoist conflict, Community Forestry and Livelihoods: Pro-poor Innovations in Forest Management in Nepal. Forest Action Discussion Paper. Kathmandu : Forestry Nepal.

Pandey, V. P., Manandhar, S., and Kazama, F. (2012). Water Poverty Situation of Medium-sized River Basins in Nepal. *Water Resources Management*, *26*(9), 2475-2489.

Pappenberger, F., Beven, K. J., Hunter, N. M., Bates, D. P., Gouweleeuw, B. T., Thielen, L., and Deroo, A. P. J. (2005). Cascading model uncertainty from medium range weather forecasts (10 days) through a rainfall runoff model to flood inundation predications within the European Flood Forecasting System (EFFS). *Hydrology and Earth System Sciences, 9*, 381-393.

Petherick, A. (2011). Refreshing REDD. *Nature Climate Change, 1*(9), 440-441.

Rasul, G., Chettri, N., and Sharma, E. (2011). Framework for valuing ecosystem services in the Himalayas. Kathmandu, Nepal: ICIMOD.

Rasul, G., and Karki, M. (2007). A Pro-poor Policy Agenda for Sustainable Agricultural Development in the Hindu Kush-Himalayan Region. Kathmandu, Nepal: ICIMOD.

Rees, G. H., and Collins, D. N. (2004). An Assessment of the Impacts of Deglaciation on the Water Resources of the Himalaya *Snow and Glacier Aspects of Water Resources management in the Himalayas*. Wallingford: Centre for Ecology and Hydrology.

Rees, H. G., and Collins, D. N. (2006). Regional differences in response of flow in glacier-fed Himalayan rivers to climatic warming. *Hydrological Processes, 20*(10), 2157-2169.

Renoj, J., Thayyen, J. T., and Dobhai, D. P. (2007). Role of glaciers and snow cover on headwater river hydrology in monsoon regime – Micro-scale study of Din Gad catchment, Garhwal Himalaya, India. *Current Science, 92*(3), 376-382.

Richards, P. (1985). *Indigenous agricultural revolution: ecology and food production in West Africa*. London: Hutchinson Education.

Richards, P. (1986). *Coping with hunger: hazard and experiment in an African rice-farming system* (Vol. 11). Boston: Allen & Unwin.

Rietbergen-McCracken, J., and Narayan-Parker, D. (1998). *Participation and Social Assessment: Tools and Techniques*. Washington, D.C.: International Bank for Reconstruction and Development/World Bank.

Sachs, J. D., and Warner, A. M. (1997). Natural Resource Abundance and Economic Growth. Harvard University, Cambridge MA: Centre for International Development and Harvard Institute for International Development.

Sahn, D., and Stifel, D. (2003). Exploring Alternative Measures of Welfare in the Absence of Expenditure Data. *Review of Income and Wealth, 49*(4), 463-489.

Sarantakos, S. (2005). *Social research*. New York: Palgrave Macmillan.

Schild, A. (2008). The Case of the Hindu Kush-Himalayas: ICIMOD's Position on Climate Change and Mountain Systems. *Mountain Research and Development, 28*(3/4), 328.

Scoones, I. (1995). Investigation Difference: Applications of Wealth Ranking and Household Survey Approaches among Farming Households in Southern Zimbabwe. *Development and Change, 26*(1), 67-88.

Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis. *IDS Discussion Paper 72*. Brighton: University of Sussex.

Sen, A. (1993). Capability and Well-Being. In M. C. Nussbaum & A. Sen (Eds.), *The Quality of Life*. Oxford: Oxford University Press.

Shah, A. (2010). Nepal's first climate refugee village in Mustang, *Republica*. Retrieved from http://archives.myrepublica.com/portal/index.php?action=news_details&news_id=19341

Shah, T. (2006). Is India Ripe for Integrated Water Resources Management? Fitting Water Policy to National Development Context. *Economic and Political Weekly, 41*(31), 3413-3421.

Sharma, R. C., and Rawat, J. S. (2009). Monitoring of aquatic macroinvertebrates as bioindicator for assessing the health of wetlands: A case study in the Central Himalayas, India. *Ecological Indicators, 9*(1), 118-128.

Shreshta, L. K. (2003). Global Change Impact Assessment for Himalayan Mountain Region for Environmental Management and Sustainable Development. Lalitpur, Nepal: Asia Pacific Network for Global Change Research.

Shrestha, A. B., and Devkota, L. P. (2010). Climate change in the eastern Himalayas: Observed trends and model projections *Climate change impact and vulnerability in the Eastern Himalayas - Technical report 1*. Kathmandu: ICIMOD.

Shrestha, A. B., Wake, C. P., Dibb, J. E., and Mayewski, P. A. (2000). Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters. *International Journal of Climatology, 20*(3), 317-327.

Shrestha, A. B., Wake, C. P., Mayewski, P. A., and Dibb, J. E. (1999). Maximum Temperature Trends in the Himalaya and Its Vicinity: An Analysis Based on Temperature Records from Nepal for the Period 1971-94. *Journal of Climate, 12*, 2775-2786.

Singh, D. K., and Singh, A. K. (2002). Groundwater Situation in India: Problems and Perspective. *International Journal of Water Resources Development, 18*(4), 563-580.

Singh, P., and Bengtsson, L. (2004). Hydrological sensitivity of a large Himalayan basin to climate change. *Hydrological Processes, 18*(13), 2363-2385.

Singh, S. P., Bassignana-Khadka, I., Karky, B. S., and Sharma, E. (2011). Climate change in the Hindu Kush-Himalayas: The state of current knowledge. Kathmandu: ICIMOD.

Smit, B., and Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, 16*(3), 282-292.

SPCR. (2010). Nepal: Strategic Program for Climate Resilience *Pilot Program for Climate Resilience*. Kathmandu: Ministry of Environment, Government of Nepal.

Stern, N. (2006). The Stern Review on the Economic Effects of Climate Change. *Population and Development Review, 32*(4), 793-798.

Stewart, I. T. (2009). Changes in snowpack and snowmelt runoff for key mountain regions. *Hydrological Processes, 23*, 78-94.

Sthapit, K. M., and Dhakal, M. (2010). Travel Report - Mustang District *High Mountain Agribusiness and Livelihood Improvement Project*. Kathmandu: ICIMOD.

Sthapit, K. M., Dhakal, M., and Pandey, T. (2010). Travel Report - Jumla District *High Mountain Agribusiness and Livelihood Improvement-Project*. Kathmandu: ICIMOD.

Sullivan, C., and Meigh, J. (2005). Targeting attention on local vulnerabilities using an integrated index approach: the example of the climate vulnerability index. *Water Science and Technology, 51*(5), 69-78.

Sullivan, C., and Meigh, J. (2006). Application of the Water Poverty Index at Different Scales: A Cautionary Tale. *Water International, 31*(3), 412-426.

Sullivan, C. A., Meigh, J. R., and Giacomello, A. M. (2003). The Water Poverty Index: Development and application at the community scale. *Natural Resources Forum, 27*(3), 189-199.

Suweis, S., Rinaldo, A., Maritan, A., and D'Odorico, P. (2013). Water-controlled wealth of nations. *Proceedings of the National Academy of Sciences of the United States of America, 110*(11), 4230.

Tamea, S., Allamano, P., Carr, J. A., Claps, P., Laio, F., and Ridolfi, L. (2013). Local and global perspectives on the virtual water trade. *Hydrology and Earth System Sciences, 17*(3), 1205-1215.

Thayyen, R. J., Gergan, J. T., and Dobhal, D. P. (2007). Role of glaciers and snow cover on headwater river hydrology in monsoon regimes - micro scale study of Din Gad catchment, Garhwal Himalaya, India. *Current Science, 92*(3), 367-375.

Todaro, M. P. (1989). *Economic development in the Third World*. New York: Longman.

UNDP. (1996). Human Development Report 1996. Oxford University Press, New York: United Nations development Programme.

UNICEF. (2012). Info By Country: Nepal. Retrieved: 1/3/2012, from http://www.unicef.org/infobycountry/nepal_nepal_background.html

Upreti, B. R. (2004). Dynamics of Resource Governance, Resource Scarcity and Conflict in Nepal. *Journal of Forest and Livelihood, 4*(1), 13-19.

Vaidya, R. A. (2009). Role of Water Storage in Adaptation to Climate Change in the HKH Region *Water Storage - A strategy for climate change adaptation in the Himalayas*. Kathmandu: International Centre for Integrated Mountain Development.

Valdiya, K. S., and Bartarya, S. K. (1989). Diminishing discharges of mountain springs in a part of Kumaun Himalaya. *Current Science, 58*(8), 417-427.

Van Campenhout, B. F. H. (2007). Locally Adapted Poverty Indicators Derived from Participatory Wealth Rankings: A Case of Four Villages in Rural Tanzania. *Journal of African Economies, 16*(3), 406-438.

Vedwan, N., and Rhoades, R. E. (2001). Climate Change in the Western Himalayas of India: a Study of Local Perception and Response. *Climate Research, 19*, 109-117.

Veenhoven, R. (1996). Happy Life-Expectancy: A Comprehensive Measure of Quality-of-Life in Nations. *Social Indicators Research, 39*(1), 1-58.

Ward, R. C. (1975). *Principles of Hydrology*. Maidenhead, England: McGraw-Hill Publishing Company Ltd.

White, S., and Pettit, J. (2004). Participatory Methods and the Measurement of Well-being. *Participatory Learning and Action, 50*, 88-96.

Whiteman, P. T. S. (1985). The Mountain Environment: An Agronomist's Perspective with a Case Study from Jumla, Nepal. *Mountain Research and Development, 5*(2), 151-162.

WHO. (2003). Climate Change and Human Health - Risks and Responses. Summary. Retrieved 28/2/2013, from http://www.who.int/globalchange/summary/en/index.html

World Bank. (2008). Agriculture for Development: World Development Report 2008. Washington DC, USA: World Bank.

Xiaoyun, L., Zhang, C., Zhou, L., Yonggong, L., Remenyi, J., and Sibin, W. (2001). Methodology of County Poverty Alleviation Planning in China. People's Republic of China: Asian Development Bank.

Xu, J., Grumbine, R. E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y. U. N., and Wilkes, A. (2009). The Melting Himalayas: Cascading Effects of Climate Change on Water, Biodiversity, and Livelihoods

Zhang, X., Zwiers, F. W., Hegerl, G. C., Lambert, F. H., Gillett, N. P., Solomon, S., and Nozawa, T. (2007). Detection of human influence in twentieth-century precipitation trends. *Nature, 448*, 461-465.

Appendix One

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

Water Stress Vulnerability in the Himalayas of Nepal

INFORMATION SHEET FOR PARTICIPANTS

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you and we thank you for considering our request.

What is the Aim of the Project?

This project looks to investigate water stress using a combination of physical and social science. Possible changes in mountain water resources with respect to climate change will be assessed through the review of physical scientific papers and reports. The ways in which mountain communities interact with water stress (including contribution to, and management of, water stress) will be assessed using interviews and surveys of mountain communities in the Mid-Himalayas of Nepal. The investigation then aims to compare the communities' capacity to adapt with the likely changes in water resources over the coming decades in order to determine how vulnerable communities are to water stress.

What Type of Participants are being sought?

The study looks to interview members of society with a working knowledge of how water stress interacts with livelihood practices such as agriculture. For this reason the study will focus on heads of households and exclude children and dependants.

What will Participants be Asked to Do?

Should you agree to take part in this project, you will be asked to provide information on economic/livelihood practices which you use to manage periods of too much or too little water. The information sought will include things like the cost of adopting new strategies and the economic benefits of such changes. Efforts will be made to quantify these costs and benefits into rupee amounts; however, as with the rest of the information solicited, this will remain anonymous through the rest of the investigation.

The surveys are expected to take approximately 2 hours to complete however this time may vary in each individual case.

Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind.

What Data or Information will be Collected and What Use will be Made of it?

Information will be gathered using an interpreter to guide participants through a series of questions about how they interact with water stress. The data will then be anonymously aggregated with all other respondents in order to assess interaction with water stress in the community as a whole.

This anonymous, aggregated data will be used by the researchers to draw conclusions about water stress vulnerability in the region. This data will therefore constitute part of the completed thesis and may be included in any subsequent publications. This data will be retained in a secure location for at least 5 years after the thesis is completed.

Transcriptions of each survey will be kept in a secure location until the submission of the research, after which they will be destroyed. It is intended that all information presented in the thesis will remain anonymous. Survey responses will be treated statistically.

Participants will have the opportunity to correct or withdraw information throughout the research period. No personal information relating to the participant will be included in the thesis and the participant will not receive a copy of their completed survey. In light of new information coming to hand, however, the participants will be given details of how to contact the researchers and amend parts of their survey they believe to have changed.

While the results of the study will be anonymous, the small study size makes it possible that these anonymous data could be interpreted and/or associated with individuals who take part in this research. Efforts will be made to avoid presenting data in ways in which it may be interpreted but the participant must be aware there is always some small risk of this.

At the conclusion of the study efforts will be made to present results of the investigation in the form of community meetings in the studied area.

Can Participants Change their Mind and Withdraw from the Project?

You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:-

David Gawith	and/or	*Doug Hill*
Department of Geography		Department of Geography
University of Otago		University of Otago
Email Address: gawith@gmail.com		Email Address: hildo59p@geography.otago.ac.nz

This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research you may contact the Committee through the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.

Appendix Two

Household Survey

Location:		Date:	
Interview Time:		Distance from town centre (m):	

1. Respondent Information

1.1 Respondent's sex

Male		Female	

1.2 How old are you?

Age (years)	

1.3 What is your relationship to the household head?

head (1)	husband, wife (2)	son, daughter (3)	grandchild (4)	father, mother (5)
brother, sister (6)	nephew, niece (7)	son-, daughter-in-law (8)	brother-, sister-in-law (9)	father-, mother-in-law (10)
other family relative (11)	servant, servant's relative (12)	tenant, tenant's relative (13)	co-wife, co-husband (14)	other (15)

2. Household Profile

2.1 How many persons currently **eat and sleep (stay/reside)** in your household?

# of People:	

2.2 Of this number, how many of those are **females and males** of the following age groups: age 5 or younger, age 6 to 14, age 15 to 64, and age 65 and older?

males age 0-15		males age 16-49		males age 50+	
females age 0-15		females age 16-49		females age 50+	

2.3 What is the **religion** of the household head?

Hindu (1)	Muslim (2)	Christian (3)	Buddhist (4)	Other (5)

2.4 - What is the **caste/tribe** of the household head?

Brahman/Chetri (1)	Terrai Middle Caste (2)	Dalits (3)	Newar (4)
Hill Janajaties (5)	Terai Janajatis (6)	Muslim (7)	Other Minorities (8)

Castes/Ethnic Groupings:

1. Brahmin/Chhetri: Brahman, Chhetri, Thakuri, Sanyasi, Kayashta,Rajput,Baniya, Marwadi,Jaine,Nurang,Bengali
2. Terai Middle Castes: Yadav, Teli, Kalwar, Sudi, Sonar, Lohar, Koiri, Kurmi, Kanu, Haluwai,Hajam/Thakur, Badhe, Rajbhar, Kewat Mallah, Numhar, Kahar, Lodha, Bing/Banda,Bhediyar, Mali, Kamar Dhunia
3. Dalits: Kami, Damai, Sarki, Gaine, Badi, Chamar, Musahar, Tatma, Bantar, Dhsadadh/Paswan, Khatway, Dom, Chidimar,Dhobi, Halkhor, Unidentified Dalit
4. Newar: All Newari Castes
5. Janajatis (Hill): Magar, Tamang, Rai, Gurung, Limbu, Sherpa, Bhote, Walung, Buansi, Hyolmo, Gharti/Bhujel, Kumal, Sunuwar, Baramu, Pahari, Adivasi Janajati, Yakkha,Shantal, Jirel, Darai, Dura, Majhi, Dunuwar, Thami, Lepcha, Chepang, Bote, Raji, Hayu, Raute, Kusunda
6. Janajatis (Terai): Tharu, Dhanuk, Rajbanshi, Tajpuriya, Gangai, Dhimal, Meche, Kisan, Munda, Santhal/Satar/Dhangad/Jhangad, Koche, Pattarkatta/Kusbadiya
7. Muslims: Muslim, Churoute
8. Others

2.5 During the last 12 months, what are the 3 most important **staple crops** your household grew?

Staple crops: #1		#2		#3	

Early paddy (1)	Main paddy (2)	Upland paddy (3)	Wheat (4)	Winter/spring maize (5)
Summer maize (6)	Millet (7)	Barley (8)	Buckwheat (9)	Other cereals (10)
Soybean (11)	Grass pea (12)	Horse gram (13)	Pea (14)	Green gram (15)
Coarse gram (16)	Cow pea (17)	Other legumes (18)	Summer potato (19)	Colocasia (20)
Other tubes (21)				

2.6 (a) What quantity of these three important **staple crops** did your household produce over the last 12 months? (b) Have you observed any changes in the productivity of any of these crops (per unit area) over the last 10 years? If so, what is the main reason for this change?

Increasing productivity (+1)	No Change (0)	Decreasing productivity (-1)

Staple crop code	Production in last 12 months	Change in productivity over the last 10 years	Main reason for change

2.7 During the last 12 months, what are the 3 most important **cash crops** your household grew?

Cash crops:	#1		#2		#3	

Mustard (1)	Ground nut (2)	Chillies (3)	Onions (4)	Garlic (5)
Coriander Seed (6)	Other spices (7)	Winter vegetables (8)	Summer vegetables (9)	Pomegranate (10)
Pear (11)	Apple (12)	Plum (13)	Other fruit (14)	
Thatch (15)	Podder trees (16)	Bamboo (small size (17)	Apricot (18)	Walnut (19)
Other trees (20)	Other cash crops (21)			

2.8 (a) What quantity of these three important **cash crops** did your household produce over the last 12 months? (b) Have you observed any changes in the productivity of any of these crops (per unit area) over the last 10 years? If so, what is the main reason for this change?

Increasing productivity (+1)	No Change (0)	Decreasing productivity (-1)

Cash crop code	Production in last 12 months	Change in productivity over the last 10 years	Main reason for change

2.9 Does your household own livestock?

Yes (1)	No (2) Go to question 2.12

2.10 How many of the following animals do your household own?

Cattle(Bullock/Cow/Ox)		Horse/Donkey/Mule	
Buffalo		Pig	
Goat		Poultry/Duck/Pigeon	
Other Livestock		Sheep	

2.11 How did you feed the following animals during the last 12 months? (Read out options)

Livestock	Stall Fed		Grazed in public land		Grazed in irrigated land owned by the household		Grazed in un-irrigated land owned by the household	
	No. of animals	No. of months	No. of animals	No. of months	No. of animals	No. of months	No. of animals	No. of months
Bullock/ Cow/Ox								
Buffalo								
Goat								
Sheep								
Yak/Nak/ Dzo/ Mithun								
Horse/ Donkey/ Mule								

2.12 What is the total yearly income (in NRs.) your household would expect from each of the following sources?

Crop, vegetable, fruit sales		Livestock & livestock product sales	
Herb sales		Forest products sales (firewood/NTFP)	
Paid Employment (in community/area)		Medical & aromatic plant sales	
Tourism (service provision/business)		Other business/trade income	
Rent, interest on loan, or returns from share		Pension	
Remittances		Development aid projects	
Gifts or begging		Governmental social benefit schemes	

3. Indicators of Natural Capital

3.1 - How much land does your household have for agriculture (for crops, grass, trees, etc.)?

Area in Ha.	

3.2 - What area of your household's land fits into the following categories?

Flat		Steep	

Gently Sloping		Terraced	

3.3 - What kind of soil covers the **majority** of your household’s land?

Stony-gravely (1)	Clay (2)	Loamy [mixed clay, sand &/or silt] (3)	Sandy (4)

Wet (5)	Droughty (6)	Mixed, specify (7):	Other, specify (8):	Don’t know (-1)

3.4 During the last 12 months, for how many months was there **not enough** water for your household’s livestock?

# of Months	

3.5 What impact(s) did this water shortage have on your livestock?

Livestock lost weight		Livestock had to be sold	
Livestock died		Milk production declined	
Livestock diseases increased		Livestock became weakened	
Occurred (1)	Did not occur (2)		

4. Indicators of Physical Capital

4.1 Does your household **own** this dwelling?

Yes (1)	No (2)

4.2 If someone wanted to rent this dwelling today, how much money would they have to pay each month?

Amount in NRs.	

4.3 During the last 12 months, which of the following did you use on your farm? If used, was the animal/machine rented or does the household own it?

Ox/Male Buffalo/Horse		Tractor		Harvester	
Power Tiller		Thresher			

Used and owned by the household (1)	Rented/borrowed for use (2)	Not used (3)

4.4 For how many months do your current harvested food stocks last to feed all household members?

Rice stocks		Paddy stocks		Wheat grain stocks	
Wheat flour stocks		Maize stocks		Millet stocks	
Barley stocks		Buck wheat stocks		Potato stocks	

5. Indicators of Economic Capital

5.1 What was your household’s total income from all activities for the last 12 months?

Total income in NRs.	

5.2 During the last 12 months, how many adult **female** and **male** members of your household had **lived and worked in a different town or village within the country** for 0 to 3 months, 4 to 6 months, 7 to 9 months, and 10 months or more?

	# of Female	# of Male
0 to 3 months		
4 to 6 months		
7 to 9 months		
10 months or more		

5.3 What was the total value of remittances, cash and in-kind, that your household has received during the last 12 month **from people within the country**?

Amount in NRs.	

5.4 During the last 12 months, how many adult **female** and **male** members of your household had **lived and worked in a town or village in another country** for 0 to 3 months, 4 to 6 months, 7 to 9 months, and 10 months or more?

	# of Female	# of Male
0 to 3 months		
4 to 6 months		
7 to 9 months		
10 months or more		

5.5 What was the total value of remittances, cash and in-kind, that your household has received during the last 12 month **from people outside the country**?

Amount in NRs.	

6. Indicators of Human Capital

6.1 Is the head of your household literate?

Yes (1)	No (2)

6.2 What is the **highest completed** level of education of the household head?

Class 1-5 (1)	Class 6-8 (2)	Class 9-11 (3)	Class 12/ Intermediate level (4)
Bachelor level (5)	Master level (6)	Professional degree (7)	Don't know (-1)

6.3 How many female and male members of your household age 6 and older can **read and write** a letter?

# of Female		# of Male	

6.4 In the last 12 months, how often has a member of your household been **seriously** ill (meaning they are so ill that they cannot work)?

Never (1)	Once or twice (2)	Once a month (3)	A few times a month (4)
About once a week (5)	A few times a week (6)	Every day (7)	Don't know (-1)

7. Indicators of Social Capital

7.1 Is your household currently in debt?

No (1) Go to question 7.3	Yes, a little (2)	Yes, a moderate amount (3)	Yes, a lot (4)

7.2 To whom is the **majority** of this debt owed? (Once answered, skip to section 8)

1. Relatives	2. Friends	3. Village fund
4. Village government	5. Rural credit cooperative	6. Private money lender
7. Microfinance institution	8. Government bank	9. Private bank
10. Joint village & bank fund	11. Joint development project & bank fund	12. Self-help group
13. Women's group	14. Other community organisations	15. Other, specify:

7.3 If your household wanted to borrow money, whom would you approach **first**?

1. Relatives	2. Friends	3. Village fund
4. Village government	5. Rural credit cooperative	6. Private money lender
7. Microfinance institution	8. Government bank	9. Private bank
10. Joint village & bank fund	11. Joint development project & bank fund	12. Self help group
13. Women's group	14. Other community organisations	15. Other, specify:

7.4 - How easy would it be to borrow money?

Very difficult (1)	Difficult (2)	Neither/nor (3)	Easy (4)	Very easy (5)

8. General Capital Indicators

8.1 During the last 12 months, for how many months was your household **unable** to grow, collect or buy enough fodder to feed your livestock?

# of Months	

8.2 During the last 12 months, for how many months did you **not have enough** food to feed all members of your household?

# of Months	

8.3 During the last 12 months, how often did any member of your household eat **fewer meals**, or **smaller portions**, than usual because there was not enough food?

Never (1) Go to question 8.5	Once or twice (2)	Once a month (3)	A few times a month (4)
About once a week (5)	A few times a week (6)	Every day (7)	Don't know (-1)

8.4 During the past 12 months, did any member of your household ever experience **one full day** with no food to eat?

Never (1)	Once or twice (2)	Approximately once a month (3)
Approximately every two weeks (4)	Approximately every week (5)	Don't know (-1)

8.5 Does your household have an insurance policy that covers the following risks?

Property damage		Crop damage		Livestock death		Damage/loss to business	
Health		Death (Life insurance)		Other, specify:			

Yes (1)	No (2)

9. Water Use Profile

9.1 - How much of the household's land is **irrigated**?

Area in Ropani (500m2)	Area in Ha. Irrigated	(If 0 skip to section 10)

9.2 (a) How much irrigation water do you use to irrigate your crops/gardens in each of the following seasons? (b) - Has this amount changed over the last 10 years?

Increased Slightly (+1)	Increased Substantially (+2)	No (0)
Decreased Slightly (-1)	Decreased Substantially (-2)	Don't know (-6)

Season	# of pots of Irrigation Water	Change
Monsoon		

Post Monsoon		
Winter		
Pre Monsoon		

9.3 What is the main source of your irrigation water?

During the Monsoon		During the post Monsoon	
During the Winter		During the Pre Monsoon	

River (1)	Small Local Stream (2)	Community Well (3)
Private Well (4)	Irrigation Canal (5)	Communal Reservoir (6)
Private Reservoir (7)	Harvested Rainwater (8)	Recycled Household Water (9)
Borehole (10)	Public Standpipe (11)	Piped water (12)
Vendor Provided (13)	Water Tanker (14)	Other, specify:

9.4 Do you have to pay for any of the water you use for irrigation?

Yes (1)	No (2) Skip to section 10

9.5 What percentage of the water you use for irrigation do you have to pay for?

%

9.6 How much on average do you expect to pay for irrigation water each year?

Amount (NRs.)	

9.7 What is the most your household has ever had to pay for irrigation water in a single year?

Amount (NRs.)	

9.8 What year was this?

Year (A.D.)	

10. Water Access and Control Profile

10.1 Does your household have access to as much water as you need free of charge throughout the year?

Yes (1) Skip to question 10.4	No (2)

10.2 If not, what season(s) does your household not have access to enough water free of charge?

Monsoon (1)	Post Monsoon (2)	Winter (3)	Pre Monsoon (4)

10.3 Why does your household not have access to enough free water in this season? Is there not enough water available or is water use is restricted by those in control?

Not Enough Water Available (1)	Use Restricted by Those in Control (2)

10.4 Could everyone have access to enough water free of charge if it were managed or controlled more effectively in your community?

Yes (1)	No (2)

10.5 How much water do you need per day for use in your household?

# of Pots	

10.6 How much water do you need per day for your household's livestock?

# of Pots	

10.7 **Approximately** how much time (in minutes) does it take a member of your household to collect water for your needs for a normal day?

During the Monsoon		During the Post Monsoon	
During the Winter		During the Pre Monsoon	

10.8 On average, for how many months per year is there **not** have enough water to meet your household's needs (e.g. drinking, cooking, and washing)? During which months of the year is this often the case (Mark appropriate month(s))?

# of Months	

Jan	Feb	Mar	Apr	May	Jun
Jul	Aug	Sep	Oct	Nov	Dec

10.9 On average, for how many months per year is there **not** enough water for your household's crops? During which months of the year is this often the case (Mark appropriate month(s))?

# of Months	

Jan	Feb	Mar	Apr	May	Jun
Jul	Aug	Sep	Oct	Nov	Dec

10.10 On average, for how many months per year is there **not** enough water for your household's livestock? During which months of the year is this often the case (Mark appropriate month(s))?

# of Months	

Jan	Feb	Mar	Apr	May	Jun
Jul	Aug	Sep	Oct	Nov	Dec

10.11 How often are there **conflicts** over the **use of water** (for any purpose) in your community?

Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)

10.12 How often are there **conflicts** over the **use of water** (for any purpose) between your community and other communities?

Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)

10.13 Has the amount of water your household has access to for domestic use changed over the last 10-20 years?

Yes (1)	No (2) Skip to section 11

10.14 - In which season and in what way has the amount of water your household has access to for domestic use changed?

Season	Change
Monsoon	
Post Monsoon	
Winter	
Pre Monsoon	

Increased Slightly (+1)	Increased Substantially (+2)
Decreased Slightly (-1)	Decreased Substantially (-2)

10.15 Has the amount of water your household has access to for irrigation changed over the last 10-20 years?

Yes (1)	No (2) Skip to section 11

10.16 - In which season and in what way has the amount of water your household has access to for irrigation changed?

Season	Change
Monsoon	
Post Monsoon	
Winter	
Pre Monsoon	

Increased Slightly (+1)	Increased Substantially (+2)
Decreased Slightly (-1)	Decreased Substantially (-2)

11.Perceived Changes in Water Availability

11.1 During the last 10 years, have you observed any changes in your environment which **have not occurred before**?

Yes (1)	No (2) Skip to question 11.3

11.2 What kind of events have you observed which **had not occurred in your community before**?

Drought		Dry spell		Flood	
Erratic rainfall		Soil problems		Landslide/erosion	
Earthquake		Avalanche		Irrigation problems	
Strong wind		Dust storm		Fire	
High temperatures		Low temperatures		Human disease	
Livestock disease		Insect attack		Crop pests	
Occurrence of new plant species		Occurrence of new animal species (e.g. mosquitoes)			
Other, specify:					

Observed (1)	Not observed (2)

11.3 Overall, would you say that the temperature patterns in your area/community have changed over the **last 10 years**?

Yes (1)	No (2) Skip to question 11.5

11.4 How have the temperature patterns changed in your area/community over the **last 10 years**?

It has significantly warmed		It has slightly warmed		It has significantly cooled	
It has slightly cooled		Hot seasons have become hotter		Hot seasons have become cooler	
Cold seasons have become colder		Cold seasons have become warmer		Frost is more common	
Frost is less common		Heat waves are more frequent		Cold waves are more frequent	
No perceived changes		Other, specify:			

Observed (1)	Not observed (2)

11.5 Overall, would you say that the precipitation patterns in your area/community have changed over the **last 10 years**?

Yes (1)	No (2) Skip to question 11.7

11.6 How have the precipitation patterns changed in your area/community over the **last 10 years**?

Annual amount has increased		Annual amount has decreased		Monsoon precipitation has increased	
Monsoon precipitation has decreased		Winter precipitation has increased		Winter precipitation has decreased	
Timing of precipitation has advanced		Timing of precipitation is delayed		Number of rainy days have increased	
Number of rainy days have decreased		Number of snowfall days have increased		Number of snowfall days have decreased	
Precipitation intensities have increased		Precipitation intensities have decreased		Hail storms are more frequent	
Hail storms are less frequent		More erratic precipitation		No perceived changes	
Other, specify:					

Observed (1)	Not observed (2)

11.7 Overall, would you say that river or stream flow has changed in your area over the **last 10 years**?

Yes (1)	No (2) Skip to question 11.9

11.8 How has river or stream flow changed in your area in the last 10 years?

Annual flow has increased		Annual flow has decreased		Monsoon flow has increased	
Monsoon flow has decreased		Winter flow has increased		Winter flow has decreased	
The timing of peak flow has advanced		The timing of peak flow is delayed		River flow is more erratic	
No perceived changes		Other, specify			

Observed (1)	Not observed (2)

11.9 Because of these changes occurring in your village, has your household done any of the following:

Given up planting certain types of crops		Introduced new crop types and varieties	
Given up rearing certain types of livestock		Introduced new types of livestock	
Changed grazing practices		Changed farming practices (delayed sowing or harvesting, early sowing or harvesting)	
Given up off-farm activities		Taken on new off-farm activities (i.e. wage labour)	
Stopped migrating for work		Migrated for work	
Farmland was left fallow		Abandoned farming	
Household invested in irrigation infrastructure		Community invested in irrigation infrastructure	
Household invested in disaster preparedness		Initiation of community level disaster preparedness programmes	
Have done nothing (Answer question 11.9 (supplement)		Other, specify:	

Done (1)	Not done (2)

11.9 (Supplement) Why did your household not do anything in response to these changes occurring in your community?

Aware, but does not expect a disaster		Expects a disaster, but does not anticipate loss	
Expects loss, but not serious loss		Expects loss, but have accepted as cost of gaining locational benefits	
Have no resources to undertake loss reduction measures		The changes are too erratic in nature to respond	
Other, specify:			

Yes (1)	No (2)

11.10 Are changes in water availability of greater or lesser concern to you than other changes you see in your community (such as new/invasive pests or changes in labour migration)?

Greater concern (1)	Lesser concern (2)

12.Adaptive Capacity Assessment

12.1 Which (if any) of the following strategies has your household used during periods of serious water shortage? If the strategy has been used, is it also used to manage other stresses in periods of sufficient water?

Relied on less preferred/ less expensive food (1)		Received compensation (22)	
Relied on relief assistance (2)		Bought food on credit (23)	
Borrowed money from bank (3)		Borrowed money from moneylender (24)	
Borrowed money from relatives (4)		Borrowed money from friends (25)	

Borrowed money from cooperative/village fund (5)		Begged for money or food (26)	
Spent savings on food (6)		Collected wild food (27)	
Collected and sold firewood/NTFP (7)		Reduced proportions/number of meals (28)	
Slaughtered livestock for food (8)		Sold livestock (29)	
Restricted consumption of adults (9)		Skipped day without eating (30)	
Consumed seed stocks held for next season (10)		Took children out of school to work (31)	
Moved children to a less expensive school (11)		Sent children to school to benefit from incentive (32)	
Sent children to work outside the HH (12)		Non-working HH member started to work (33)	
Sent women and children to live with relatives (13)		HH member sought wage employment in same community (34)	
HH members sought shelter in another place within the same community (displaced) (14)		HH members sought shelter in other communities (displaced) (35)	
Reduced spending on education (15)		HH member sought work elsewhere (migration) (36)	
Reduced spending on clothes (16)		Reduced spending on health (37)	
Sold farmland (17)		Leased out farmland (38)	
Sold agricultural assets (tools, seeds) (18)		Farmland was left fallow (39)	
Changed farming practices (delayed sowing or harvesting, early sowing or harvesting) (19)		Used alternate crop varieties (40)	
Changed grazing practices (20)		Used new variety of the same crop (41)	
Other, specify: (21)		Sold HH assets (small animals, jewellery) (42)	
Done only in periods of water shortage (1)			
Done to manage various stresses (2)			
Not done (3)			

12.2 Of the strategies you employ to cope with periods of water shortage, which three do you implement first?

#1		#2		#3	

12.3 Are you aware of the concept of climate variability and change?

Yes (1)	No (2) Skip to question 12.5

12.4 What effects do you think climate variability and change will have on water availability in your community?

Annual water availability will increase		Annual water availability will decrease		Summer water availability will increase	
Summer water availability will decrease		Winter water availability will increase		Winter water availability will decrease	
Water availability will become more erratic		Water availability will become more consistent		No changes expected	

Expected (1)	Not expected (2)

12.5 Do you use any of the following water efficient technologies to save water?

Micro Irrigation (sprinkler and drip irrigation).	
Mulching	
Multiple Uses of Water (MUS)	
Other (specify):	
Used (1)	Not used (2)

12.6 Do you employ any of the following strategies or mechanisms to reduce your use of water during periods of water shortage? If so, how much water does each strategy/mechanism save per week?

		# of pots of water saved
Given up planting certain types of crops		
Introduced new crop types and varieties		
Sold livestock		
Slaughtered livestock		
Changed the type of livestock reared		
Changed farming practices (delayed sowing or		

harvesting, early sowing or harvesting)		
Farmland was left fallow		
Leased out farmland		
Sold farmland		
Abandoned farming		
Household invested in new irrigation infrastructure		
Community invested new in irrigation infrastructure		
Reduced household drinking water		
Reduced household water for cleaning		
Reduced water for sanitation		
Have done nothing		
Other, specify:		

Done (1)	Not done (2)

12.7 Do you think that these strategies and mechanisms will be sufficient to ensure that you will have enough water during dry periods in the future?

Yes (1)	No (2)

12.8 Do you receive information about flood/drought forecasting?

Yes (1)	No (2)

12.9 Do you have power to influence household decision making about which strategies and mechanisms to adopt to mitigate water stress?

No (1)	Yes, a small amount (2)	Yes, a moderate amount (3)	Yes, a lot (4)

12.10 Do you have power to influence community decision making about which strategies and mechanisms to adopt to mitigate water stress?

No (1)	Yes, a small amount (2)	Yes, a moderate amount (3)	Yes, a lot (4)

12.11 Do you have power to influence which strategies and mechanisms are implemented by external agencies on the local, national and international level?

No (1)	Yes, a small amount (2)	Yes, a moderate amount (3)	Yes, a lot (4)

12.12 What obstacles do you face with respect to taking part in water management decision making?

Discrimination on the basis of caste	
Discrimination on the basis of class	
Discrimination on the basis of ethnicity	
Discrimination on the basis of gender	
Discrimination on the basis of age	
Discrimination on the basis of social status	
Difficulty in attending decision making forums	
No obstacles faced	
Other, specify:	

Faced (1)	Not Faced (2)

13.Institutional Involvement

13.1 Who of the following assisted your household to deal with the effects of periods of water shortage?

Family		Friends		People of the community	
Insurance company		Financial institution		Local government	
Provincial government		National government		Local NGO	
IO (e.g. WFP, FAO)		Community organisation		Women SHG/ cooperative	
Foreign government					

Has assisted (1)	Has not assisted (2)

13.2 What is the percentage contribution of the following sources to the household food consumption in the last 12 months?

Self-produced	%
Bought from store/market	%
Food received as food aid from NGOs/IOs	%
Food received as food aid from friends and relatives	%
Subsidised food from public distribution system	%
From share-cropping of leased out land	%
Other, specify:	%

Total %	

13.3 In periods of drought, which of the following **community** organisations do you receive support from? On a scale of 1-5, how effective is their support?

1= Ineffective	2= only slightly effective	3= Moderately effective	4= Quite effective	5= Extremely effective

		Effectiveness (1-5)
Community Support Group		
Community Insurance Arrangement		
Community Women’s Group		
Local Farmers’ Association		
Local Government Agencies		
No Community Support Received		
Other, Specify:		

Received (1)	Not Received (2)

13.4 In periods of drought, which of the following **national** organisations do you receive support from? On a scale of 1-5, how effective is their support?

		Effectiveness (1-5)
National Social Welfare System		
National Disaster Relief		
Nepali NGOs		
No National Support Received		
Other, Specify:		

Received (1)	Not Received (2)

13.5 In periods of drought, which of the following **international** organisations do you receive support from? On a scale of 1-5, how effective is their support?

		Effectiveness (1-5)
International Organisations (FAO, UN etc.)		
International NGOs		
Internationally based Insurance		
No International Support Received		
Other, Specify:		

Received (1)	Not Received (2)

Appendix Three

The findings presented in this appendix are useful in triangulating the expected changes in water availability outlined in Chapter Three. These results demonstrate that the observed changes in climate outlined in Section 3.2.3 are being felt by people in Panglin and Tallo Lorpa. They also show how these perceived changes in climate affect water availability and therefore demonstrate local understanding equivalent to the perceptual model outlined in Section 3.3. These findings generally align with the expectations outlined in Chapter Three. They act to strengthen the findings of this thesis although they do not contribute to the thrust of the thesis and are, therefore, relegated to the appendices.

Perceived Changes in Temperature

Changes in temperature over the last 10-20 years were perceived by respondents in both Panglin and Tallo Lorpa. While responses showed variability within each community, the differences between communities give reason to believe they are experiencing different changes in temperature.

In Panglin, 22 of the 34 respondents believe that temperature patterns have changed in their area over the last 10-20 years. Temperature changes observed by many in the community, shown in Table A3.1, along with results from Tallo Lorpa, included hot seasons becoming colder and cold seasons becoming colder.

In Tallo Lorpa, 58 of the 61 respondents believe that temperature patterns have changed in their area over the last 10 years. The three that did not believe this was the case all came from the youngest age quartile. Temperature changes observed by many in the community included significant warming, slight warming and hot seasons becoming hotter. Of these, significant warming and hot seasons becoming hotter are disproportionately observed by the oldest age quartile. These observations are reflected by a member of the local Forestry Group who recalled “we have warm temperature nowadays, before they used to be very cold”.

Table A3.1: Perceived changes in temperature over the last 10-20 years and frequency of response.

Temperature Change	# of Households Observed in Tallo Lorpa	# of Households Observed in Panglin
Significantly Warmed	29	4
Slightly Warmed	29	4
Hot Seasons have become Hotter	36	3
Hot Seasons have become Colder	5	6
Cold Seasons have become Colder	14	13
Cold Seasons have become Hotter	22	0

Perceived Changes in Snowfall

Anecdotal evidence for reductions in snowfall over the last 10-20 years is overwhelming in both Panglin and Tallo Lorpa. Anecdotal evidence of changes in snowfall may be viewed with greater confidence than that for precipitation and temperature because snowfall is an especially salient phenomenon (Vedwan & Rhoades, 2001). Changes in snowfall are important both as proxies for changes in temperature and for the influence that snowmelt has on catchment hydrology in both the Pan Khola and Ghatte Khola Catchments. As explained by the elderly key informant in Panglin:

> "When snow falls, the grass for the cows grows well, it helps for agriculture activities as well, the snow falls and fills in the holes and at this time of the year (May), it gets warm, the snow melts and river becomes big. If snowfall doesn't occur during winter, there will be no water in canal and buckwheat field remains bare*"*.

Responses in Panglin suggest that the aggregate amount of annual snowfall has reduced and that the variability of snowfall has simultaneously increased. A member of the men's focus group summarises these concepts by saying: "In the past, snowfall used to occur in December and January but now it might occur in October or during February or March. There is not any guarantee. The snow also falls in less amount compared to past*"*.

Evidence from Tallo Lorpa also indicates an overall decrease coupled with increased variability. These changes are linked closely to temperature by a member of the local Forestry group who said:

> "…we have low snow fall nowadays and also snow fall time is late. We have seen rainfall at the time of snow fall. Upper places have snow fall and lower places haver rainfall and only at the peak snow time we have some snow around our houses, but before we had lots of snow - up to 4 feet. Now it's changed. And the snow does not remain a long time now it melts… but before we had snow for long time*"*.

A member of the local Woman's group provided particularly vivid anecdotal evidence of reductions in snowfall by explaining that "Now snow can be cleared by our broom but before we used shovels and hardly we could remove snow from around our house or village*"*. It is interesting to note that in conjunction with the ecosystem services that snowfall affords Panglin and Tallo Lorpa, it can also bring substantial hardship to the communities. Taken together, reduced snowfall can be seen as positive in a number of respects. As the elderly key informant from Tallo Lorpa pointed out:

> "…snow was dangerous before, it buried our houses before, now just to our feet. We used to be tired of throwing the snow or clearing the snow around our village. As we throw snow once, again the snow covers next day that time. Nowadays less snow it feels good for us old people*"*.

Perceived Changes in Stream Flow

As with precipitation, changes in stream and river flow were more frequently perceived in Tallo Lorpa than in Panglin over the last 10-20 years. Strong anecdotal evidence, however, exists for stream flow decreases in both communities. Of the 34 respondents in Panglin, 19 believed that stream flow had changed while as many as 56 of the 61 respondents in Tallo Lorpa believed this to be the case. Table A3.2 shows commonly cited changes in stream flow in both communities.

Table A3.2: Perceived changes in stream flow over the last 10-20 years and frequency of response.

Stream-flow Change	# of Households Observed in Tallo Lorpa	# of Households Observed in Panglin
Annual Increase	13	10
Annual Decrease	37	8
Monsoon Increase	24	3
Monsoon Decrease	20	2
Winter Decrease	41	2
Timing Advanced	17	0
Timing Delayed	12	1

In Panglin, again, survey responses appear contradictory with the most common observation being an annual increase closely followed by an annual decrease. A member of the men's focus group, however, provides strong anecdotal evidence of stream flow decrease, stating that "In the past, as all said just earlier, cow and buffalo couldn't cross the canal… the water in the canal has now decreased tremendously…" This observation was echoed by the elderly key informant who recalled that "In the past, there used to be heavy snowfall, and big rainfall used to make the river big… and river used to carry many things along with it…when snowfall stopped, the water in the river dried up… and the only source of water then was from the spring*"*.

The most common observations in Tallo Lorpa were annual decreases and winter decreases in stream flow, each of which were disproportionately observed by respondents in the oldest quartile. A member of the Water Stewardship Group recalled that "definitely [the] river is very small nowadays we think there used to be more water before, and the mill is also not able to run on some seasons due to lack of water*"*. A member of the local Forestry Group suggests increasing variability along with decreases in overall flow by stating "due to low rainfall or no rainfall we see less water flowing in the river. Normally water is very [much] less than before in both winter and monsoon. Floods are also common and last year our land was swept by flood and we had great loss*"*.

Perceived Effects of Changes in Climate

Changes in water resource availability were identified by their effects on agriculture in both communities. Changes in water availability were identified as the main reason for production decreases in Panglin's three most prominent staple crops: wheat, potato and buckwheat. In Tallo Lorpa, 'erratic rainfall' was identified as the main reason for production decreases in the community's three most prominent staple crops: maize, potato and millet, and 'water problems' were identified as the main reason for production decreases of the community’s two most prominent cash crops: chilli and garlic.

Changes in water resource availability were also perceived directly. Of the 34 respondents in Panglin, 25 believe that the amount of water they have access to for domestic use has changed over the last 10-20 years. Of the 61 respondents in Tallo Lorpa, 54 thought this was the case.
The direction and magnitude of perceived changes seem to show random variation within each community and systematic variation between communities. In other words while there is some uncertainty as to the nature of water resource change within each community, divergence in responses between communities provides reason to believe that the changes seen in each community are different.

Table A3.3 lists specific changes in water availability for household use and the number of respondents in each community who observed each change.

Table A3.3: Number of respondents observing specific changes in water availability for household use in both Panglin and Tallo Lorpa.

Panglin	**Increased Slightly**	**Increased Substantially**	**Decreased Slightly**	**Decreased Substantially**
Monsoon	16	8	1	0
Post-Monsoon	16	8	1	0
Winter	12	0	4	3
Pre-Monsoon	16	8	1	0
Tallo Lorpa	**Increased Slightly**	**Increased Substantially**	**Decreased Slightly**	**Decreased Substantially**
Monsoon	16	21	14	1
Post-Monsoon	19	11	20	0
Winter	19	10	19	0
Pre-Monsoon	24	23	8	0

In Panglin, the largest number of respondents saw water resources as increasing slightly during each of the four seasons. In Tallo Lorpa, the largest number of respondents saw water resources as increasing substantially during the monsoon, decreasing slightly during the post-monsoon and increasing slightly during the pre-monsoon. Equal numbers saw a slight increase and a slight decrease during the winter.

Changes in water available for irrigation were also perceived by respondents in both communities. In Panglin, 14 out of 34 respondents believe that the amount of irrigation water they have access to has changed over the last 10-20 years while in Tallo Lorpa, as many as 51 of the 61 respondents believed this to be the case.

In Tallo Lorpa, anecdotal evidence of change in irrigation water exists. When asked about changes in the use of water over time, a member of the Tallo Lorpa Forestry Group responded: “before we used to have canal irrigation. Most of the land nearby our houses used to be irrigated in our village. But now due to water shortage we have very [little] irrigation so we left some of the crops”. This shift away from irrigation due to lack of water was echoed by a member of the Water

Stewardship Group who stated: "People have left most of their land abandoned, due to lack of irrigation. Piped water is not enough for irrigation".

These reports of irrigation water decrease are generally reflected in survey responses for Tallo Lorpa shown in Table A3.4 (along with responses from Panglin). In Tallo Lorpa, the greatest number of respondents thought that irrigation water had decreased slightly during the monsoon, post monsoon and winter, while increasing slightly in the pre monsoon. In Panglin, the greatest number of respondents thought that irrigation water had increased slightly in all four seasons.

Table A3.4: Number of respondents observing specific changes in water availability for irrigation in both Panglin and Tallo Lorpa.

Panglin	**Increased Slightly**	**Increased Substantially**	**Decreased Slightly**	**Decreased Substantially**
Monsoon	10	4	0	0
Post Monsoon	10	4	0	0
Winter	7	1	1	1
Pre Monsoon	10	4	0	0
Tallo Lorpa	**Increased Slightly**	**Increased Substantially**	**Decreased Slightly**	**Decreased Substantially**
Monsoon	11	7	17	9
Post Monsoon	9	3	17	4
Winter	9	5	15	6
Pre Monsoon	20	16	7	8