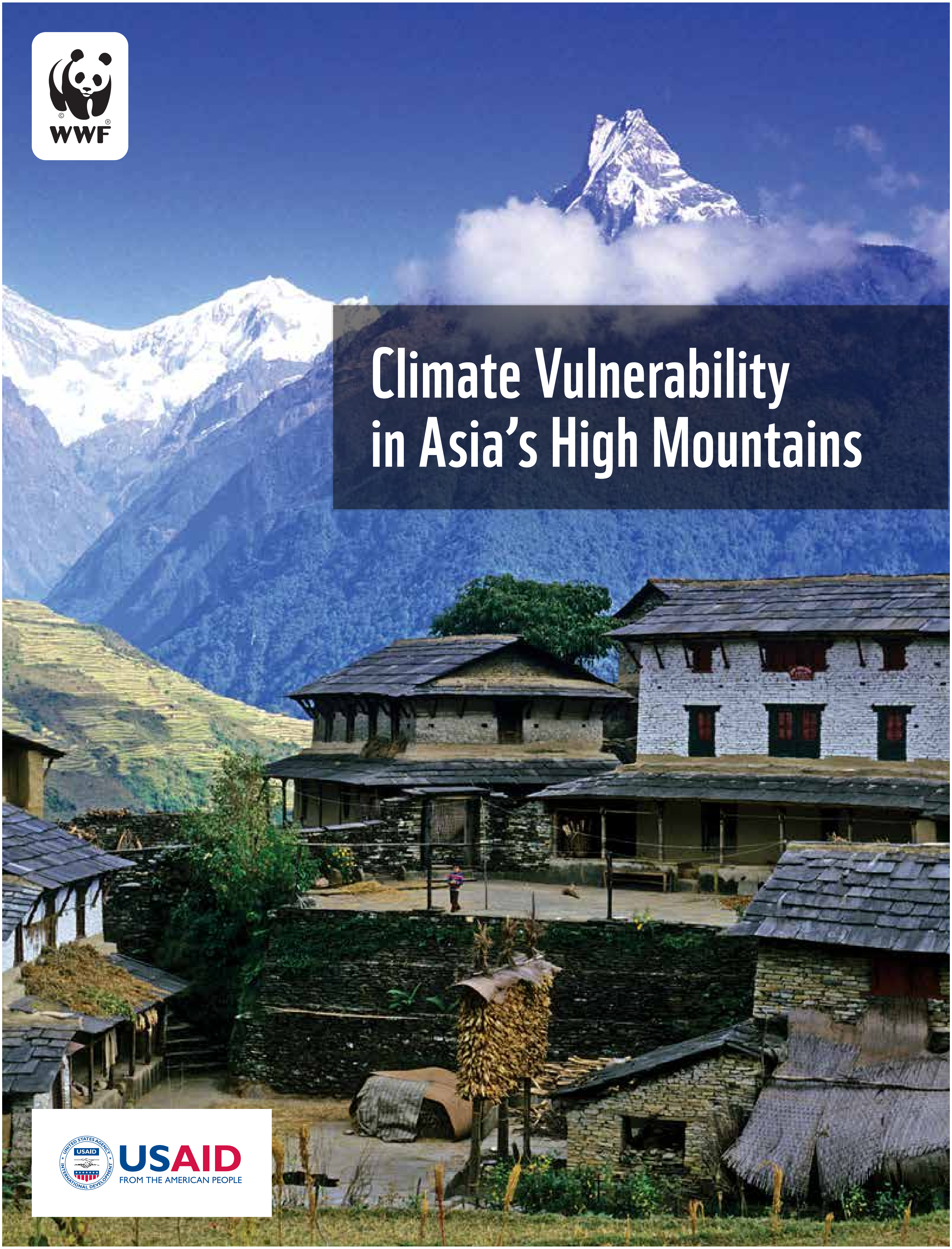
WWF



Climate Vulnerability in Asia's High Mountains

USAID
FROM THE AMERICAN PEOPLE

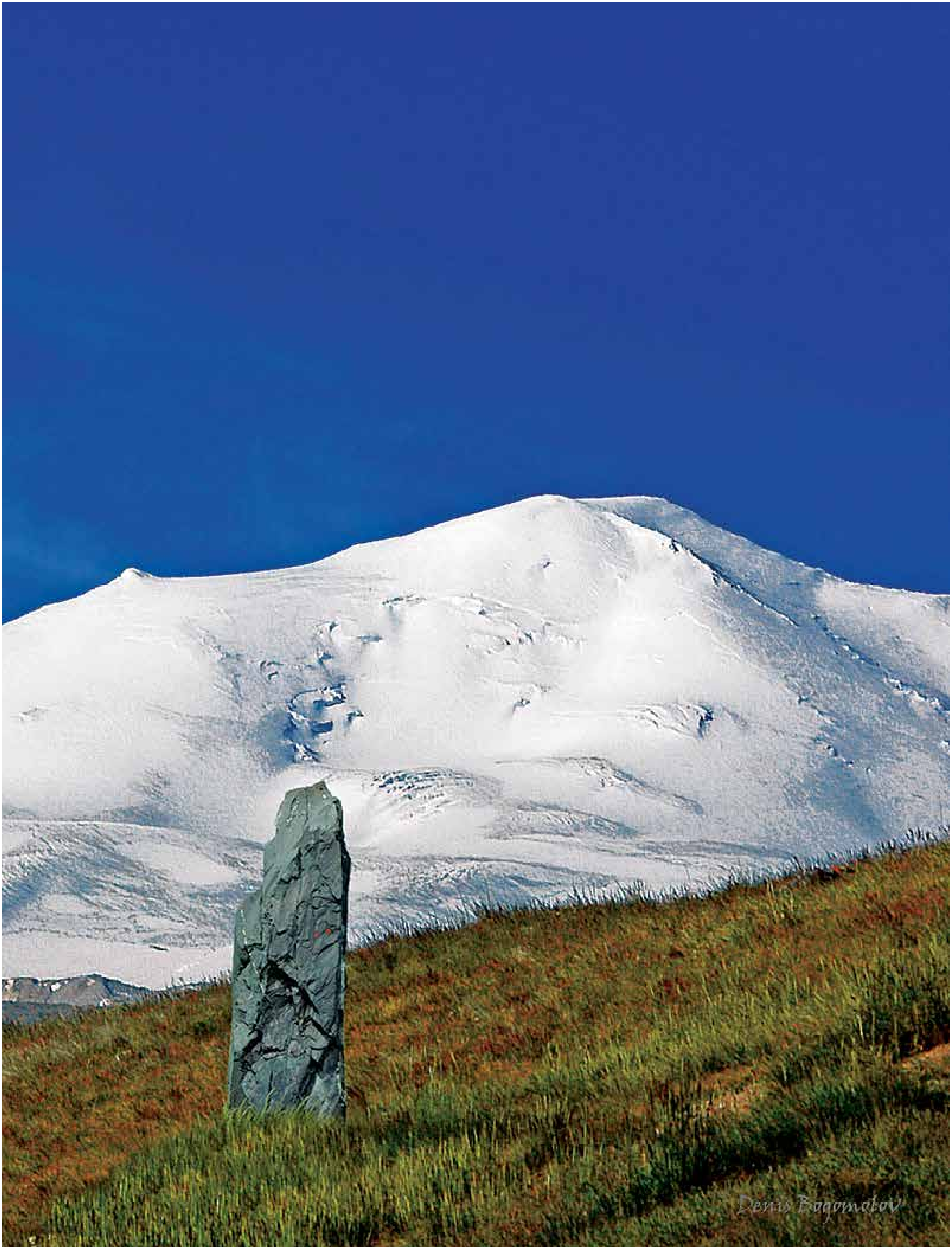
COVER: VILLAGE OF GANDRUNG NESTLED IN THE HIMALAYAS. ANNAPURNA AREA, NEPAL; © GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

Climate Vulnerability in Asia's High Mountains

May 2014

PREPARED BY
TAYLOR SMITH
Independent Consultant
ttsmith89@gmail.com

This report is made possible by the generous support of the American people through the United States Agency for International Development (USAID). The contents are the responsibility of WWF and do not necessarily reflect the views of USAID or the United States Government.



THE UKOK PLATEAU NATURAL PARK, REPUBLIC OF ALTAI;

CONTENTS

Figures

ACRONYMS AND ABBREVIATIONS

ADB .... Asian Development Bank
AHM .... Asia's High Mountains
ASTER .... Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR .... Advanced Very High Resolution Radiometer
AVNIR .... Advanced Visible and Near Infrared Radiometer
CALIOP ...... Cloud-Aerosol Lidar with Orthogonal Polarization
DEM .... Digital Elevation Model
ENSO .... El Niño-Southern Oscillation
FAO .... Food and Agriculture Organization
GCM .... Global Circulation Models
GIC .... Glacier Inventory of China
GIS .... Geographic Information System
GLIMS .... Global Land Ice Measurements from Space
GLOF .... Glacial Lake Outburst Flood
GRACE ...... Gravity Recovery and Climate Experiment
HKH .... Hindu Kush-Karakorum-Himalaya
ICIMOD ...... International Centre for Integrated Mountain Development
IPCC .... Intergovernmental Panel on Climate Change
ISM .... Indian Summer Monsoon
IWT .... Indus Water Treaty
LIS .... Lightning Imaging Sensor
LLOF .... Landslide Lake Outburst Flood
MODIS .... Moderate Resolution Imaging Spectroradiometer
PRISM .... Panchromatic Remote-sensing Instrument for Stereo Mapping
REDD .... Reducing Emissions from Deforestation and Forest Degradation
SAARC ...... South Asian Association for Regional Cooperation
SLRC .... Snow Leopard Range Country
SPOT .... Satellite Pour l'Observation de la Terre
SRTM .... Shuttle Radar Topography Mission
SWE .... Snow-Water Equivalent
TOMS .... Total Ozone Mapping Spectrometer
TRMM .... Tropical Rainfall Measurement Mission
UNFCCC .... United Nations Framework Convention on Climate Change
USAID .... United States Agency for International Development
VRMC .... Village Resource Management Committee
WGMS .... World Glacier Monitoring Service
WHO .... World Health Organization
WWD .... Winter Westerly Disturbance
WWF .... World Wildlife Fund

HARVEST TIME, CHOMORONG; © GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

EXECUTIVE SUMMARY

Asia's High Mountains (AHM) are at particular risk from shifting climate, as much of the region is highly dependent on seasonal rainfall and glacial runoff for water resources, and many communities lack the resources to respond to the effects of rapidly shifting climate. AHM are also vulnerable to increases in frequency and intensity of extreme weather. Management strategies are complicated by large spatial gradients in precipitation regimes throughout AHM, and management strategies based on regional estimates of climate change are unlikely to apply at smaller scales. Distinct climatological influences, such as summer monsoons and winter westerly disturbances, and substantially different topographies between mountain ranges require diverse climate adaptation strategies. For example, water management strategies that work in the monsoon-driven eastern and central Himalaya should not be applied in the snow- and ice-melt-driven northwestern Himalaya and Karakoram without accounting for local variation in the hydrologic cycle.

State of Knowledge on Climate Change Impacts

In its 2013 Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) identified AHM as a region likely to receive increasingly extreme and variable weather due to shifts in climate (IPCC, 2013b). Regional studies have shown that a single extreme weather event can account for as much as 10% of a catchment's yearly water intake, and 50% of yearly rainfall can occur within a 10-day period in monsoon regions (Dahal and Hasegawa, 2008; Bookhagen, 2010; Wulf et al., 2010). These massive storms not only have a large impact on water resources, but also have an outsized impact on erosion, and can drastically increase the amount of sediment present in river systems. Changing water and sediment quantities, with their coupled effects on water quality, hydropower generation and agriculture, can significantly influence ecosystem and human vulnerability in the region.

Extreme storms and changing climate can also have devastating rapid effects in the form of glacial lake outburst floods (GLOFs). GLOFs have become more common in the region in the past few decades, as shrinking glaciers shed their water into lakes (Stone, 2009; Ives et al., 2010; ICIMOD, 2011). These lakes are typically dammed by weakly bound sediment deposits and moraines, which can breach during avalanches, earthquakes, storms – especially rain-on-snow events – or even just during seasonal buildup of glacier melt water. Similarly, landslide lake outburst floods (LLOFs) can occur when a landslide dams a river channel, forming a temporary lake which can subsequently breach, sending water pouring downstream (Gupta and Sah, 2008; Mool, 2012; Wulf et al., 2012). GLOFs and LLOFs have been responsible for several catastrophic floods in the region, and are a continuing risk throughout AHM.

Though water is the typical focus of climate risk assessments, suspended sediment can be equally important. As precipitation becomes more extreme, additional sediment is often flushed into rivers (Wulf et al., 2010). Shifts in storm timing may catch landscapes when they are not equipped to absorb the rainfall. For example, a storm occurring during the rainy season when vegetation is maximal causes typical or minimal erosion. However, if the same storm were to occur during the dry season, it would result in more erosion, as the lack of plants decreases slope and soil cohesion and allows more material to be washed into streams (Wulf et al., 2010; 2012; Burbank et al., 2012). Extra sediment can wear down hydropower turbines, increase purification or filtration needs for human consumption, and degrade irrigation systems. Thus, dissecting the link between water and sediment budgets in the region is an important factor in characterizing the climate-induced water risks in the region.

State of Knowledge on Human Vulnerability

Studies throughout AHM have identified several common areas of human vulnerability to climate change. The primary mechanisms that drive vulnerability are climate hazards such as flooding, droughts and landslides; changing sedimentation patterns; damage to ecosystem services, including changes in plant distribution and phenology; impacts to human health such as increased range of malaria; and declining water availability. In general, as climate patterns become more extreme, flood risk will increase, and as population pressure pushes human settlements into more remote and rugged areas, the potential damages due to floods will increase (Tiwari and Joshi, 2012). Sedimentation will have negative impacts throughout AHM, primarily through disruption of hydropower and infilling of irrigation networks. Ecosystem services are under threat from both anthropogenic factors such as overgrazing, and climate factors such as increased incidence of drought, which have resulted in steady declines in ecosystem health throughout AHM. These ecosystem changes also bring with them changing disease risk factors. Warmer climates have extended the range of some vector-borne diseases, such as malaria, while decreased food security and the resulting impact on nutrition have reduced the capacity of populations to resist those diseases. Declining water resources, and increased competition for those resources, has already impacted agricultural networks in the region through loss of landscape productivity and lost crops due to extreme weather. In general, the most disadvantaged populations are the least capable of adaptation, and are at the highest risk of climate-induced suffering. These communities include both subsistence farmers who rely on consistent weather patterns for cropping, and nomadic communities who rely on the distribution and phenology of plant species for grazing livestock.

Many of the climate-induced risks facing AHM have been documented, and activities have been planned to mitigate and respond to them, although these interventions do not cover all populations at risk in this vast and topographically complex region. In general, adaptation efforts have focused around the problems of too much and too little water. Flooding, due to GLOFs, LLOFs and intense rainfall events – sometimes referred to as "cloudburst" floods – continue to be addressed through structural measures, such as diversions, dams and spillways, and through non-structural measures such as early warning systems and community hazard plans. In general, those adaptations which engaged with communities directly, and where community members played an active part in implementing adaptation plans, have been the most successful.

Water availability has been in decline in AHM over the past few decades. This decline is driven by both anthropogenic factors and climate change. Reduced water availability has been addressed through a range of methods, primarily centered on changes in land management. Degraded landscapes often reduce water infiltration, which limits groundwater storage. Reforesting sub-optimal agricultural land can both encourage groundwater recharge, and provide alternate livelihoods based around ecosystem services such as fiber and tourism (Chaudhary and Aryal, 2009). Updates to irrigation systems have also been proposed, as many irrigation systems in the region are outdated and inefficient (Lioubimtseva and Henebry, 2009). The application of traditional irrigation practices, with the support of modern engineering techniques, is likely to provide more sustainable and ecosystem-friendly solutions, with minimal reduction in services (Groenfeldt, 1991), though these practices must be updated based on current climate trends and projections to increase their potential for long-term viability.

Although much of the climate vulnerability in AHM is driven by problems of too much and too little water, weather variability is also a major driver of climate vulnerability. In many areas, annual precipitation has remained fairly consistent, but has included both more droughts and more extreme rainstorms. Furthermore, changes in the timing of rainfall and frosts have impacted both farming and herding communities, as well as natural ecosystems. Livelihood diversification has been one of the most effective ways of minimizing this vulnerability in AHM. For example, in some farming communities, the integration of vegetable crops into farm rotations has provided additional income sources, as well as decreased reliance on a single crop (WWF Nepal, 2012). In nomadic communities, herd diversification and emphasis on alternative livelihoods such as traditional crafts have been effective in increasing community resilience (WWF China, 2010).

Knowledge Gaps and Policy Perspective

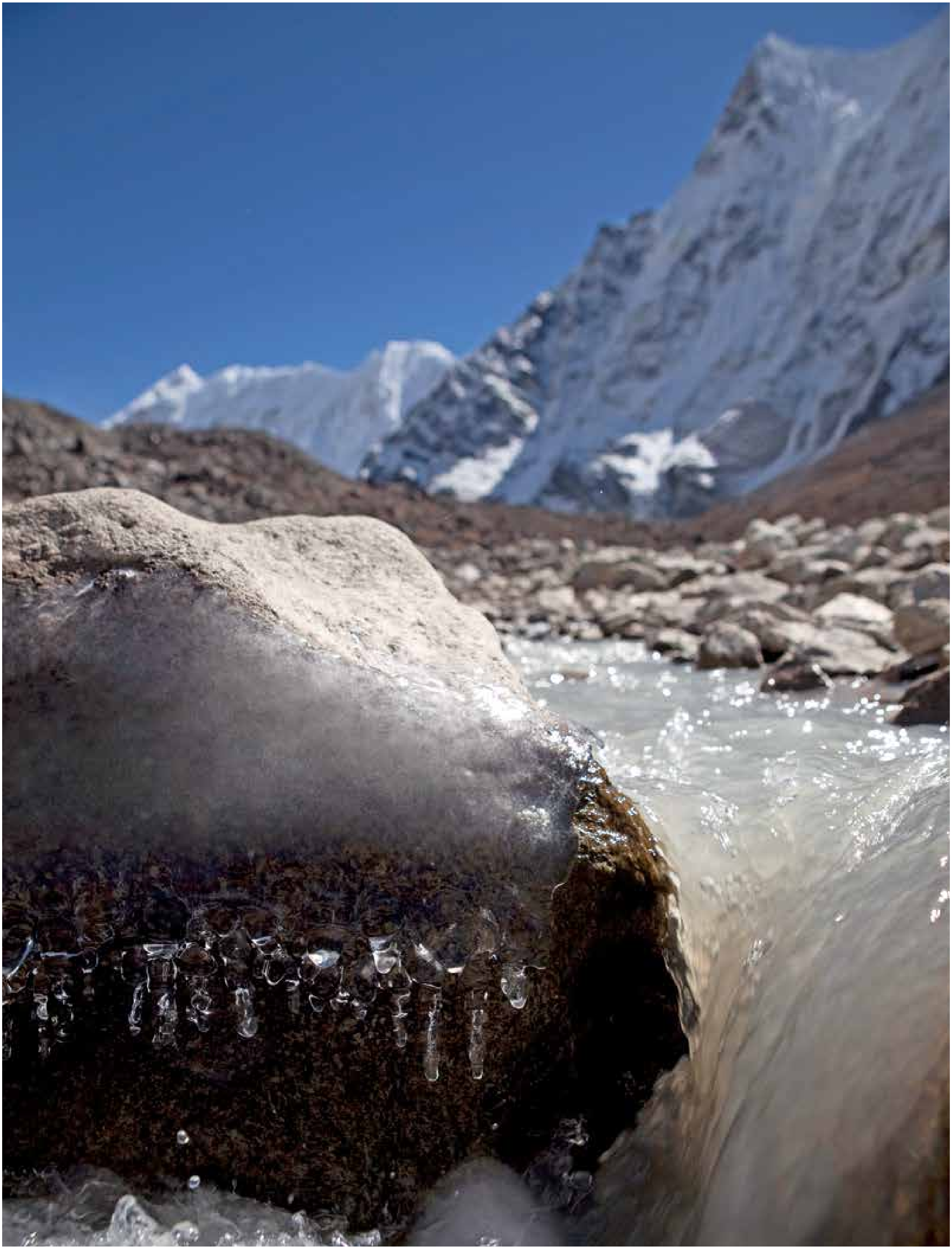
As climate continues to shift, adaptation methods and practices will have to be modified to suit changing conditions. However, projected changes in climate are often rough and lack the spatial or temporal resolution to provide adequate guidance in the planning of interventions. Several key data gaps have been identified, centered on the need for more accurate and widespread measurements of environmental and climate data. These data are often sparse in the rugged and high-elevation areas of AHM, but are essential to accurate climate modeling and prediction of the effects of climate change. Furthermore, there are large gaps in the body of scientific knowledge, including on the effects of black carbon, melting permafrost, and transient groundwater storage on water regimes. Methods for applying satellite remote sensing data to mitigate data shortages are being developed, and can help inform environmental analyses in the region, as well as aid in GLOF risk monitoring and regional climate analysis. There is a wide range of opportunities for local and international organizations to address some of these shortcomings, through both direct interventions and policy initiatives.

Over the past few decades, climate change has taken an increasingly important role in policy discussions in the region. This is often reflected at the national and international level, where each partner country is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), and several have developed a National Adaptation Program of Action, but these commitments are rarely reflected in provincial or city-specific policies. Furthermore, the majority of partner countries cite lack of resources as one of the main limitations to implementing effective climate change adaptation strategies. This is a key area where international expertise and resources can be leveraged to improve adaptive capacity and climate resilience in AHM.

Recommendations for Future Adaptation Efforts

This report provides a suite of adaptation recommendations at multiple scales, contextualized by data availability and the experiences of a range of implementers. In general, community education and engagement, restoration of natural ecosystems based on existing and anticipated shifts in climate (for example, through introducing more temperature-tolerant native species, or through targeting areas vulnerable to extreme events), integration of traditional management techniques, and synchronization of diverse climate policies across levels of government are strategies that can be applied throughout AHM at multiple scales to build resilience in communities and ecosystems. As climate change is a regional issue, many solutions require enhanced regional cooperation. There are several avenues of collaboration in building climate resilience in AHM, including in disaster risk management, regional resource management, technical capacity building, and data sharing and standardization. Using and strengthening existing platforms to address these issues at a regional level is critical to increase adaptive capacity throughout the region.

In addition to the regional solutions appropriate for broader approaches to climate change in AHM, this report suggests a range of possible interventions to provide more immediate benefits to communities in AHM. These interventions must be applied within the context of each individual range in AHM, as well as the context of individual sub-areas within the range. Most of these interventions focus on mediating the impact of too much and too little water, which are most likely to affect human livelihoods in the region. Through integrating policy-level and small-scale interventions, it is possible to increase the adaptive capacity of populations throughout AHM in the face of climate change.



IMJA RIVER; © WWF-CANON / STEVE MORGAN

SECTION I
Introduction

1.1 Context of the Report

In 2010, the United States Agency for International Development (USAID) published the report *Changing Glaciers and Hydrology in Asia: Addressing Vulnerabilities to Glacier Melt Impacts* (Malone, 2010) in response to heightened awareness of glacial changes in Asia's High Mountains (AHM) and their impacts on human populations. The 2010 report reviewed the science concerning glacier melt in Asia and identified key glacier melt vulnerabilities in a subset of AHM. It also reviewed known responses to these vulnerabilities, identified organizations working on glacier melt and its impacts in Asia, and suggested strategic cross-sectoral responses to mediate risks posed by the vulnerabilities.

The 2010 report provided a comprehensive review of glacial health in the Hindu Kush–Karakorum–Himalaya (HKH), Pamir and Tien Shan mountain ranges. This report builds on the 2010 USAID report by updating the review of glacial health; expanding the geographic focus to include the Kunlun and Altai mountain ranges; adding a review of the evidence of changes in the broader hydrologic system, water budget and climate patterns in AHM, and their contributions to the region's vulnerabilities; and broadening discussion of current adaptation efforts in the region.

1.2 Objectives of the Report

The goal of this report is to review and summarize climate change vulnerability and impacts in AHM, including the Altai, Tien Shan, Kunlun, Pamir, Hindu Kush, Karakorum and Himalaya ranges. The report is designed to provide baseline information for the World Wildlife Fund (WWF) project *Conservation and Adaptation in Asia's High Mountain Landscapes and Communities* (2012-2016) funded by USAID. Through transnational collaboration on snow leopard conservation and climate change adaptation, the project promotes climate-smart management of high mountain landscapes and enhanced water security in local communities throughout the snow leopard range in Asia's High Mountains.

The seven objectives of this report are addressed as individual Sections 2-7:

- **Section 2** updates the comprehensive literature review on glacier character and behavior completed as part of the work published by USAID in 2010 (Malone, 2010), and expands it to include the Kunlun and Altai ranges. The Section further describes the state of scientific knowledge of hydrology and climate change in AHM broadly and in each of the seven ranges, including changing storm seasonality and atmospheric patterns and their potential impact on water budgets in the region.

- **Section 3** summarizes published and gray literature on climate change vulnerability and impacts in AHM. Vulnerabilities focus on flooding, sedimentation, ecosystem changes which can impact food security, livelihoods, human health, ecosystem services and infrastructure, including hydropower generation. The Section describes range-specific evidence where available, and presents climate impacts both at a range and watershed scale.

- **Section 4** summarizes current adaptation efforts and results in AHM using white and gray literature, supplemented by information provided by World Wildlife Fund (WWF) and USAID offices and partners in the region. These efforts include adaptation to reduced water availability, flooding and landslides, and are presented on a range-specific basis where information is available.

- **Section 5** assesses limitations of current evidence and describes key research and data needs for assessing climate change, glacier melt and their effects on ecosystems and communities in AHM. Given the scarcity of data in the region relative to its vast size and remoteness, the Section reviews potential applications and limitations of satellite sensing techniques, and assesses the possible use of free or inexpensive imagery available through US Government sources.

- **Section 6** documents current policy initiatives to improve adaptation and climate resiliency in AHM. These initiatives include national, sub-national and range-wide initiatives, including transnational agreements and international cooperative statements.

- **Section 7** outlines recommendations for future adaptation efforts in AHM, building on recommendations made in the 2010 USAID report (Malone, 2010). Section 8 assesses new avenues of collaboration and regional-scale climate impact planning, contextualized within both a regional framework and a range-specific scientific, climatic and vulnerability setting. The Section identifies synergies between range-specific recommendations and region-wide efforts where appropriate.

1.3 Methodology

The report is based on a systematic review of available scientific, white, and gray literature. The review was supplemented by communications with key global and regional scientific experts, as well as staff of the WWF and USAID country offices in the region and their implementing partners. However, time constraints limited input from field staff into this report. This review did not include work published in languages other than English, although an effort was made to include published syntheses of non-English publications and reports.

1.4 Study Area

This report focuses on mountain ranges that cut across six countries – India, Nepal, Bhutan, Pakistan, Kyrgyzstan and Mongolia – that are home to field sites in the USAID-funded project *Conservation and Adaptation in Asia's High Mountain Landscapes and Communities*. The seven ranges included in the report are the Altai, Tien Shan, Kunlun, Pamir, Hindu Kush, Karakorum and Himalaya.

Data availability for each of these ranges varies, from the relatively well-studied Hindu Kush, Karakorum and Himalaya Ranges, to the data-poor Pamir, Altai and Kunlun Ranges. In some cases, ranges have been grouped for analyses depending on data availability. For example, because of the general ambiguity of range delineations between the Hindu Kush, Karakorum and Himalaya ranges, these will be examined as a single range as Hindu Kush-Karakorum-Himalaya (HKH) in some sections. However, regional variation within HKH will be documented where data are available. Field-site countries, glaciated areas, major drainage basins, and generalized snow leopard range are illustrated below in Figure 1.

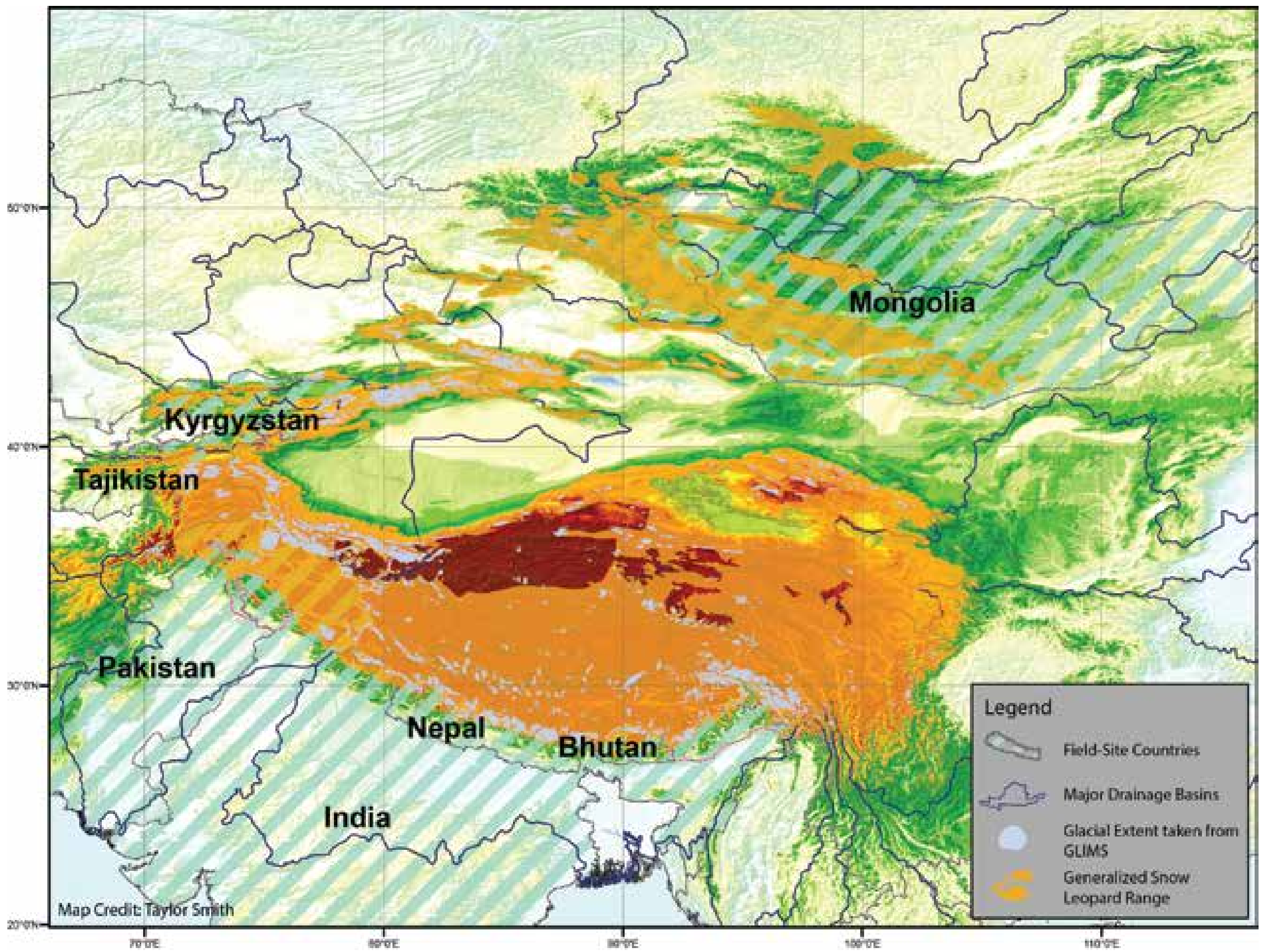


Figure 1 - Geographic and political overview map of the study area, including field-site countries, glacial extents (Global Land Ice Measurements from Space, Armstrong et al., 2013), principal watersheds (Hydrosheds, Lehner et al., 2008), and generalized snow leopard range (from ISLT, 2008).

ARGUT NATURAL PARK; © BOGOMOLOV DENIS / WWF-RUSSIA

SECTION II
State of Scientific Knowledge on Glaciology, Hydrology and Climate Change

This section (1) describes the basics of glacier science, (2) summarizes climate pattern changes in AHM, and (3) reviews current knowledge on glacier and hydrological response to climate change in each of the region's seven mountain ranges. The USAID report *Changing Glaciers and Hydrology in Asia*, which serves as a basis for this report, provides an in-depth overview of basic glacier science, and some of the predicted impacts of changing glacier character in AHM (Malone, 2010).

2.1 Glacial Science

There is a wide range of estimates of glacial extent in AHM. The World Glacier Monitoring Service (WGMS) uses the number 114,800 km^2 to describe glacial coverage in the "greater Himalayan region" which does not include the Altai range (estimated with a glacial coverage of 3,500 km^2) (Zemp et al., 2008). Many of these glaciers are estimated to have shrunk, though there are significant difficulties in quantifying glacial change (Zemp et al., 2008), due to problems of accessibility; lack of adequate hydrologic models; limited, incomplete or inaccurate measurements; and a dearth of long-term datasets (Malone, 2010). These glaciers represent the "third pole" of the earth, and together represent the largest mass of ice outside of the Arctic and Antarctic (Larson, 2011). These glaciers serve as an important seasonal water storage mechanism, and help provide year-round water to millions of downstream users.

Glacier change can be assessed using two main methods: measurement of glacier terminus or area, and measurement of glacial mass balance. Glacial terminus measurements involve simply measuring the furthest point a glacier extends down a valley (Figure 2), while areal measurements trace the outline of glaciers from maps or satellite imagery. These measurements can be taken at a range of timescales (i.e., hourly, daily, seasonally, yearly), depending on data availability and purpose. Because terminus and areal measurements can be taken over large areas using satellite imagery, much of the world's glacial inventory is based on terminus measurements, and many modern climate models predict glacial change in terms of terminus retreat. However, terminus measurements fail to capture the changes in height or volume of a glacier – a critical component of understanding glacier mass balances (Cuffey and Paterson, 2010).

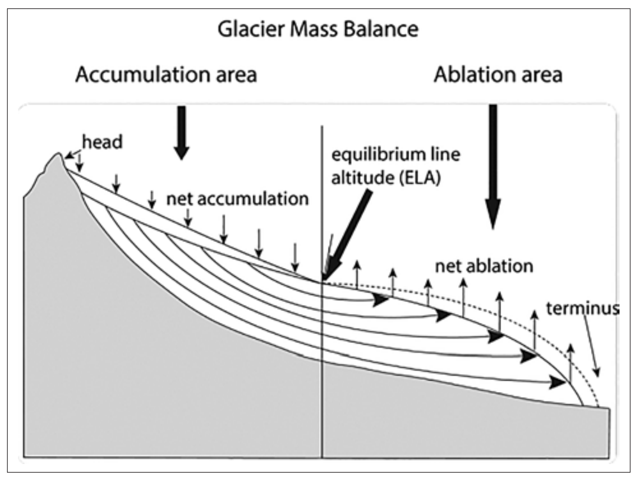


Figure 2 - Glacier mass balance, showing accumulation, ablation and equilibrium zones (Armstrong, 2010).

Mass balance methods more accurately measure how much water equivalent or mass a glacier has gained or lost. Glaciers grow and shrink throughout the year, as snowfall accumulates during colder or wetter periods, and warmer summer temperatures drive melting. Glaciers are defined by two main zones: the accumulation area and ablation area (Figure 2). The accumulation area is the upper portion of the glacier, where there is a net increase in mass over the year, and the ablation area is the lower area where there is a net mass loss over the year. Mass balance is a measurement of the overall net gain or loss of mass or volume of the glacier through a fixed period of time, be it seasonal, yearly or decadal. Mass balance has been determined using a wide range of techniques, from field surveys, to ice cores (Kehrwald et al., 2008), to elevation models derived from satellite imagery (Berthier et al., 2007; Gardelle et al., 2012; Aizen et al., 2007a; Bolch et al., 2012). The vast majority of glaciers in AHM have yet to receive detailed mass balance estimates.

Glacier extent and mass balance are controlled by a variety of natural factors, including precipitation, air temperature, debris cover, slope and aspect (direction in which a slope faces).[1] Glacial size is also an important factor, where larger glaciers tend to respond less quickly to changing climate (also known as glacial response time) and can result in significant time lag between changing climate conditions and corresponding glacial changes. Anthropogenic factors, such as the presence of black carbon, can increase melting rate or extend melting throughout longer periods of time by increasing heat absorption and reducing reflectivity (Scherler et al., 2011b).

Black carbon, as well as other aerosols, has been shown to impact glaciers and snowpack in AHM (National Research Council, 2012; International Resources Group, 2010). As aerosols – particularly black carbon – are deposited on snow surfaces, they can both cause a decrease in glacier reflectivity (albedo), and serve as strong solar absorbers themselves, which can speed up melting processes (National Research Council, 2012). However, the response of glaciers to aerosols is not uniform. Low slope glaciers, such as those prevalent in the western HKH, are likely to see more rapid melting caused by the influence of black carbon due to low snow mixing (Scherler et al., 2011b); low snow mixing allows black carbon to progressively thicken over multiple seasons, with limited new snowfall or few avalanches to bury surface deposits. In areas of higher slopes, especially those with high incidence of avalanches, snow mixing may help bury some of the aerosols and reduce their sun-absorbing effects. However, there are few detailed studies, or studies with sufficient spatial resolution, to quantify the impacts of aerosols. Regardless of their effects on solar radiation absorption, aerosols have a clear impact on glacier melt through increases in ambient air temperatures (Lau et al., 2006).

Recently, debris cover, which can act as a shield against insolation, has been implicated in glacial stability (Scherler et al., 2011b; Bolch et al., 2012). Debris cover is influenced by glacier slope, as well as the frequency of avalanches (Scherler et al., 2011b). Low slope glaciers are less subject to avalanches and landslides that provide debris, particularly those situated in areas of low relief. Conversely, glaciers located in steep topography, regardless of the slope of the glacier itself, show a much higher rate of debris cover. This debris cover can either increase or reduce melting depending on several factors, the most important of which is thickness of debris layer. As debris is darker than ice, it will absorb more solar radiation. Thin debris layers transmit this energy directly to the glacier and help to increase melting. However, thick debris layers can act to insulate the glacier due to the low heat conductivity of thick rocky debris, and help slow melting (Racoviteanu et al., 2013).

Given current data limitations, and the multitude of factors influencing changes within individual glaciers, predictions of glacial change within a single range are likely to be unreliable, and predictions for the entirety of AHM even more so, despite several decades of glacier research. This is due in part to data scarcity, which limits model efficacy at the scale of individual glaciers, and also due to the number of microclimates throughout AHM, which make generalizing climate models in the region difficult. This is particularly true for glacial changes. Some differences in individual range response can, however, be used to predict general or average response of glaciers within different ranges. For example, while most studies predict significant glacial retreat in coming decades in AHM (i.e., IPCC, 2013b), the Karakorum and Pamir Ranges have gained glacial mass over the period of 1999–2008 (Hewitt, 2005; Gardelle et al., 2012; 2013), and studies have shown only small climate impacts on glaciers in the Kunlun Range (Shangguan et al., 2007).

1 For a more complete review of factors controlling glacial mass balance, refer to the 2010 USAID report *Changing Glaciers and Hydrology in Asia* (Malone, 2010).

2.2 Climate Pattern Changes

AHM are likely to receive increasingly extreme and variable weather due to shifts in climate, with all analyzed models showing increases in mean and extreme precipitation from the Indian Summer Monsoon (ISM) (IPCC, 2013a; 2013b). This is due to a range of factors, including above-average estimated temperature increases and changes in monsoon patterns driven by changing sea surface temperatures (IPCC, 2013b; Wang et al., 2014). The IPCC 2007 report states that "all of Asia is very likely to warm during this century," and that many parts of Asia will see warming "above the global mean" (IPCC, 2007). This warming is projected across all of the climate models analyzed in both the IPCC 2007 report, and the more recently updated IPCC 2013 report, which are based on global circulation models (GCM).

The climate in AHM is primarily driven by the interaction between the ISM and the Winter Westerly Disturbances (WWDs), which collide over the western edge of the Himalaya. In the southeastern reaches of AHM, precipitation is primarily driven by the ISM, which accounts for nearly 80% of yearly precipitation (Lang and Barros, 2004; Bookhagen and Burbank, 2010). Conversely, in western areas of AHM, the WWDs supply more than 50% of the yearly precipitation. The northern ranges (Altai and Tien Shan) are also influenced by the North Atlantic Oscillation, though precipitation is generally low in these regions (Cohen and Entekhabi, 1999). A large body of research has shown that human-induced environmental changes can have significant impacts on these atmospheric circulation systems (e.g., Gautam et al., 2009; Fu, 2003; Bookhagen and Burbank, 2010).

As early as the 1970s, changing land cover was recognized as a driver of changing climate patterns (e.g., Charney, 1975; Charney et al., 1977). Charney et al.'s (1977) primary finding, from data collected in North America, Asia and Africa, was that changes in albedo, or landscape reflectivity, could significantly alter weather patterns in both monsoonal and arid regions. More recent research has identified additional factors, such as changing surface roughness, forest cover, evapotranspiration and seasonal water storage, as drivers of climate change (Fu, 2003). Asia, and particularly Southeast Asia, has seen some of the most dramatic land cover changes in the world.

Three thousand years of human habitation in the context of increasing population have altered much of the landscape from jungle to farmland, as well as both directly and indirectly increasing degraded and desertified landscapes (Fu, 2003). Fu's (2003) analysis indicates that human activities have weakened the East Asian summer monsoon,[2] and enhanced the winter monsoon in Southeast Asia and the eastern reaches of the Himalaya.

Climate in the southern and eastern areas of AHM is influenced by summer monsoonal rainfall, which is driven by temperature gradients between the Indian Subcontinent and Indian Ocean that contribute to the ISM (Barlow et al., 2005). Recent work has indicated that the steep orographic gradient of the Himalayas is primarily responsible for these temperature gradients, as it separates warm, moist air over the Indian subcontinent from the colder and drier regions of AHM (Boos and Kuang, 2010). These, however, are structural controls, and are unlikely to influence climate at a human-relevant timescale, or account for observed increased monsoon severity.

Several studies have provided insights on the reasons for increased severity of the ISM, including an observed 20% increase in early summer monsoon rain since the 1950s (Gautum et al., 2009; Menon et al., 2013; Kitoh et al., 2013). Kitoh et al. (2013) showed that increases in moisture availability, particularly over the Indian Ocean, have led to a progressively more powerful and erratic summer monsoon in Southeast Asia. The IPCC 2013 report notes that monsoon seasons are likely to increase in severity, and potentially in duration as well (IPCC, 2013a). Atmospheric aerosols have also been implicated in this process, particularly the "atmospheric brown cloud" over industrializing areas of Asia. Gautum et al. (2009) have shown significant and increasing aerosols in Southeast Asia, and have linked shifts in the ISM to these aerosol changes.

A range of mechanisms through which aerosols modify rainfall patterns have been proposed. Ramanathan et al. (2005) posited that aerosols – particularly black carbon -- reduce sea surface temperature by blocking incoming solar radiation, decreasing evaporation and thus water availability for monsoon generation.

2 Changes in the Southeast Asian monsoons have been well documented (e.g., Lau and Yang, 1997; Fu, 2003), but are not discussed here due to minimal impacts on rainfall in HMA.

This mechanism would suggest that monsoon generation will decrease as aerosols increase. An alternative proposed mechanism by which stronger monsoons might be generated is that the aerosols work to trap heat above the ocean and increase evaporation (Ramanathan et al., 2005). Regardless of actual monsoon strength, Lau et al. (2006) propose a mechanism that would account for the observed increase in early summer monsoon rain through aerosols stacking up against the Himalaya and creating positive temperature anomalies in the region, which drive moisture out of the atmosphere earlier than normal. The aerosols could also induce early cloud formation by serving as cloud condensation nuclei and thus promoting early precipitation, though this is likely to be a geographically isolated effect, and highly dependent on regional microclimates (Lau et al., 2006). It is clear that the effect of aerosols on weather patterns is not completely understood, and that no one mechanism has been identified for monsoon modification through aerosols. Furthermore, it is not yet clear whether anthropogenic aerosols, such as black carbon, or increased windborne dust due to desertification plays a larger role in the region (Gautum et al., 2009).

Scientists have also observed inter-annual changes in monsoonal rainfall driven by natural cycles, such as El Niño-Southern Oscillation (ENSO) variations, seasonal snow cover changes and seasonal aerosol content (Bookhagen et al., 2005a). However, even these cyclical variations have shown an upward trend in storm intensity, associated with increasing anthropogenic influence in the region (Bookhagen et al., 2005a). These abnormal rains are shown to extend further than average into the drier reaches of the HKH, where landscapes lack the same type and density of vegetation cover to manage intense rains (Bookhagen et al., 2005a). As the hillsides are less well vegetated, these storms are often heavy drivers of erosion, including large erosion events such as landslides (Wulf et al., 2010; 2012; Paul et al., 2000; Barnard et al., 2001). Thus, short, inter-annual variations in rainfall can have an important effect on water and sediment fluxes in the region, and will likely become more intense due to climate change.

Central Asia and the northwestern Himalaya are affected by very different atmospheric processes than the southeastern areas of AHM (Lioubimtseva et al., 2005; Palazzi et al., 2013). WWDs, originating from as far west as the Mediterranean, are driven by low-level jet streams as opposed to the temperature gradients between land and sea that contribute to the ISM (Barlow et al., 2005). These winter storms carry less moisture than the monsoon, and tend to deposit snow rather than rain. This snow serves as a critical water storage mechanism and accounts for much of the summer water availability in the region.

As in the southern parts of AHM, anthropogenic processes have significant impacts on atmospheric patterns in Central Asia. Central Asia received massive amounts of infrastructural investment in the 1960s, leading to the cotton monoculture which has subsequently degraded water and soil resources (Lioubimtseva et al., 2005). A striking example of this is the dramatic reduction of the Aral Sea due to extensive Soviet irrigation systems. Data analyzed by Lioubimtseva et al. (2005) indicate that Central Asia's rainy season has shifted earlier by around a month, and winters have become longer. They posit that the increase of aerial dust content due to desertification of large swathes of land, as well as regional warming, could substantially alter weather patterns. However, following the collapse of the Soviet Union, many climate stations in the region fell into disrepair, and thus accurate and long-scale climate records are sparse, making analysis difficult.

Several models have been developed to clarify some of the interactions between the spatially complex and diverse responses of atmospheric patterns to climate change (e.g., Bookhagen and Burbank, 2010; Palazzi et al., 2013). Most models agree that Southeast Asia will see increasingly early and extreme summer rains, and that Central Asia will be affected by increasing desertification, as well as increasingly extreme precipitation events when they do occur (Palazzi et al., 2013). However, small-scale topographic and climatic controls – even those as simple as valley orientation and elevation – can offset or amplify these responses within the vast study region.

2.3 Current Knowledge by Mountain Range

Section 2.3 describes current evidence on glacial and hydrological response to climate change in each of the seven mountain ranges comprising AHM. The Hindu Kush, Karakorum and Himalayan ranges have been combined due to close climatic linkages, as well as a wealth of studies considering the three regions as a single unit. This is true to a lesser extent for other ranges; where data in a study extend beyond a single mountain range, results are noted under both ranges below, for example, the Pamir/Tien Shan, and Kunlun/Pamir. Figure 3 provides delineations for each mountain range. These borders are not universally recognized, and are not well defined in the scientific literature.

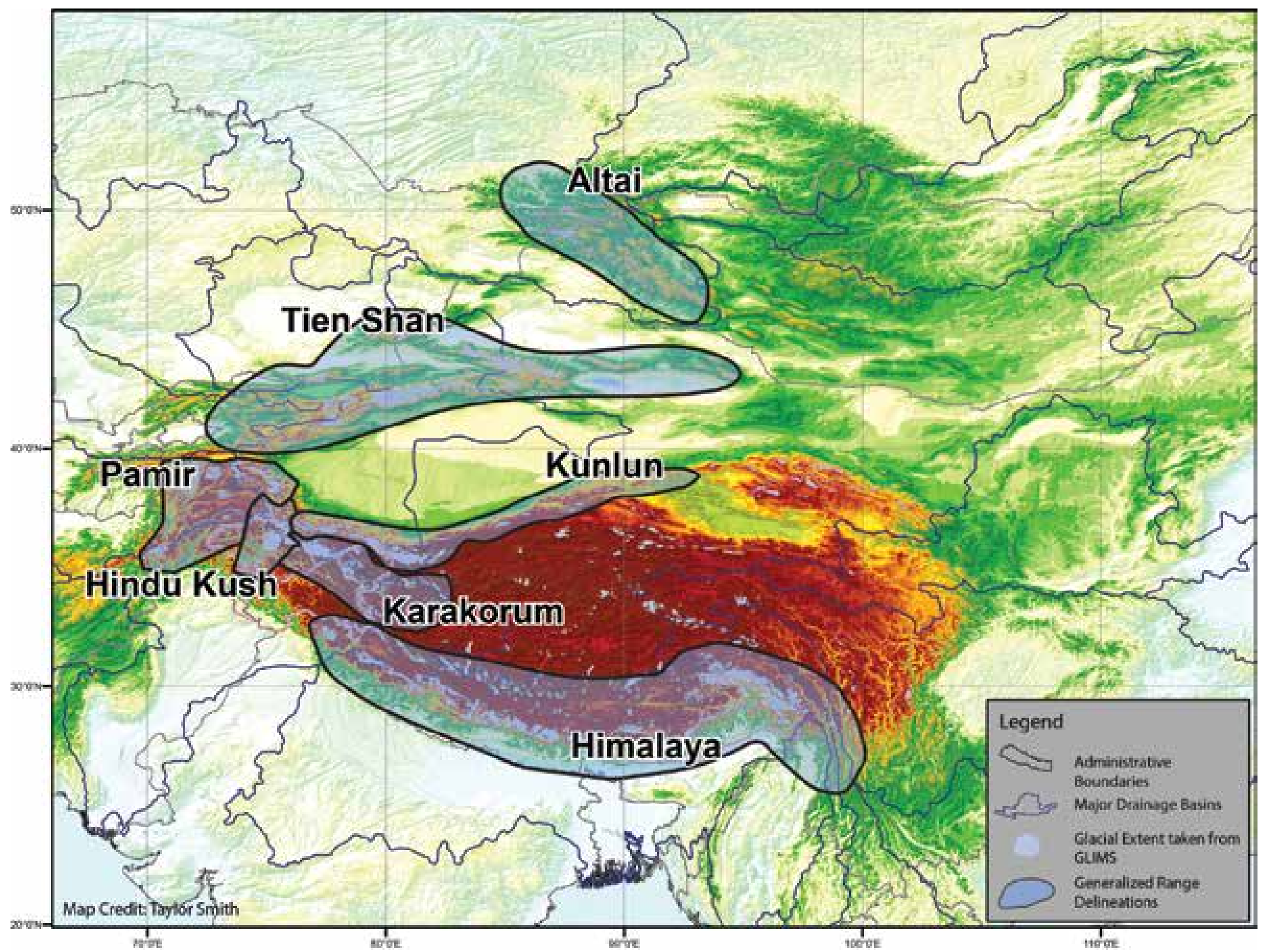


Figure 3 - Generalized range boundaries for AHM, showing major drainage basins, glacial extent and administrative boundaries.

2.3.1 THE HINDU KUSH–KARAKORUM–HIMALAYA REGION

The HKH region extends from northeastern Afghanistan down through Pakistan, India, Nepal and Bhutan, and terminates in western China (Figure 3). Glaciers within the region help provide water for a rapidly growing population of upwards of one billion through the Amu Darya, Indus, Ganges, Sutlej and Bhramaputra Rivers, as well as countless smaller tributaries (Bookhagen and Burbank, 2010; Bolch et al., 2012). The HKH region is unquestionably the best-studied region in AHM.

Rainfall in the HKH region is primarily fed by the ISM, which weakens as it moves from the eastern reaches of the Himalaya northwest towards the Hindu Kush, and by WWDs, which bring moisture in from the Arabian Sea (Barlow et al., 2005; Lang and Barros, 2004). These two main precipitation regimes cause strong spatial, but also temporal, gradients in precipitation throughout the HKH region. The eastern reaches are typically summer-fed, and do not have a large glacial or snowfall contribution to melt water (Palazzi et al., 2013). On the other hand, the western reaches receive more of their precipitation in the winter, and have a much higher glacial and snowfall contribution to melt water (Figure 4) (Bookhagen and Burbank, 2010).

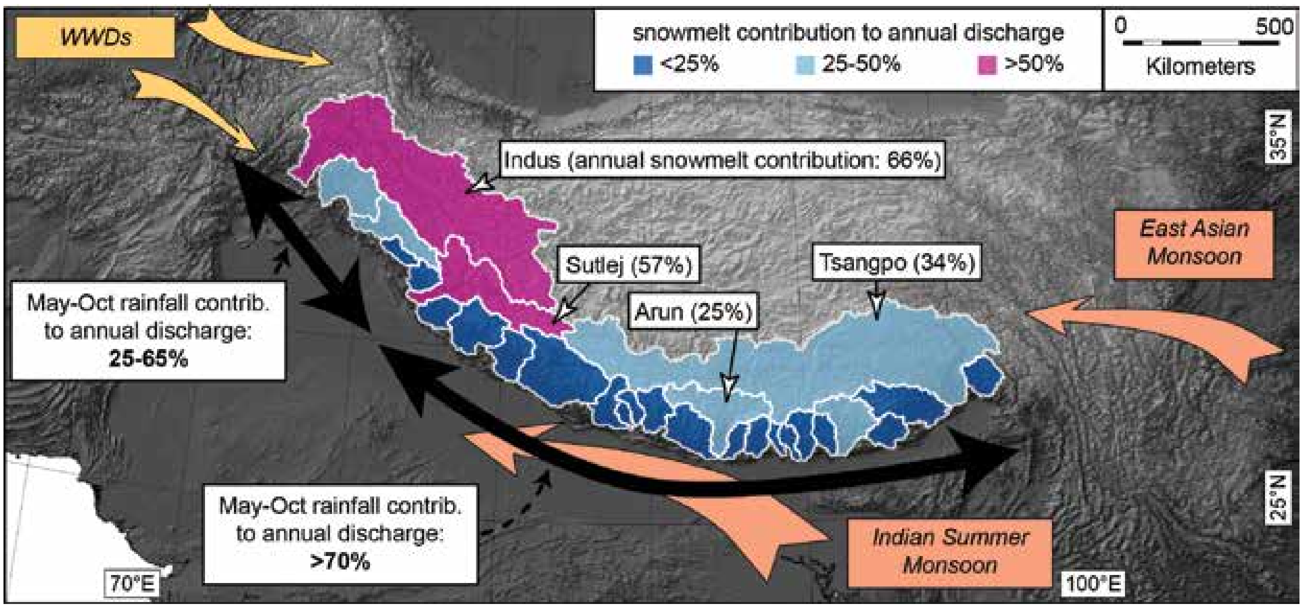


Figure 4 - Snowmelt contribution and weather patterns in the HKH, showing the variable influence of the ISM (May-Oct) and WWDs. Bands of >70% and 25-65% contribution of rainfall to annual discharge indicated by dark arrows. Data derived from satellite precipitation data sets, monitoring stations in the region, and satellite-based snow monitoring. Modified from Bookhagen and Burbank (2010).

The HKH region is also defined by orographic "steps," which create two main rainfall bands that feed the lower and higher elevations of the HKH (Bookhagen and Burbank, 2006; 2010): where relief is between one and 1.5 km, 40% to 50% of precipitation can be extracted from storm systems, and when relief approaches three km, more than 80% of precipitation can be extracted (Bookhagen and Burbank, 2010; Burbank et al., 2012). This two-tiered system has strong implications for downstream impacts in diverse elevation and relief areas throughout the HKH.

Glaciers in the HKH have been described in a number of papers (i.e., Kehrwald et al., 2008; Aizen et al., 2002; Alford and Armstrong, 2010; Kamp et al., 2011; Berthier et al., 2007; Scherler et al., 2011a; 2011b; Bolch et al., 2012). These studies indicate wide ranges of glacial change, although with the exception of glaciers in the Karakorum, the majority of glaciers in HKH have retreated (Figure 5) (Bolch et al., 2012). Glacial retreat rates have accelerated in the majority of the HKH region in the last few decades (Armstrong, 2010). Based on surveillance of HKH glaciers over the past 40 years, retreat rates have varied greatly by glacier, from 2% to 20%, based partly on glacier position, debris cover and other factors further discussed in Section 2.1. Kehrwald et al. (2008) also note that even high elevation glaciers (above 6,000 m) are losing mass. Additionally, numerous small (less than 0.5 km^2) glaciers have disappeared since the 1950s (Armstrong, 2010).

© WWF-CANON / STEVE MORGAN

The Karakorum, and to a lesser extent the western Himalaya, are characterized by stable or slightly advancing glaciers (Hewitt, 2005; Scherler et al., 2011b; Gardelle et al., 2012). Recent studies estimate that over 50% of glaciers have been growing since 2000 (Hewitt, 2005; Gardelle et al., 2012). Factors such as moisture source regions, winter instead of summer accumulation, debris cover and topography have been linked to this regional glacial stability, but the primary driver of glacier growth in the region is likely the trend towards decreased summer temperatures and increased winter precipitation observed since 1961 (Gardelle et al., 2012). These climate trends are not apparent throughout the HKH region, but are a function of the unique climatic setting of the Karakorum Range.

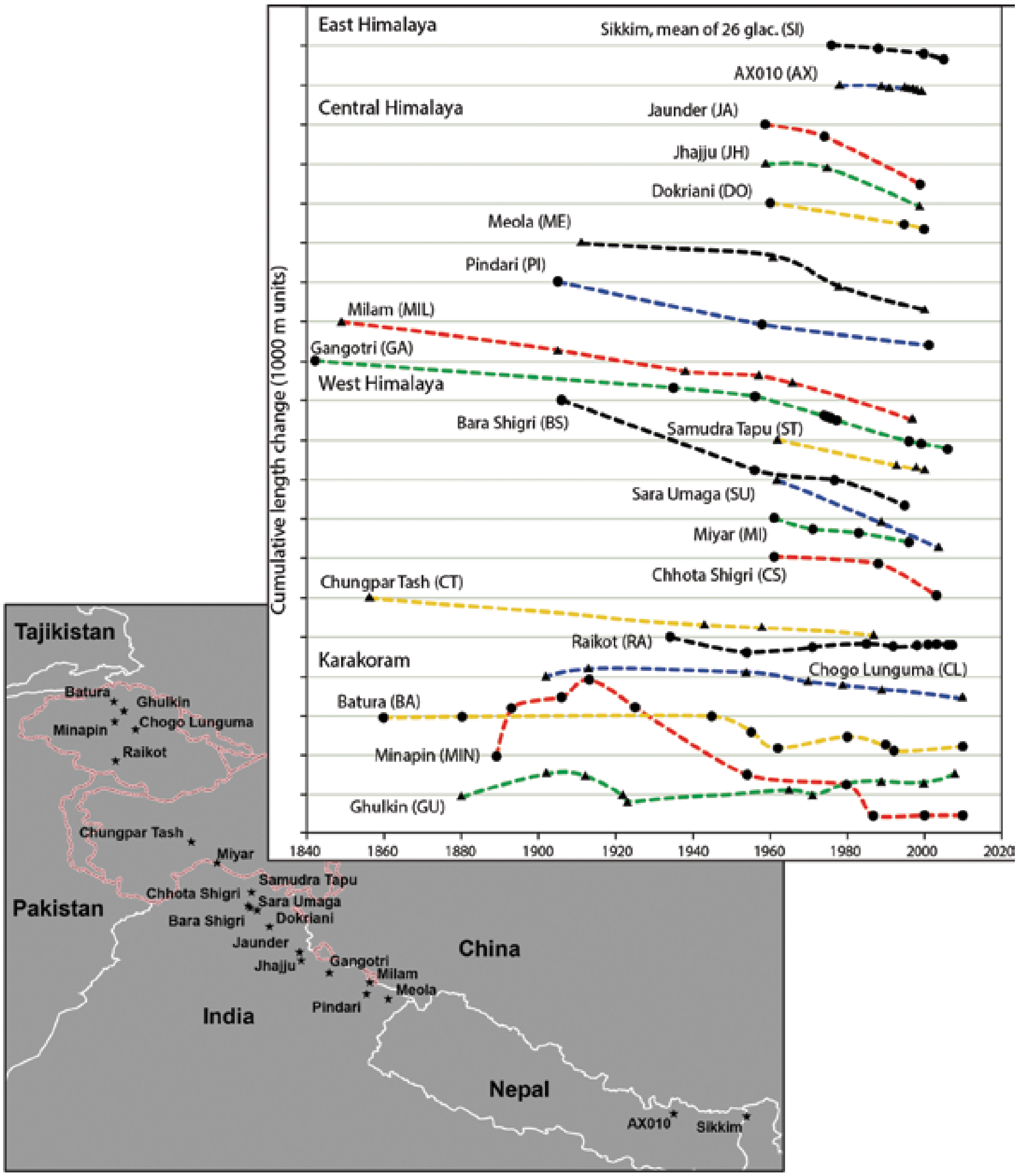


Figure 5 - Glacial length changes throughout the HKH region, showing the growth of glaciers in the Karakorum and the shrinking of glaciers throughout the Himalaya, with inset map showing positions of index glaciers. Modified from Bolch et al. (2012).

Due to the high spatial heterogeneity in glacial responses, and the availability of watershed level studies of glacial character in the HKH, the hydrology and glacial character of four major Asian watersheds are described below: the Amu Darya Basin, Indus Basin, Ganges Basin and Tsangpo/Brahmaputra Basins.

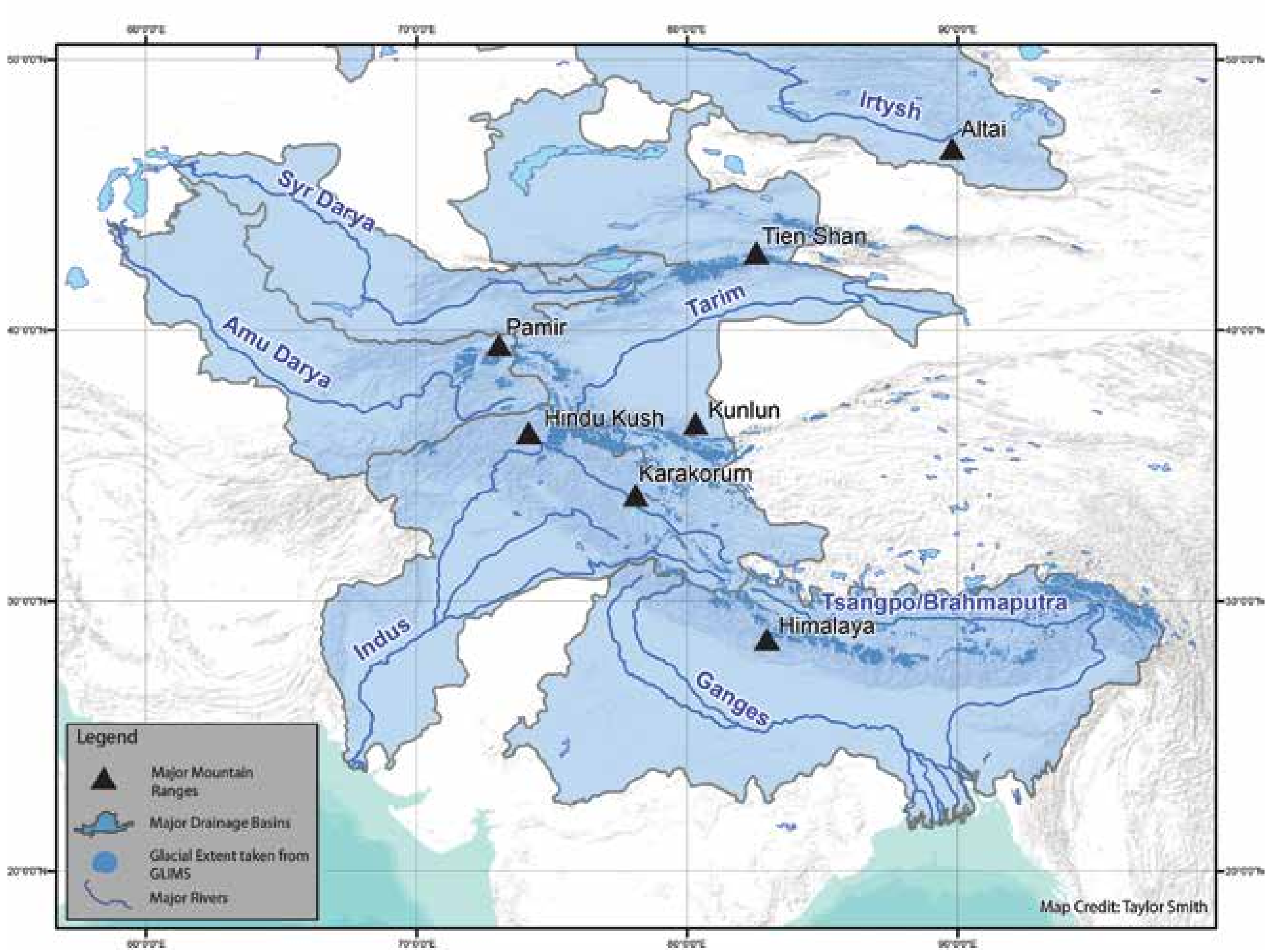


Figure 6 - Major River Basins and Mountain Ranges of South and Central Asia.

2.3.1.1 AMU DARYA BASIN

The Amu Darya Basin has a catchment area of approximately 645,726 km^2, and runs more than 2,500 km from Tajikistan and Kyrgyzstan into the Aral Sea (Bajracharya and Shrestha, 2011). A 2011 inventory identifies 3,277 glaciers, with a total area of 2,566 km^2 and 163 km^3 of ice reserves (Bajracharya and Shrestha, 2011). Average glacial area was 0.8 km^2, ranging up to 40 km^2, with the vast majority of glaciers under 0.5 km^2 (Bajracharya and Shrestha, 2011). The Amu Darya Basin is fed via glaciers in both the HKH and the Pamir Ranges. Glacier melt forms a significant portion of summer water availability in the basin (Bookhagen and Burbank, 2010). A 2006 study predicted only a 0.4% decrease in annual mean discharge in the Amu Darya, though the study was limited by roughness of climate models and the strong impact of irrigation systems in the region, which are difficult to account for in the model (Nohara et al., 2006).

2.3.1.2 INDUS BASIN

The Indus Basin comprises around 1,116,086 km^2, of which nearly half lies within the HKH region (Bajracharya and Shrestha, 2011). It contains 18,495 glaciers, with a total area of 21,192 km^2 and ice reserves of 2,696 km^3. The largest glacier within the basin is 926 km^2, though the average glacier area is only 1.15 km^2 (Bajracharya and Shrestha, 2011). As with the Amu Darya, the vast majority of glaciers have an area of less than 0.5 km^2 (Bajracharya and Shrestha, 2011). The Indus provides water for nearly 90% of food production in Pakistan, as well as 13 gigawatts of hydroelectric power in Pakistan, Afghanistan and India (Cook et al., 2013).

Snow melt and, to a much lesser extent, glacial melt are considered the primary drivers of water availability in the Indus Basin, at 34% of the total hydrological budget (Miller et al., 2012). Jeelani et al. (2012) found that in one sub-catchment of the Indus, snowmelt accounted for nearly 60% of runoff, while glacier melt comprised only 2%. Miller et al. (2012) cite 26% of runoff basin-wide as glacially derived, highlighting both the uncertainty and spatial variability in runoff projections. However, data on winter and summer flows indicate decreasing snow accumulation during winter months and decreased glacier melt availability in summer months in both study areas (Miller et al., 2012; Jeelani et al., 2012). Based on data from Bookhagen and Burbank (2010) and Immerzeel et al. (2010), Miller et al. (2012) project that the Indus will see fairly stable annual water availability for the next few decades, followed by a steep decline as small glaciers disappear. Although water availability annually may remain stable, it is likely that the Indus will see decreased summer flows. It is important to note that these projections are uncertain due to poor monitoring in the region, lack of comprehensive glacial mass balances, and the poorly defined role of permafrost in regional water budgets.

A recent study by Cook et al. (2013) indicates that there are decadal-scale fluctuations in the Indus River's discharge, and that there have been previous long periods of anomalously low flow. They further note that the measured average stream flow between 1962 and 2008 (the period for which modern recordings were made) is 3.5% higher than average flow from the total historical flow record (1452-2008, derived from tree ring studies). These findings indicate that there is decadal or multi-decadal variation in the flow of the Indus River, and that annual reduction or increase in water availability has historical precedent. Unfortunately, the modern flow record is not adequately robust to trace the impacts of climate change on river flow rates or seasonal variability. The main implication of the above-average flow in the last 46 years is that any water allocation plans based on data from this period are likely to overestimate the potential use of the Indus; a multi-century history presented by tree rings would produce a more conservative estimate for such planning.

2.3.1.3 GANGES BASIN

The Ganges Basin has a total area of 1,001,019 km^2, with 244,806 km^2 contained within the HKH region (Bajracharya and Shrestha, 2011). Notably, the basin extends from Mt. Everest, the highest point in the world, down to sea level. The Ganges Basin contains 7,963 glaciers with a total area of 9,012 km^2, and ice reserves of 794 km^3. The largest glacier is 177 km^2, and average glacial area is 1.13 km^2. In general, higher elevations are characterized by larger glaciers (Bajracharya and Shrestha, 2011).

The Ganges Basin is not heavily dependent on glacier melting; studies have shown that only 8.7% of the discharge of the Ganges is related to snow and ice melt (Miller et al., 2012). Precipitation in the Ganges Basin is driven by summer monsoon rains (Bookhagen and Burbank, 2010; Miller et al., 2012). Andermann et al. (2012c) argue that groundwater is a more important water reservoir than glaciers, and that groundwater reservoirs have almost twice the storage capacity of glaciers in the region. However, there are alternative explanations for the data collected by Andermann et al. (2012c), such as melting permafrost reserves and temporary water storage in plants (Bookhagen, 2012). Thus the effects of climate change on water resources in the Ganges are complex and insufficiently informed by data. Transient storage in ice and other water reservoirs drives seasonal availability of water, and acts as a buffering mechanism to provide year-round water in the region (Bookhagen, 2012). Recent scholarship on climate-induced changes in the ISM (e.g. Ramanathan et al., 2005; Gautum et al., 2009) notes that the impacts of climate change upon weather patterns are still debated, although there is a consensus that flows will become more erratic, and that there will be strong fluctuations in water availability between wet and dry seasons. Predictions of seasonal water storage in the region – the most important source of water during the dry season – are as yet unclear, though both aerosols and warming trends in the region have contributed to accelerated snow melt in the Himalayas (Lau et al., 2010).

A recent study has shown that nearly 60% of evaporation from irrigated lands within the Ganges is recycled back into Himalayan rainfall (Harding et al., 2013). As the Ganges Basin is one of the most irrigated areas in the world, this irrigation-driven evaporation is quite significant, and accounts for nearly 40% of precipitation within northern India and Pakistan. This evaporation provides fuel for increased cloud cover, and in turn can lead to increased local rainfall (Harding et al., 2013). However, this rainfall does not necessarily occur in close proximity to the evaporation, and its links to overall monsoon variation are unclear. Harding et al. (2013) posit that the trapping of water in this irrigation-evaporation cycle will reduce overall monsoon circulation, and has the potential to modify regional rainfall; these changes could result in increased rainfall variability, with the potential for larger rainfall events if cloud-building processes are enhanced. As irrigation networks expand in the region, this effect is likely to become more pronounced.

2.3.1.4 TSANGPO/BRAHMAPUTRA BASIN

The Tsangpo/Brahmaputra Basin runs from within the Tibetan Plateau, through north-eastern India, and eventually west to connect to the Ganges.[3] It has a total catchment area of 528,079 km^2, of which 432,480 km^2 lies within the HKH region (Bajracharya and Shrestha, 2011). A total of 14,020 km^2 of the basin is glaciated, with ice reserves of 1,303 km^3. The largest glacier is 204 km^2, and the average size is 1.22 km^2. The majority of glaciers are less than 0.5 km^2 (Bajracharya and Shrestha, 2011). The Brahmaputra Basin is somewhat dependent on glacial water storage, although precipitation is primarily driven by summer monsoon rains (Miller et al., 2012). Seasonal water availability is strongly affected by glacier melt contribution, even if the annual contribution of melt to the overall water budget is low (Bookhagen and Burbank, 2010).

Miller et al. (2012) estimate that between 19% and 21% of the Brahmaputra's discharge is related to snow and ice melt, with the remainder of discharge related to rainfall. There are no data on the high reaches of the Brahmaputra catchment, and thus these estimates have not been fully validated. The Brahmaputra's average discharge is expected to remain somewhat stable (Miller et al., 2012), though it is expected to have higher peak flows, and increased early flows due to quicker snowmelt or rain instead of snowfall as air temperatures increase. This discharge is responsible for moving massive amounts of sediment through the basin, up to two million tons a day in the monsoon season (ICIMOD, 2013).

2.3.2 THE PAMIR RANGE

The Pamir Range sits at the junction of several other ranges in AHM (the Kunlun, Karakorum, Hindu Kush and Tien Shan). Unfortunately, there has never been a comprehensive study of glacial character in the Pamir Range, due to complex topography, lack of field measurements and geopolitical strife in the region, particularly in Afghanistan (Haritashya et al., 2009).

Haritashya et al. (2009) note that many of the most recent measurements of glaciers in the Afghan Pamir were undertaken in the 1980s by Soviet surveys. Utilizing data from these surveys as a base, Haritashya et al. (2009) identified 30 glaciers, and noted an average retreat distance of 294 meters over the period of 1976 to 2003 (10.9 meters per year). They noted a substantial increase in the frequency of lakes formed below wasting glaciers. Their study does not identify any increase in melting rate over time, potentially as a result of insufficient data (Haritashya et al., 2009).

One of the few additional studies focused explicitly on the Pamir Range comes from a Chinese study of the eastern reaches of the Pamir (Shangguan, 2006). Shangguan (2006) notes that between the 1960s and 1990, glacial retreat was on average six m/yr, and between 1990 and 1999, that rate jumped to 11.2 m/yr. Total glacial area was seen to decrease by 8%, and increases in summer temperatures are identified as the main driver of glacial wasting (Shangguan, 2006).

Khromova et al.'s (2006) results indicate that the glaciers in the eastern Pamir have lost between 8% and 12% of their areal extent between 1978 and 2001, with a trend towards faster losses from the 1990s onwards. However, more recent work has suggested that glaciers in the Pamir Range have remained

3 In much of the literature, the Tsangpo/Brahmaputra Basin is referred to as simply the Brahmaputra Basin, though the upstream section within Tibet (China) is often referred to as the Tsangpo Basin, and the downstream section, once it has entered India, is referred to as the Brahmaputra Basin. For clarity, it will be referred to in this report as simply the Brahmaputra Basin.

stable or gained mass over the period of 1999–2011, based on satellite-derived mass balance estimates (Gardelle et al., 2013). This agrees with regional estimates made in the Karakorum (i.e., Gardelle et al., 2012). It is likely that the same weather pattern effects occurring in the Karakorum have influenced the glaciers in the Pamir (Gardelle et al., 2013). Furthermore, Gardelle et al. (2013) note that the Pamir has been characterized by numerous surging glaciers. The disagreement between previous studies purporting general glacial retreat in the region and Gardelle et al.'s (2013) estimates of glacier growth is unfortunately not discussed, though methodological, data source and temporal differences could be responsible for some of the disagreement in estimates.

2.3.3 THE KUNLUN RANGE

The Kunlun Range sits along the edge of the Tibetan plateau, and occupies a very cold and low-precipitation region completely contained within China. In the 1970s, the Chinese government initiated the Glacial Inventory of China (GIC), which was completed in the early 2000s (Shi et al., 2006). A subsequent inventory has begun, but results are not yet published. Several studies have drawn upon the GIC data to estimate glacial loss in the Kunlun Range.

Using GIC data through 2001, Shangguan et al. (2007) note in their survey of 278 glaciers in the Kunlun Range that retreat rates are smaller than in other ranges of AHM over the same time period. Total area decreased by only 10 km^2 (0.4%), though the rate of retreat increased after 1990 (Shangguan et al., 2007).

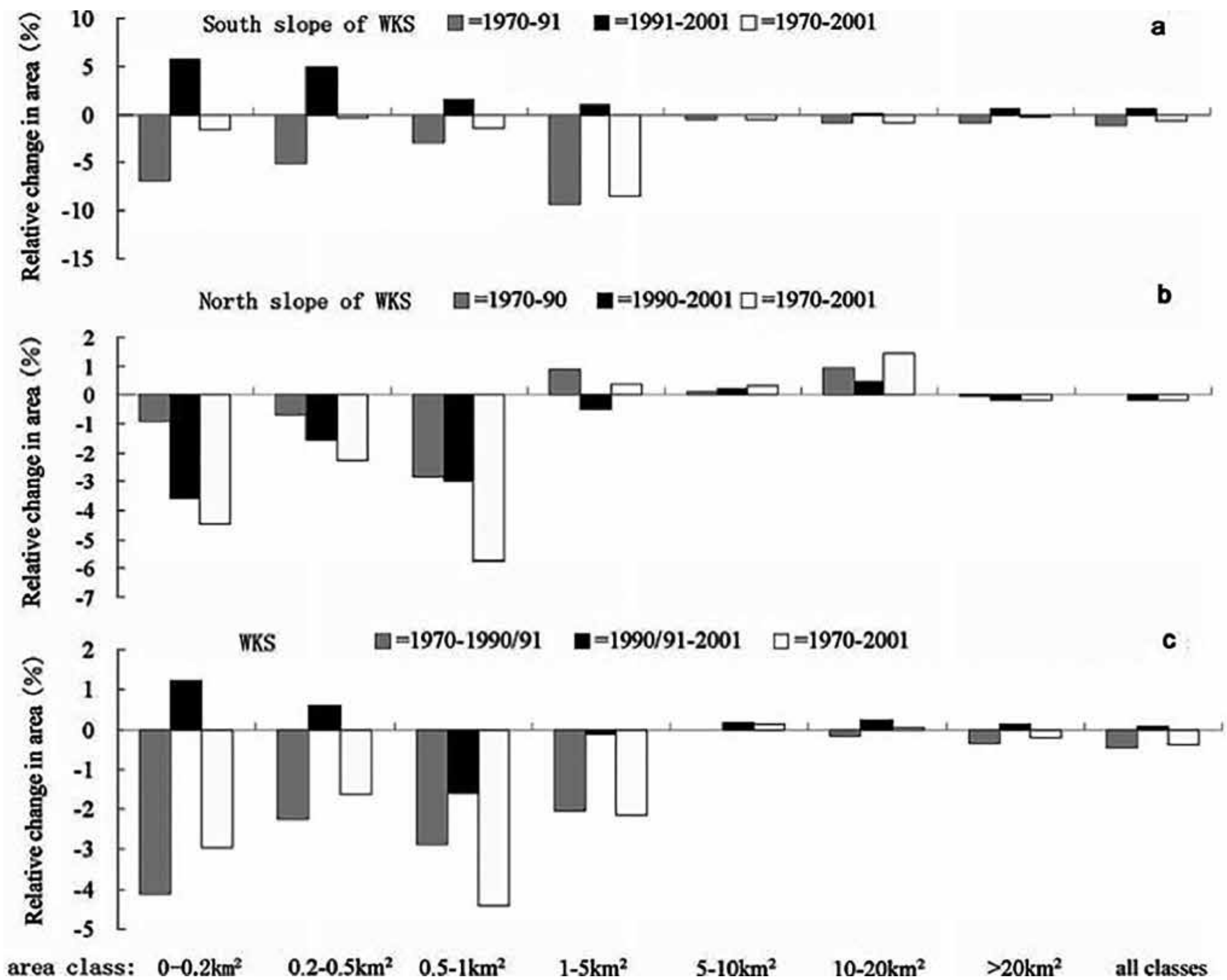


Figure 7 - Glacial area changes by glacial area class on the south (a) and north (b) slopes and their aggregates (c) of the Western Kunlun Shan (WKS), showing less glacial retreat on the south facing side and in larger glaciers (Shangguan et al., 2007).

Another general survey of the characteristics of Chinese glaciers using GIC data found that glaciers in the Kunlun region had not significantly retreated (Ding et al., 2006). They note that although more than 80 percent of glaciers in China had retreated during the period of 1970 to 2001, some glaciers in the Kunlun had in fact advanced during that time. The researchers attributed their findings to warming trends occurring during winter months as opposed to during the glacial ablation season, and to slight increases in precipitation in the region over the last 40 years (Ding et al., 2006). Studies completed in the Kunlun indicate that the region is still somewhat sheltered from the effects of climate change, although with projected increased air temperatures throughout AHM, glacial retreat is likely over the coming decades.

2.3.4 THE TIEN SHAN RANGE

The Tien Shan Range (also known as the Tian Shan) extends almost 2,800 km from Tajikistan northeast into China. Its climate is controlled by both the WWDs and the Siberian High, which together create strong precipitation gradients throughout the range (Narama et al., 2010a). Precipitation also varies seasonally. The western edges of the range tend to have more winter precipitation in the form of snow, with precipitation concentrated in the spring and summer in the central and eastern reaches of the Tien Shan (Narama et al., 2010a).

Sorg et al. (2012) note that due to the interaction of the Siberian High and more western continental atmospheric patterns such as WWDs, the Tien Shan Range has a distinct precipitation gradient with decreasing precipitation from the northwest to southeast. There is also a strong gradient between outer and inner reaches of the Tien Shan, as moisture is trapped by the topography of the range (Sorg et al., 2012). They note that precipitation occurs earlier in the outer and eastern reaches of the Tien Shan, though general precipitation throughout the region is low (Sorg et al., 2012).

© HARTMUT JUNGIUS / WWF-CANON

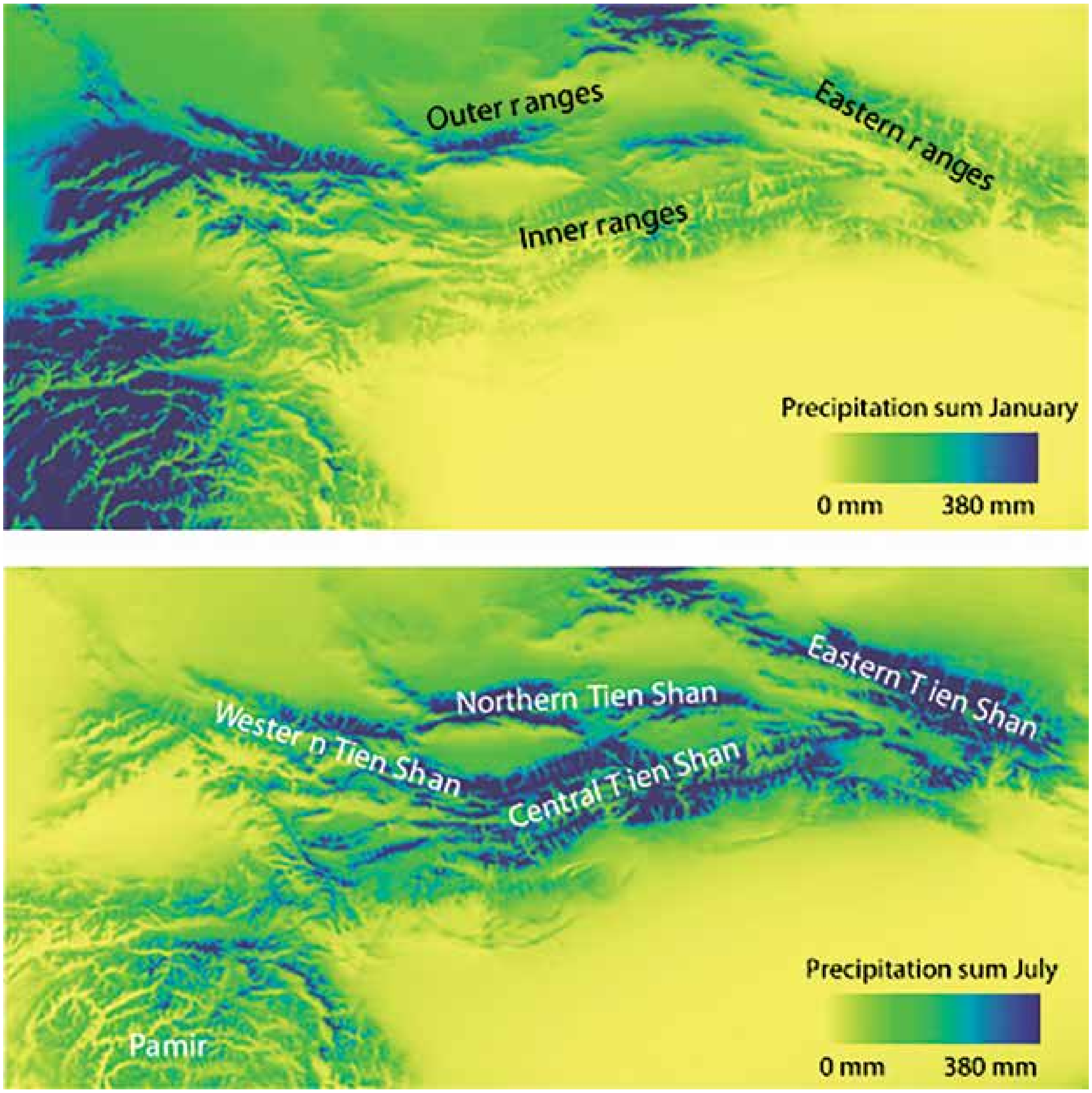


Figure 8 - Averaged seasonality in precipitation throughout the Tien Shan in January (top) and July (bottom), 1961-1990. Data from Bohner (2006), analyzing NCAR/CDAS GCM data. Modified from Sorg et al. (2012).

As can be seen in Figure 8, there is distinct seasonality in the precipitation in the diverse areas of the Tien Shan. Thus, the different sub-ranges react differently to climate change. More glacier loss was noted in the outer ranges than in the inner ranges (Sorg et al., 2012). Recent estimates put the total glacier mass loss in the Tien Shan at -5 ± 6 gigatons per year between 2003 and 2010 (Jacob et al., 2012).

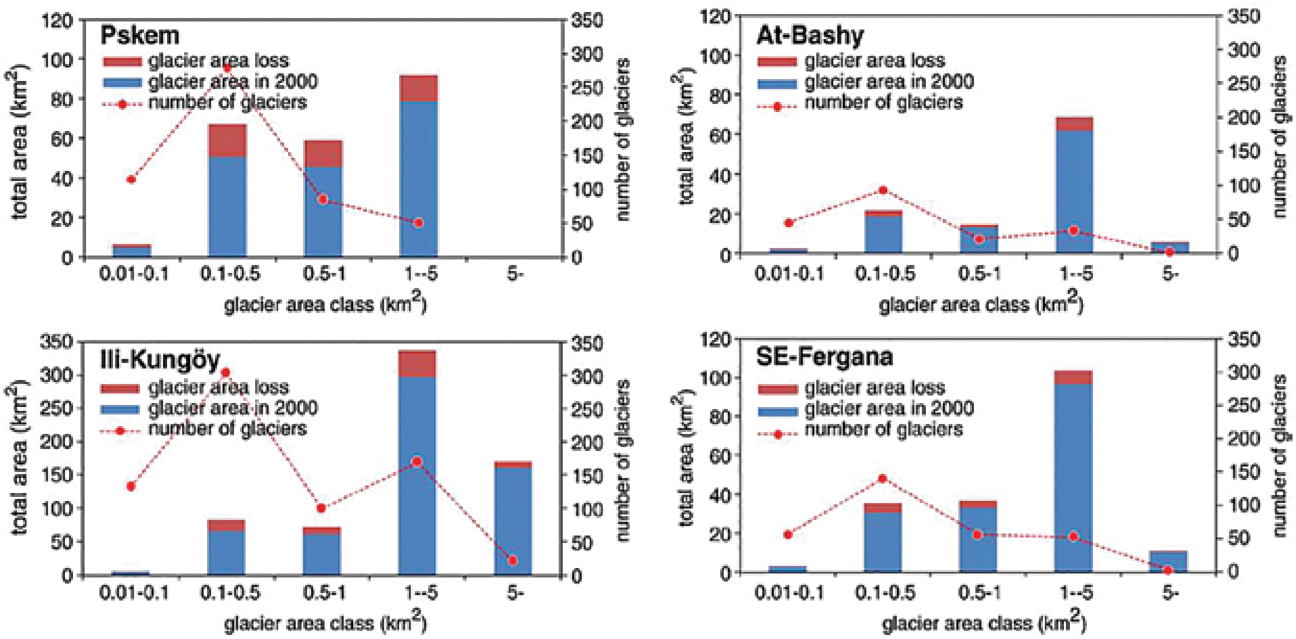


Figure 9 - Representative glacial loss throughout the Tien Shan (~1970-~2000) (Narama et al., 2010a).

In a smaller scale study, Narama et al. (2010a) found that for the period of 1970-2010, glacial area decreased between 9% and 19%, depending on the subregion of the Tien Shan analyzed. Glacial loss was then seen to accelerate between 2000 and 2007, except in a few cases in the southeastern reaches of the Tien Shan (Narama et al., 2010a). This agrees generally with work by Aizen et al. (2006), which noted that total glaciated area in the northern and central Tien Shan had shrunk by 14.2% between the 1860s and 2003, with the bulk of shrinking occurring between 1977 and 2003. Recent work by Pieczonka et al. (2013) noted that though there has generally been mass loss throughout the central Tien Shan over the last few decades, the retreat rate has been slowing over the past 15 years.

As with other ranges in AHM, small glaciers were more responsive to warming trends, and played a disproportionate role in glacial shrinking in the region (Aizen et al., 2006; Narama et al., 2010a). Isolated areas were also noted for glacial surging in the period of 2000-2007, with some glaciers growing by as much as 1,400 meters (Narama et al., 2010a).

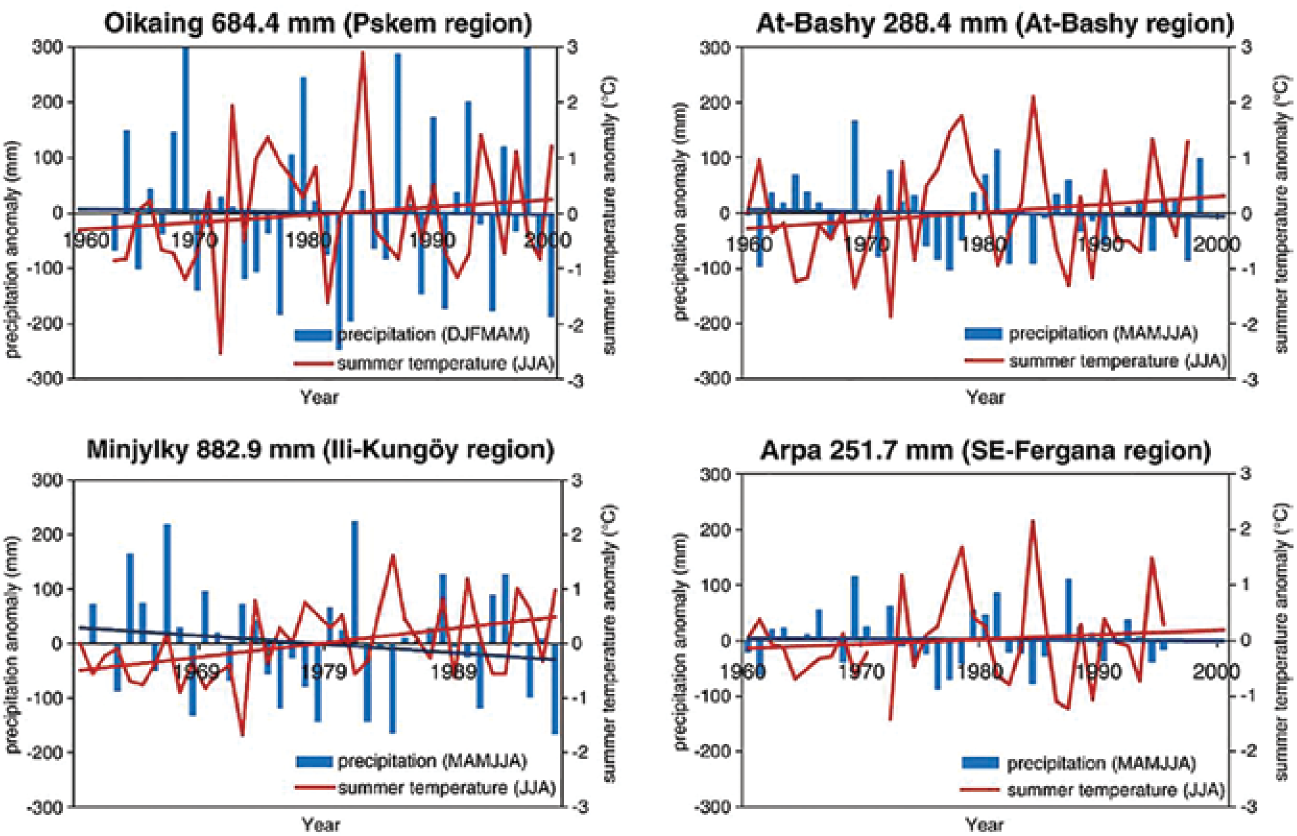


Figure 10 - Trends in summer temperature and precipitation throughout the Tien Shan, showing slight summer temperature increases and precipitation decreases during the four decades from 1961-2000. Data averaged over four weather stations in each region (Narama et al., 2010a).

Temperature trends are consistent with the overall melting regime. As seen above in Figure 10, summer (June-July-August) temperatures increased, and precipitation decreased slightly or remained stable (Narama et al., 2010a). These conditions could result in increased glacial ablation during the summer. Over time, if warming trends continue, water flux in the region will increase and then decrease as smaller glaciers disappear entirely (Narama et al., 2010a).

2.3.5 THE ALTAI RANGE

The Altai Range runs roughly 1,400 km southeast from southern Siberia in Russia through Mongolia and China (Kadota and Gombo, 2007). Though it is an extensive mountain range, significantly less research has been conducted in the Altai region than in the HKH region. To date, there has been no comprehensive study of the glaciers of the Altai range, and the WGMS Global Land Ice Measurements from Space (GLIMS) database lists only a handful of glaciers in northwest Mongolia (Armstrong et al., 2013). This review did not include work published in languages other than English, although an effort was made to include syntheses of results published in non-English journals, for example, as provided by Lioubimtseva and Henebry (2009).

Dahe et al. (2006) note that temperature changes in the Altai mountain range in northern China have a very strong correlation with global temperature changes. They note that unlike the more southern ranges of AHM, the Altai are primarily influenced by fluctuations in the North Atlantic Oscillation, which runs between the Azores and Iceland (Cohen and Entekhabi, 1999). These fluctuations lead to primarily cold arctic air masses which do not transport large amounts of precipitation. Indeed, snow cover is not typical of much of the region, and glaciers are located only at high elevations, despite the generally low temperature year round (Shahgedanova et al., 2010). Additionally, the glaciers in the Altai Range are characterized by a single season of both accretion and ablation, as the Altai receives the majority of its precipitation between April and September (Shahgedanova et al., 2010). These types of glaciers are less well understood than the glaciers typical of the European Alps, and thus the impacts of climate change on glacial extents are not well constrained.

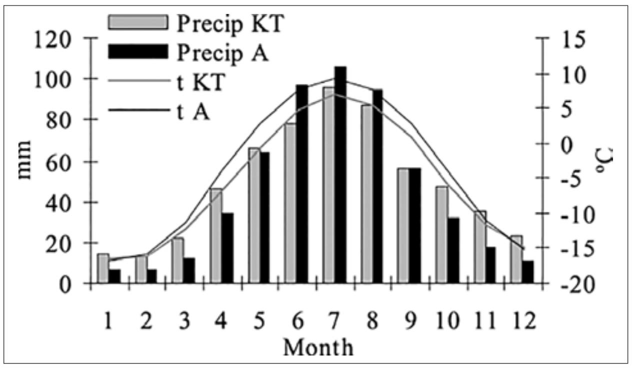
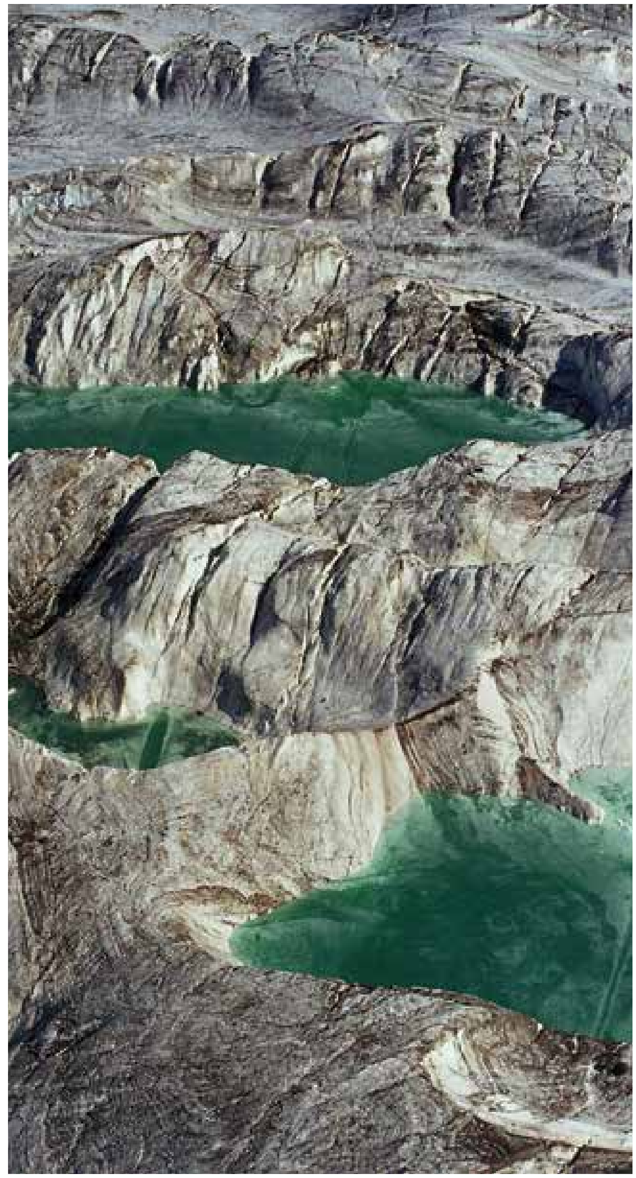


Figure 11 - Average monthly precipitation and temperature data for the Kara-Tyurek (KT) and Akkem (A) stations in Mongolia, 1952-2004 (Shahgedanova et al., 2010).



© NIKOLAY KUZNETSOV / WWF-RUSSIA

Shahgedanova et al. (2010) identify a 1960 glacial area of 910 km² throughout the Altai, but do not provide a current estimate. Using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery from 2004, they mapped 256 glaciers with a combined area of 253 km² in the Russian Altai (Shahgedanova et al., 2010). They found an 82 km² reduction from 1952 levels among glaciers with areas greater than 0.5 km², translating into a 20% reduction in glacial extent. A similar study in Mongolia noted a 10% to 30% reduction in glacial area over four study regions (Kadota and Gombo, 2007), which agrees well with the results of the Russian survey. Glaciers with areas less than two km² were shown to lose significantly more of their mass, indicating that smaller glaciers are more responsive to warming trends. Aspect control was also observed in that glaciers facing east or west (those which receive the least insolation) shrunk the least (Shahgedanova et al., 2010). Elevation has also been shown to be an important control on glaciers in the region, as temperature changes above 2,500 meters have been less significant than those below (Surazakov et al., 2007).

Batima et al. (2005) note that Mongolia has seen an increasing trend of warming, as well as increasingly long heat waves. Similarly, the duration of cold waves has decreased throughout the country (Batima et al., 2005). They have noted that general climate throughout Mongolia is getting warmer and slightly drier (Figure 12), although there are large spatial variations. In particular, the central areas of Mongolia are seeing less precipitation, while the eastern and western extremes are seeing slightly more (Batima et al., 2005).

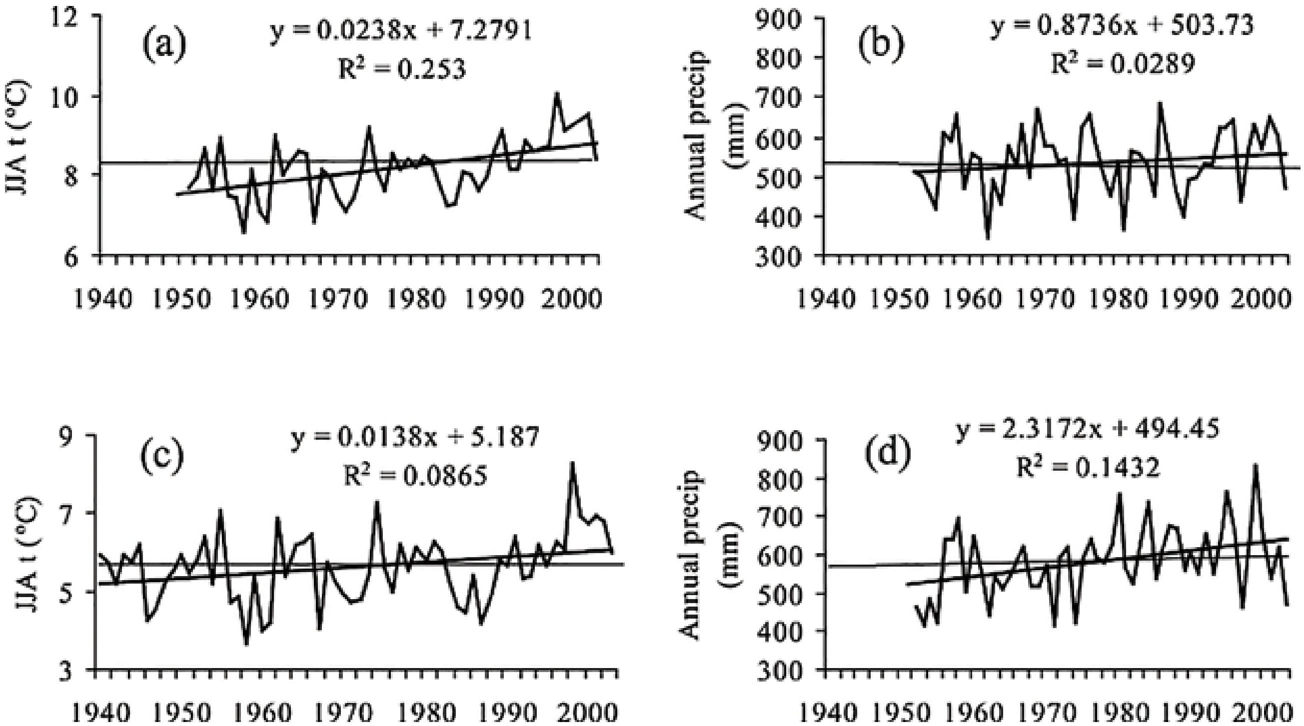
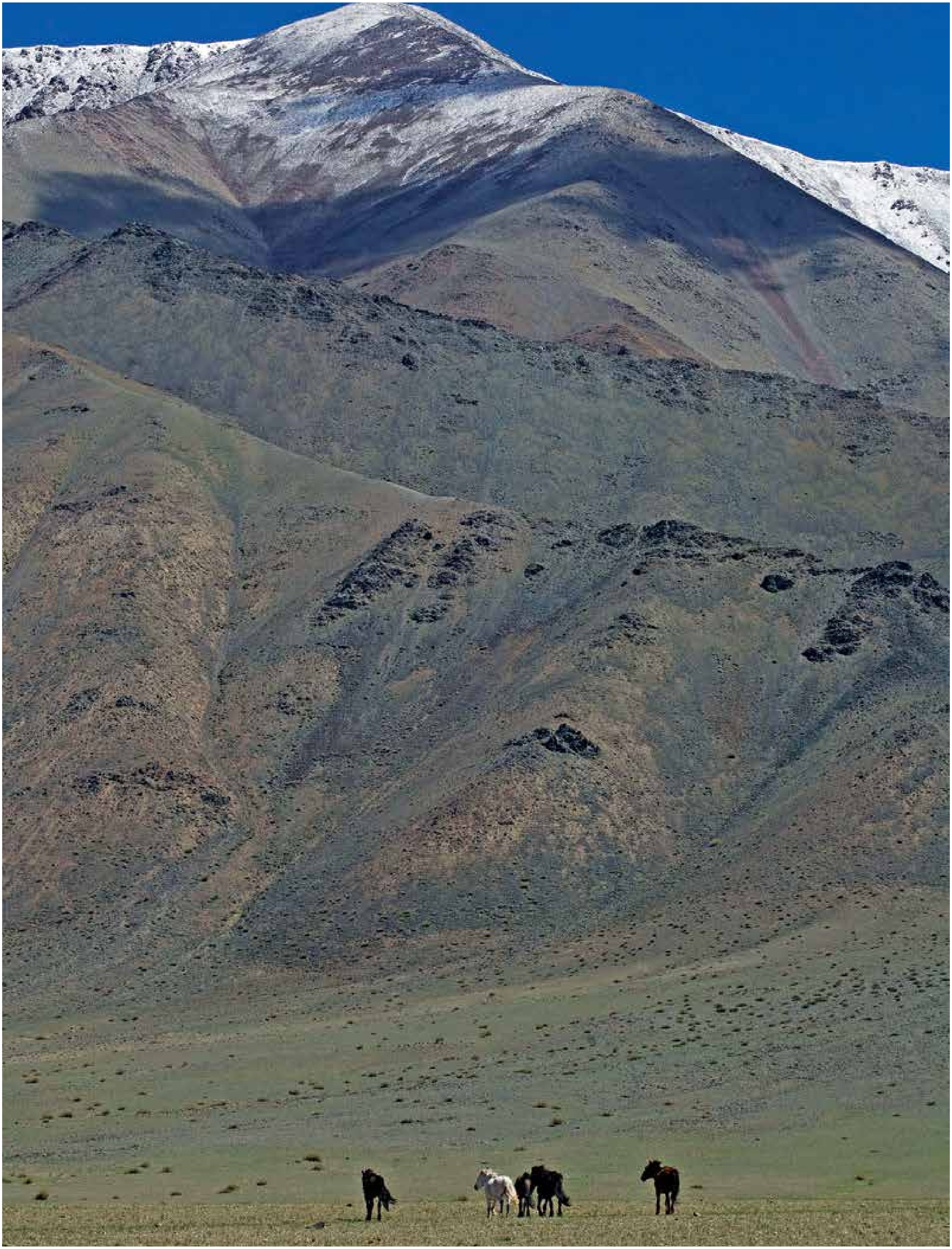


Figure 12 - Average temperature and precipitation trends for Akkem (a, b) and Kara-Tyurek (c, d) stations, 1940-2004. Temperature data shown only for June-July-August (JJA) (Shahgedanova et al., 2010).

2.3.6 SUMMARY OF RANGE-SPECIFIC KNOWLEDGE

In general, water availability in the Hindu Kush and Himalaya Ranges is strongly controlled by seasonal rainfall, and glacial melt has less of an impact than in other ranges of AHM. They are also at the highest risk of cloudburst-type floods, and have seen more GLOF than other ranges due to glacial retreat. The Karakorum and Pamir Ranges have seen slight mass gain in glaciers, which has slightly decreased runoff in streams in the region as more water is stored in glaciers. This also creates hazards in the form of jökulhlaups (ice-dammed lake floods) which can occur due to surging glaciers blocking rivers. Glaciers in the Kunlun Range have yet to be strongly affected by climate change due to high altitudes and generally low temperatures. However, some smaller glaciers have been noted to retreat in the region. The Altai and Tien Shan regions have also experienced glacial retreat, which is likely to intensify over the coming decades. Furthermore, weather pattern changes in the region have increased the incidence of extreme weather, and particularly the incidence of summer heat waves.



JARGALANT MOUNTAIN IN MONGOLIA; © WWF-CANON / SIMON RAWLES

SECTION III
Summary of Literature on Climate Change Vulnerability and Impacts

This section (1) describes the implications of climate change on flood risk, sedimentation, ecosystem services and human health; and (2) reviews current knowledge on vulnerability to, and impacts of, climate change in each of the region's seven mountain ranges.

The inhabitants of AHM are predominantly livestock herders and small-scale farmers, and are highly dependent on consistent water availability and quality (Malone, 2010). These populations are also some of the poorest in the region, and the least adaptable to increased seasonality in water availability and other environmental changes brought on by climate shifts.

Though seasonal and yearly fluctuations in rain and snowfall are primary drivers of vulnerability through flooding, sedimentation and ecosystem changes, more rapid processes, such as glacial lake outburst floods (GLOF), heat waves, cloudburst floods and droughts, can also have a significant impact on downstream populations.

AHM also provide water for millions of people downstream. As can be seen in Figure 13, major rivers sourced within glaciated areas provide water for some of the most densely populated areas of Asia.

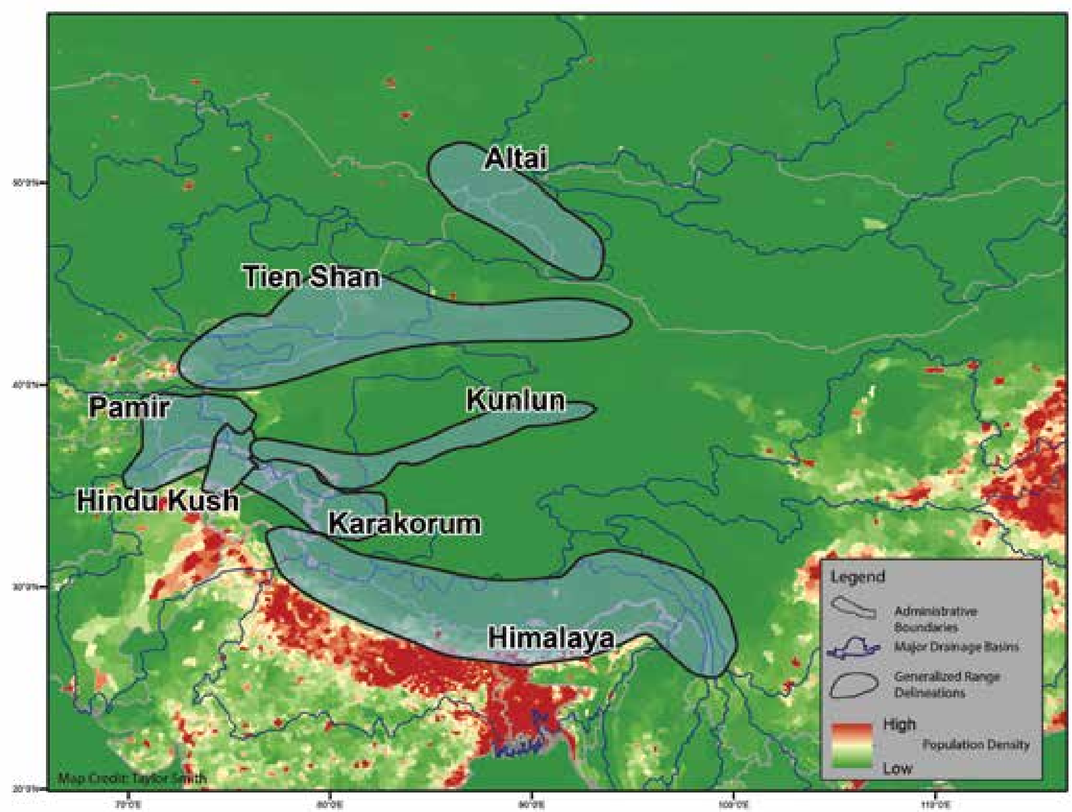


Figure 13 - Population density in 2005, showing range delineations, administrative boundaries, glaciated areas and major watersheds. Population density in the region ranges from 0-120,000 people/km². Population data from Gridded Population of the World, v3 (Balk and Yetman, 2005).

Several reports have also linked climate change to human health impacts, such as the spread of vector-borne disease, decreased food security and increased incidence of heat waves (e.g., Malone, 2010; Patz et al., 2003; Githeko et al., 2000; WHO, 2011; 2012).

3.1 Flooding

Southeast Asia is characterized by semi-regular extreme floods on many of its major waterways, including those sourced from AHM. However, this watershed-level flooding is driven largely by monsoonal and other large storms; glacier melt is unlikely to play a large role in watershed-level flooding, even under the most extreme warming scenarios (Armstrong, 2010).

Flash flooding is a danger throughout AHM, particularly at higher elevations, and will likely become increasingly prevalent as storm systems become more extreme (IPCC, 2013b). Flash floods stem from a range of sources – GLOF, landslide lake outburst floods (LLOF), rain-on-snow events, and cloudburst floods being the most common. Flash floods introduce a range of problems, including rapid sediment mobilization, mudslides and landslides, and the destructive force of rapidly-moving masses of water which collectively destroy infrastructure and can cause loss of human life (Shrestha et al., 2008a). They also result in second-order impacts, such as loss of tourist revenue and perishable agricultural products due to destruction of transportation networks.

The primary mechanism through which glaciers influence flooding is through GLOFs. When glaciers retreat, they typically create moraines – piles of sediment and rocks deposited by retreating glaciers (Cuffey and Paterson, 2010). These moraines are weakly bonded, but are often strong enough to form lakes from glacier melt water. As glaciers retreat under most warming scenarios, these lakes are likely to become more prevalent and to store more water. Furthermore, as lake levels rise, the danger of surge waves due to avalanches, rockslides or glacial calving increases (Ives et al., 2010). These factors can cause the lakes to overtop their dams and flood downstream areas, or even completely empty in the case of a catastrophic dam failure.

In those areas in AHM where glaciers are more likely to be advancing, such as the western reaches of the HKH (Karakorum), jökulhlaups (ice-dammed lake floods) create a similar flooding risk (Armstrong, 2010). Ice-dam floods occur when a glacier advances across a river or stream, damming the river to form a temporary lake. If glacial ice eventually retreats or breaks up, the rapid release of trapped water can cause hard-to-predict downstream flooding. Similarly, LLOFs occur when a landslide temporarily dams a river channel, and allows water to build up (Wulf et al., 2012). As landslides can be caused by extreme weather and by glacial activity, LLOFs are included here.

Changes in weather patterns, and particularly in the spatial and temporal distribution of extreme events, are more likely to impact human populations than glacier melt, due to the large contribution of rainfall to hydrologic budgets, prevalence of cloudburst flooding, and typical location of lakes at risk of GLOF in low-population areas (Armstrong, 2010). It is notoriously difficult to predict large storms derived from the ISM, which drives much of the extreme precipitation in the HKH region (Wulf et al., 2010). However, as noted in Section 2, the entirety of AHM is at risk of increasingly extreme precipitation, even in the context of fairly stable mean regional precipitation levels (IPCC, 2013b; Gautam et al., 2009).

3.2 Sedimentation

Changes in surface water resources through rainfall and glacier melt also drive changes in downstream sedimentation rates. Excess sedimentation will have negative impacts on water quality for human consumption, agriculture and infrastructure such as roads and dams.

Sediment flux is controlled by a combination of water availability, slope cohesion, vegetation cover and lithology (Wulf et al., 2012). Wulf et al. (2012) provided evidence that the spatial distribution of storms can have an important impact on sediment flux in AHM, in that availability of erodible materials is highly dependent on yearly precipitation and plant regime. For example, in the wet eastern reaches of the HKH, heavy rain is typical, but plants are abundant, slopes are shallow, and infiltration rates are high—leading to low sediment flux. Conversely, the interior of the Himalayan Range, where rainfall is scarce, is much more sparsely vegetated, has steeper slopes, and has higher sediment availability.

Bookhagen et al. (2005a) note that the ISM has a strong inter-annual variability and can have abnormally large precipitation events that penetrate into the more arid reaches of the HKH. These storms drive a significant increase in debris flows and rapid sediment mobilization into rivers (Bookhagen et al., 2005a). Even in wetter regions, high intensity storms account for almost 30% of yearly sediment flux (Wulf et al., 2012). Thus, if storm intensity increases as predicted by the IPCC (2013b), sedimentation in the region is also likely to increase.

Glacier melt can also drive increases in sediment mobilization (Wulf et al., 2012). Glaciers often contain large amounts of incorporated debris and sediment (Cuffey and Paterson, 2010). As glaciers continue to retreat in the region, sediment flux is likely to increase through both additional water availability for erosion, and the evacuation of sediments from retreating glaciers (Wulf et al., 2012).

Land cover is also an important driver of erosion (e.g., Valentin et al., 2008; He et al., in review). In a controlled plot study, Valentin et al. (2008) analyzed the comparative sediment yield of plots under different slope, land cover and precipitation regimes over 27 catchments in five Southeast Asian countries. They concluded that, at a catchment scale, erosion was controlled primarily by land use, and that the continuous cropping of plants such as cassava and maize promoted high rates of soil erosion (Valentin et al., 2008). They note that improved soil management techniques, such as increasing vegetated soil cover through interplanting legumes or letting fields lie fallow, can slow sediment loss. It is important to emphasize that the extreme slopes in AHM, as well as extreme rainfall events, may drive more extreme sedimentation events. Studies conducted on low-slope areas may not readily translate to the extreme topography characteristic of AHM.

In addition to known impact on water quality, discussed in the section Ecosystem Services, below, the impact of sedimentation on the region's hydroelectric power generation is very important, as hydroelectric plants in AHM account for nearly 180 gigawatts/yr of renewable electricity (Lako et al., 2003).

Hydropower turbines are constantly subject to abrasion from suspended sediment (Thapa et al., 2005; Wulf et al., 2010). This abrasion increases maintenance needs, decreases turbine efficiency, and can limit the cost-effectiveness of hydropower plants, particularly when situated in remote locations where repairs are costly or difficult. Excess sediment can also build up in dammed lakes, reducing their power-generation capacity and water storage potential (Dang et al., 2010). This is true throughout AHM, but particularly in areas such as Nepal, Bhutan and northwestern India, which are characterized by extreme relief, heavy monsoon rains and high sediment availability.

The same areas of high relief, heavy rainfall and high sediment availability will see significant problems with irrigation infrastructure. As water moving through irrigation channels becomes more and more sediment-rich, these systems are subject to infilling, and equipment subject to abrasion.

3.3 Ecosystem Services

The coupled effects of anthropogenic and climate-induced land degradation have a significant effect on water resources and erosion processes. Land degradation can also impact natural ecosystems, such as river, forest and grassland environments. These environments together provide food, timber, water and pest regulation, recreation and tourism, and a range of other ecosystem services essential to communities in AHM (Millennium Ecosystem Assessment, 2005).

As noted above, both anthropogenic and climatic influences can significantly increase sediment availability in river systems (e.g., Valentin et al., 2008; Wulf et al., 2012), which in turn can significantly alter the character of river ecosystems that support a wide range of flora and fauna, as well as supply drinking water to communities in AHM. As sediment increases, concentrations of microorganisms often increase due to increased nutrient availability (Palmer et al., 2008). This can lead to degraded water quality, and can also lead to reduced dissolved oxygen, which reduces fish stocks (Ficke et al., 2007). Increasing river flows could help spread waterborne pathogens or toxins, which would impact communities previously shielded from these (Malone, 2010). Conversely, decreasing flows as a result of shrinking water availability would reduce biodiversity, as well as potentially concentrate toxins mobile in water into smaller areas (Palmer et al., 2008).

Forest ecosystems are not common in AHM, due to the high elevations. However, because vegetation cover is highly influenced by weather patterns, more extreme weather patterns may increase the incidence of drought and landslides that impact forest ecosystems (Dale et al., 2001). Although not directly related to climate change, Xu et al. (2009) show that as water tables lower in response to overuse of groundwater resources, many areas in AHM will become too dry to support forests. How forests will ultimately respond will be heavily dependent on local climate, management strategies and local water availability.

Xu et al. (2009) also predict that non-forested ecosystems in AHM, such as high meadows, are likely to lose biodiversity due to changes in temperature, phenology and pollination. As plants bloom at new times of the year, due to temperature and precipitation changes, pollinators, as well as herbivores, are likely to be affected. This is especially true of migratory species, which time their migrations based on plant phenology (Xu et al., 2009). Xu et al. (2009) also note that because of the stabilizing influence of plants on hillslopes, changes in plant range, growth pattern or diversity have potential impacts on hillslope stability in the region (Xu et al., 2009; Wulf et al., 2012).

Potentially shorter summer growing seasons, increased frequency of droughts and increased erosion are likely to affect rangeland productivity in high grasslands areas (WWF China, 2010). When coupled with human-induced degradation due to overgrazing, shifting cultivation patterns, and mining and other industrial activities, climate change is likely to increase pastoral vulnerability in AHM (WWF China, 2010). It is yet unclear whether human-induced degradation or climate change is the more important influence on changes in high rangelands, although the two factors likely have a synergistic effect that will continue to worsen in the coming decades.

These climatic and anthropogenic changes have reduced the production of many rangelands, which has in turn reduced herd sizes and decreased the amount of meat and other animal products many herders can sell, leaving certain areas with a single cash crop: *cordyceps sinensis*, better known as caterpillar fungus (WWF China, 2010). Though the caterpillar fungus has been harvested for many years, recent shifts in herd productivity have made it the primary cash crop for many communities, particularly in western China. Increased dependence on a single crop sets the stage for significant impacts on local livelihoods should the market for caterpillar fungus collapse or if the distribution or frequency of caterpillar fungus were to change (Winkler, 2008).

As many studies have shown (e.g., Valentin et al., 2008), soil and vegetation quality are important controls on runoff. As plant distributions and types change, there is great potential for increased runoff, decreased seasonal water storage, particularly in larger plants, and increased downstream sedimentation. These factors will likely impact both local communities in the higher reaches of AHM and those populations downstream of affected natural ecosystems.

3.4 Health

The World Health Organization (WHO) has released reports on the potential impacts of climate change on human health (e.g., WHO, 2011; 2012). Health impacts can result from both short-term and extreme weather events (e.g., flooding-related cholera outbreaks, deaths related to heat waves, loss of food security during a drought), or from changes in mean regional climate (i.e., increased range of mosquitoes). The 2010 USAID report (Malone, 2010) includes an extensive discussion of health impacts related to climate change.[4]

3.5 Summary of Climate Change and Vulnerability Literature by Mountain Range

Section 3.5 summarizes current knowledge on climate change in each of the ranges of AHM, and the principal vulnerabilities related to water stress, agriculture, infrastructure and flooding risk. The HKH region is the most studied range among AHM, with more limited evidence available for the other ranges.

4 For additional references, see (Patz et al., 2003), (Githeko et al., 2000), (Warraich et al., 2011), (Malik, 2012), (Bouma et al., 1996), and (Baqir et al., 2012).

The Tien Shan and Altai Ranges are combined for this section due to overlap and limited availability of vulnerability reports.

3.5.1 THE HINDU KUSH–KARAKORUM–HIMALAYA REGION

The eastern reaches of the HKH are unlikely to see drastic decreases in water availability over the coming decades, as they are primarily fed by the ISM, which is not expected to decrease (Bookhagen and Burbank, 2010). However, changes in the timing of the monsoon and the distribution of precipitation will likely increase both flooding risk and drought risk in the region (Gautum et al., 2009). Glacier melt is still an important factor in catchments across the region, both during non-monsoon months when water availability is lower, and especially in the western reaches of the region where winter precipitation is dominant. The Indian Network of Climate Change Assessment has predicted that temperatures will increase throughout the HKH region by between 0.9±0.6 °C and 2.6±0.7°C, with noticeable temperature increases throughout the year (Singh et al., 2011). Singh et al. (2011) also note that rainy days will increase between 5 to 10 days per year, and that rainfall intensity will increase by 1-2 mm per day during rainy days, although they do not include a discussion of seasonality in these rainfall increases.

3.5.1.1 WATER AVAILABILITY

A major driver of water scarcity in the region is land use change and population pressure (Tiwari and Joshi, 2012). In one catchment-level case study covering 39.9 km^2 in Uttarakhand State, India, Tiwari and Joshi (2012) found that as many as 36% of groundwater springs had disappeared during the last 20 years, and that the number of both seasonal and perennial streams had greatly decreased. When the dried springs were mapped, more than 75% occurred in regions where forest cover had been converted to agriculture or degraded land. Previous unpublished work in the catchment directly linked forest cover to groundwater infiltration rates, where well-stocked oak forests were able to capture up to 70% of a rainstorm's precipitation (Tiwari and Joshi, 2012). Furthermore, Tiwari and Joshi (2012) identified nearly 3 km of permanently dried stream channels which were associated with otherwise degraded land. They also note that land use changes in the catchment have had a dramatic impact on the incidence of landslides, as slopes denuded of vegetation are much more likely to fail during rainstorms.

Throughout the HKH region, Tiwari and Joshi (2012) identify population pressures such as excessive grazing, rapid urban growth, mining, increased tourism and increasing food demands as anthropogenic stressors on the already-fragile environment. The cumulative effect of anthropogenic forcing and climate change has been a decrease in stream discharge, diminishing and disappearance of springs, lowering of lake levels, and a loss of stream channel network capacity (Tiwari and Joshi, 2012).

3.5.1.2 AGRICULTURE AND HYDROELECTRICITY

The combined effects of water quality degradation and temperature increases will decrease production of crops which require cold periods, such as apples, or shift production to higher elevations (Singh et al., 2011). The move to higher elevations may increase human conflicts with snow leopards, as increased presence of herd animals and thus livestock depredation can increase retaliatory snow leopard deaths, though this has not been well established in the literature. Furthermore, increasing incidence of extreme weather leads to crop destruction, through both prolonged droughts and outsized storms that flatten crops (Singh et al., 2011). Many local farmers have already noted these changes anecdotally, though their recollections do not always correlate with measured climate data (Singh et al., 2011).

Increased flow variability and increased sedimentation will also likely impact irrigation systems. Most irrigation systems in the region are not designed to cope with large sediment influx, and may quickly degrade or fill in when sediment loads in water sources are increased. Any planning for water allocation from irrigation systems should consider the impact of flow variability and increased sedimentation to prevent eventual conflicts over water resources.

Though limited research has been undertaken specific to hydropower generation in the HKH, the main risks to hydropower plants are clear: increased flow variability and increased sedimentation. Suspended sediment severely limits the function of hydropower plants, and can shorten their effective lifetime through both turbine abrasion and reservoir infilling (Poudel et al., 2006). Flow variability greatly increases the planning needed to maintain electricity generation year-round, and can lead to extended periods of zero generation under some low-flow months. Hydropower in the HKH region, which is threatened by increasing risk of GLOF and other flooding events, also faces the threat of floods overtopping dams, or severely damaging infrastructure (Agrawala et al., 2003). These factors may reduce viable electricity-producing days, and limit the efficacy of investments in hydropower plants. There is also the danger that smaller hydroelectric capacity due to reduced stream flow will weaken development efforts through stalled electric capacity growth. In the short term, much of the HKH, particularly the eastern reaches, will see increased hydroelectric generation potential as glaciers melt. Once small glaciers have completely melted, however, seasonal flow could decrease significantly.

3.5.1.3 FLOODING RISK

The HKH region is characterized by multiple types of flooding, including those triggered by GLOFs, LLOFs, failure of manmade structures, cloudburst floods, and rain-on-snow events (Shrestha and Bajracharya, 2013). The eastern reaches of the HKH are at particular risk of flooding related to increased glacier melting, which can lead to GLOFs (Nie et al., 2013). Flooding risk in the entire region is growing with increasing storm variability and intensity, which leads to higher prevalence of dangerous rain-on-snow events, as well as cloudburst floods and floods triggered by dam bursts, both manmade and natural.

A prime example of flooding due to intense rainfall events came in July 2010 in Pakistan (Webster et al., 2011). These floods were driven by anomalous rainfall, which dropped more than 300 mm of rain on isolated regions of northern Pakistan. The subsequent flooding led to nearly 2,000 deaths, and estimated damages of nearly $40 billion. However, Webster et al. (2011) note that the absolute rainfall amounts in Pakistan that summer were normal; it was only the rate and spatial distribution of rainfall that was abnormal. This highlights the dangers that increasing extreme events can pose even under minimal change in overall precipitation levels.

Pakistan has also seen several major landslides in the last decade, two of which have formed large and dangerous lakes. Karli Lake, which was formed in 2005 as a result of an earthquake, filled in and eventually burst in 2010, damaging houses and downstream agricultural land (Konagai and Sattar, 2012). The Atta Abad landslide in Upper Hunza created Lake Gojal, which killed 20 people and submerged several villages, as well as long stretches of highway (Kargel et al., 2010). The lake remains dangerous, although the natural dam is holding and slowly eroding. As availability of high altitude melt water increases, the size of landslide dammed lakes will increase, and increase the risk of LLOFs.

A recent GLOF assessment estimated that out of the 8,790 glacial lakes in the HKH region, more than 200 are classified as potentially dangerous, including 24 in Bhutan, 30 in India, 20 in Nepal, and 52 in Pakistan (Ives et al., 2010). Another recent study noted 67 rapidly growing glacial lakes in the central Himalaya region (Nie et al., 2013). These lakes are often remote, which limits monitoring efforts. The western reaches of the HKH are also at risk of jökulhlaups, due to advancing glaciers in the region.

Floods are difficult to predict, and often have trans-boundary implications. Lack of effective bilateral monitoring in many regions means that upstream floods in China are often not communicated quickly to downstream populations in Nepal (Shrestha and Bajracharya, 2013). Bilateral monitoring efforts will be discussed further in Section 8.

3.5.2 THE PAMIR RANGE

Though there are limited data on the effects of climate change on the Pamir Range, some studies have drawn conclusions from regional trends. Khromova et al. (2006) estimate that the Pamir Range will see slightly increasing water availability as small glaciers continue to melt in the coming decades, followed by a decrease in flow as glaciers disappear. However, recent work by Gardelle et al. (2013) indicates that mass balances in the Pamir Range may be stable or even positive, though their study did not assess disparity in changes in small and large glaciers. It is possible that mass gain on larger glaciers could offset mass loss on smaller glaciers when a large study area is considered, and that Khromova et al.'s (2006) projections of water changes may remain valid even under a general increase in regional mass balance. Temperature is projected to increase, along with increasing incidence of hot days and heavy precipitation days (Zahid and Rasul, 2011); these increasing temperatures, particularly summer temperatures, are the main driver of glacial melting in the region (Khromova et al., 2006). The desiccation of the Aral Sea has shifted moisture patterns in the region, and may lead to a slightly more arid climate (Lioubimtseva and Henebry, 2009). The effects of warming trends on water resources are projected to be more important than changes in precipitation, given seasonal and inter-annual variability in precipitation, as well as generally low precipitation throughout the region (Lioubimtseva and Henebry, 2009).

3.5.2.1 AGRICULTURE AND WATER AVAILABILITY

Increasing aridity throughout the lowlands of Central Asia, which are fed not only by the Pamir but by the Tien Shan and Altai, will drive an increased demand for water for irrigation (Lioubimtseva and Henebry, 2009). This increased demand will be somewhat offset in the near term by increasing winter temperatures – which reduce temporary water storage in snowpack – and glacial runoff, though those same winter temperature increases are likely to extend the growing season and thus further increase water demands. Nearly 14 million hectares of the 45 million currently cropped in Central Asia require irrigation, much of which is fed by aging Soviet infrastructure (Lioubimtseva and Henebry, 2009).

Agriculture in the Pamir Range is also under the threat of increasingly variable extreme weather events. Frosts, heat waves, droughts and heavy rains are all projected to increase, which can have severe effects on farmland viability (Lioubimtseva and Henebry, 2009). Massive Soviet investment in monoculture agriculture throughout Central Asia led to the construction of huge and often inefficient irrigation systems, and greatly reduced the adaptive capacity of the region to changing water availability (Lioubimtseva and Henebry, 2009).

3.5.2.2 FLOODING AND HYDROPOWER POTENTIAL

The Pamir Range has seen a growing number of large glacial lakes, the largest of which is Lake Sarez, Tajikstan, which holds 17 km^3 of water (Stone, 2009). The Pamir Range is geologically active, and often experiences sizable earthquakes. These quakes can dislodge large landslides, which have the potential to block rivers. Lake Sarez is blocked by the tallest natural dam in the world, which rises some 567 meters and is the result of a magnitude-7.4 earthquake (Stone, 2009). Though such massive lakes pose serious risks for downstream communities, they also provide possibilities through increased regional water storage and enhanced hydropower potential. One proposal for managing Lake Sarez involves tunneling through a sidewall to take advantage of the water pressure for hydropower generation, and also to enhance water security in the region by using excess water for downstream agriculture (Stone, 2009).

3.5.3 THE KUNLUN RANGE

The Kunlun Range occupies a very cold, very low-precipitation area of China (Shangguan et al., 2007). Two studies have noted that the Kunlun have yet to experience significant effects from warming climates, as winter temperatures have not risen enough to impact snowfall (Shangguan et al., 2007; Cheng and Wu, 2007). In fact, some of the glaciers in the region have been seen to advance due to slight increases in precipitation (Shangguan et al., 2007).

3.5.3.1 WATER AVAILABILITY

With slightly increasing precipitation trends, water availability is likely to remain stable to slightly increasing in the Kunlun. Another potential source of water is melting permafrost (Cheng and Wu, 2007). Parts of the Tibetan Plateau, as well as regions within the Kunlun, have shown signs of increasing permafrost temperatures, which can release extra moisture into the environment. However, thawed permafrost is highly susceptible to erosion, and any changes in the freeze-thaw cycle of soil or degradation of permafrost in the region could have significant implications for grazing, agriculture and water budgets (Cheng and Wu, 2007).

3.5.3.2 FLOODING RISK

There are no specific investigations of flooding risk in the Kunlun. However, the Kunlun is not characterized by a large number of potentially dangerous glacial lakes (Shangguan et al., 2007). For those glaciers in the Kunlun known to be advancing, there is the possibility of glacial tongues blocking rivers and forming temporary lakes (Shangguan et al., 2007). Given expected increases in temperatures over the coming decades, the melting of permafrost could weaken glacial moraines, leading to an increased risk of GLOFs, although this danger is less pronounced in the Kunlun than it is in other regions of AHM due to lower glacial retreat rates. As with much of the rest of AHM, increases in extreme weather and land degradation have the potential to produce flooding in the Kunlun Range (Cheng and Wu, 2007).

3.5.4 THE TIEN SHAN–ALTAI REGION

The Tien Shan-Altai region is characterized by high spatial variability in precipitation and climate regimes, with winter precipitation in the western areas, and spring and summer precipitation towards the east (Narama et al., 2010a). Western regions characterized by winter precipitation are more likely to see stable or slightly advancing glaciers, while increased summer temperatures drive melting in summer-fed regions in the east. Temperature is projected to increase in the region by 3° to 5°C by 2080 (Lioubimtseva and Henebry, 2009), which will drive glacial retreat in the region, particularly at lower elevations. However, these trends are drawn from the IPCC (2013b) report, and due to lack of extensive temperature monitoring in the region, should not be treated as definitive. Similarly, slight decreases in precipitation are predicted for the region (Lioubimtseva and Henebry, 2009), but are not supported by extensive monitoring data in the region. Fortunately, a newly established permanent multi-parameter monitoring network has been established in Central Asia, which, as the temporal extent of the dataset extends, will become an increasingly valuable tool in this sparsely monitored region (Schöne et al., 2013).

3.5.4.1 WATER AVAILABILITY, AGRICULTURE AND HYDROPOWER

Water availability is expected to increase in the short term while smaller glaciers melt, and then decrease rapidly as glaciers disappear throughout the region (Narama et al., 2010a). The eastern reaches in particular are at risk of slightly decreasing precipitation, the effects of which have already been noted in the livestock sector of Mongolia (Batima et al., 2005; Fernández-Gimenez et al., 2012). Droughts in the summers of 1999-2002, along with winter dzud, killed nearly 10 million animals in Mongolia (Batima et al., 2005); an estimated 8.5 million animals perished in the dzud of 2009-2010 (Fernández-Gimenez et al., 2012).

The western reaches of the Tien Shan share a similar fate to that of the neighboring Pamir, with increasing aridity driving heightened demands on water for irrigation. Growing populations and inefficient and aging irrigation structures further increase water demands (Lioubimtseva and Henebry, 2009).

The melting glaciers have the potential to provide a short-term boost to hydroelectric plants over the next few decades (Aizen et al., 2007b). Without the influence of the monsoonal systems characteristic of southern parts of AHM, the dangers of extreme precipitation events are smaller. Short-term increases will eventually dwindle, unless hydropower plants are sited downstream from very large or high-elevation glaciers, which are likely to persist longer than smaller or lower elevation glaciers.

3.5.4.2 FLOODING RISK

The Tien Shan–Altai region is prone to both GLOFs and landslide-dammed floods (Bolch et al., 2011). Bolch et al. (2011) note that nearly 11% of mudflows in the region are associated with GLOF events. They further note that between 1970 and 2007, the number of glacial lakes within one study area had jumped from 66 to 132, reflecting the rapid increase in melting during the past few decades. They identify 47 lakes within their study area as potentially dangerous, but only two as "highly dangerous" (Bolch et al., 2011). One of these highly dangerous glacial lakes is located in a watershed which drains into the city of Almaty, Kazakhstan. Bolch et al. (2011) note such factors as thawing permafrost, which weakens moraine dam stability, high potential for avalanches, and continued glacier retreat as major factors in analyzing glacial hazard.

Narama et al. (2010b) documented the rapid evolution and impact of a glacial lake in the Teskey Ala-Too region of Kyrgyzstan below the Zyndan glacier, which grew over a period of only two and a half months and led to significant downstream devastation. Furthermore, it grew at less than a third of the rate typical of glacial lake growth in the HKH (Narama et al., 2010b). Even with its relatively small size and slow growth rate, it discharged 437,000 m^3 of water in a single event, which led to three deaths, as well as significant environmental and infrastructure damage. Though these rapidly forming lakes are not characteristic of the region, they can occur and are particularly difficult to monitor via satellite imagery due to constraints in how often images of the same area are captured. Though GLOFs in the Tien Shan–Altai region are smaller than those in the HKH region, they still pose a significant threat, and warrant increased monitoring efforts.

NOMADIC HERDER NEXT TO A FRESH WATER SPRING ON THE JARGALANT MOUNTAIN IN MONGOLIA; © WWF-CANON / SIMON RAWLES

SECTION IV
Current Adaptation Efforts

Many of the climate change-related vulnerabilities and impacts discussed in the previous Section are already being addressed through both government-led measures at a national level and smaller-scale or donor-funded activities. This section provides background on adaptation methods, their merits and potential pitfalls, as well as a range-by-range overview of adaptation efforts in AHM.

Throughout AHM, interventions that align with the country or community "ownership" principles laid out in the Paris Declaration on Aid Effectiveness (Organisation for Economic Co-operation and Development, 2005) appear to perform best. Methods that incorporate local stakeholders into adaptation planning and implementation are more likely to create sustainable and effective resilience to climate change impacts in the long term.

This discussion of adaptation may be limited by publishing bias in that experiences with unsuccessful or poorly performing interventions are less likely to be published than those that have been shown to work well. Examples of relevant development projects are included in this section, even when they were not specifically designed to respond to climate change. Those projects not focused specifically on climate change adaptation are noted in the text.

4.1 Responding to Climate Uncertainty

Livelihoods throughout AHM are impacted not only by multi-year changes in water availability, but also by events at smaller timescales, such as increased frequency and intensity of floods and droughts, as well as increases in seasonal flow variability. Impacts of these short-term and immediate effects of climate change will generally motivate day-to-day adaptation measures, but should ideally consider the eventualities of multi-year climate change as well. Solutions should be flexible so that they can be modified to respond to evolving knowledge of future climate change, as well as changes in local conditions (FAO, 2011).

4.1.1 LIVELIHOOD DIVERSIFICATION

Many examples of small-scale interventions note similar needs, despite relating to varied livelihoods. For example, several studies suggest livelihood diversification as an effective adaptation to increased climate variability (e.g., Pradhan et al., 2012; FAO, 2011; Dixit et al., 2013a). In the case of pastoral communities, this might entail increased herd diversification or the establishment of non-grazed pastures that can be used for hay in the event of food shortages or severe winter. In particular, effective management of overgrazing has been noted as an important measure for restoring ecosystem resilience (FAO, 2011; Fernández-Gimenez et al., 2012). However, simply reducing anthropogenic influence on rangelands through improved management without considering climate trends or projections does not explicitly reduce vulnerability to climate change. More targeted measures such as modifying herd grazing patterns to minimize or manage species succession can be effective interventions in adapting to climate change. Agricultural communities have used diversification of crops, particularly diversification into vegetable crops, as a means of combating increased variability in the weather. Growing multiple crops, particularly those with diverse needs and responses to climate stress, reduces vulnerability. Plans to transition to diversified crops will need to consider a number of important factors, including appropriate access to markets and seed varieties, and should include short-term community or household support options, for example from government agricultural extension services, to ease the economic burden of transition.

4.1.2 IMPROVED IRRIGATION TECHNIQUES

Irrigated agriculture uses a significant amount of water in the region (Lioubimtseva and Henebry, 2009), and can be highly inefficient; in Pakistan, 50% of water is lost on average due to improper irrigation systems and practices (Muhammad Ibrahim Khan, personal communication, May 2014). Irrigation projects range from small-scale plots on high mountain slopes to the massive Soviet-era irrigation systems constructed in Central Asia, both of which rely on water sourced throughout AHM. In many cases, these systems are highly inefficient, and vast amounts of water could be conserved through improved irrigation practices. In complex topography, traditional irrigation systems that have been in place for thousands of years are often nearly as successful as modern solutions (Groenfeldt, 1991). The implementation of systems that build on indigenous knowledge and techniques and consider local context could present opportunities for both community engagement and environmentally friendly agricultural development. However, any infrastructural investment has a potential to become maladapted if it is costly or poorly suited to the local environment, or if poorly prepared for the rapidly changing climate throughout the region.

In many regions of AHM, small-scale irrigation systems are an effective point of entry for climate-smart water resource management. One example in Nepal notes that small systems do not require huge capital or labor inputs, and are generally usable under multiple flow scenarios (Dixit et al., 2013a). Once these systems become operable, secondary developments and improvements may be built alongside or in conjunction with these small systems, depending on how effective the small-scale systems are. This step-wise strategy also allows more flexibility in both diversifying crops and planning future adaptations, as infrastructure investments are small and low-cost.

4.2 Reduced Water Availability

Much of AHM are already under water stress driven by anthropogenic factors, such as land cultivation and overgrazing (Tiwari and Joshi, 2012). Climate change will likely exacerbate this stress by further diminishing water resources in many parts of AHM (Lioubimtseva and Henebry, 2009). Though the extent of water stress will vary throughout AHM, water management strategies are often widely applicable.

4.2.1 ECOSYSTEM RESTORATION

There have been many approaches to water conservation in the region, some of which entail co-benefits to ecosystem sustainability and others that are short-term solutions. Changes in land-use patterns, such as reintroduction of plants into degraded landscapes and the planting of water-conserving trees at springs, are the primary means by which water quality improvement and sedimentation reduction have been approached in the region, and are generally cost-effective, sustainable interventions, although they are not always designed specifically to address the impacts of climate change.

One solution that helps build some resiliency to climate change is restoration of natural ecosystems. While degraded agricultural land stimulates runoff, forests and healthy high alpine pastures encourage groundwater recharge, as well as diminish rapid overland flow and enhance slope cohesion, which reduces the risk of flooding and landslides. Due to population pressures in many regions, marginal lands are under cultivation, and contribute greatly to runoff. These marginal lands are both newly developed areas which were previously unproductive, and landscapes which have degraded over time due to poor management techniques or changing climate. The transformation of marginal cultivated lands into forested or otherwise natural areas enhances ecosystem services in the region, and can help increase groundwater recharge. The challenge for such restoration is to ensure it is based on climate trends and projections where possible; for example, reforestation projects should use species that are more likely to thrive in the projected climate, rather than those that are adapted to more limited climates. This restoration could also be expanded into degraded land, or land which is no longer farmable and is lacking suitable vegetation cover. Such “climate-smart” restoration helps build resilience for communities and ecosystems, as it can help recharge important water supplies, provide co-benefits to community livelihoods through expanded access to fiber and other forest products, expand usable pasture land, and also serve mitigation benefits through increased carbon storage in the region.

4.2.2 COMMUNITY WATER MANAGEMENT

Another action that helps build community resilience to greater climate variability is implementing community-based water conservation plans. In the face of increasingly erratic weather patterns, both high-flow and low-flow scenarios will become more common. Though water conservation will be especially effective in arid regions, the majority of communities in AHM will come under climate-induced water stress and can benefit from water management and conservation efforts. Implementing community-driven water management plans also has the co-benefit of stimulating community buy-in to effectively extend the life of an intervention. It also helps increase awareness of and education on environmental issues related to water scarcity (Tiwari and Joshi, 2012). This strategy has a low potential for maladaptation, as it draws on community knowledge and enhances the incentive to adapt to climate change through increased engagement with and knowledge of climate-related issues, particularly those related to changing seasonal water availability. One example of this comes from Nepal, where several communities have invested in water storage tanks to feed irrigation systems throughout their fields (WWF Nepal, 2012). It has also been noted that though the practice of community water management is common in some regions, such as mountainous areas of Pakistan, lack of support from regional and national government bodies can limit its efficacy (Muhammad Ibrahim Khan, personal communication, May 2014).

4.3 Responding to Flooding and Landslides

Much of the danger associated with floods is their unpredictable nature. This is particularly true of flash floods, which are characterized by rapid increases in water level, and high sediment and debris loads. AHM present a particular difficulty in flash flood prediction, due to rugged terrain, relatively uninhabited areas with little monitoring capacity, the trans-border nature of many floods, and the multi-faceted risks presented by GLOFs, LLOFs, and cloudburst floods. Cloudburst flood prediction in particular suffers from a lack of adequate weather monitoring in the region, as well as the complicated nature of predicting weather patterns in complex terrain. Still, there have been several efforts to mitigate the effects of flash flooding and reduce the danger posed by glacial lakes, particularly in the HKH region of AHM.

4.3.1 FLASH FLOODING

The unpredictable nature of flash flooding lends itself to "risk management" as an adaptation strategy. These strategies must be tailored to each individual watershed or even village, as there are very strong climatic and topographic controls on flood risk. One essential method of risk management is community involvement.

Local communities can serve as essential sources of traditional knowledge, and can provide context on local opportunities and limitations. They also have a personal interest in avoiding and mitigating disasters, as well as often serving as the primary workforce for any adaptation measure. The sustainability of any project, particularly one concerned with long-term preparedness and monitoring, requires community buy-in. Without community support, interventions are likely to fall apart after an initial outside investment, reducing a community's adaptive capacity to levels similar to before the intervention.

One useful approach to community engagement is the formation of community action committees responsible for both flood preparedness and relief. These committees can serve a range of functions: (1) a single point of communication for regional flood watches, flash flood warnings and other information; (2) coordination of flood response by facilitating response planning and stocking relief supplies; (3) communication with government or donor organizations as a single unit, both to solicit funds or to engage in wider-scale planning activities; and (4) coordination of timely responses by mobilizing communities in the wake of a flood (Shrestha, 2008a).

A critical factor in flood risk management is supporting development that takes flood risk into consideration. Strategies are required to manage both the built environment and the use of natural environments. Proper risk assessments and building codes can mitigate the damage caused by flooding (Shrestha, 2008a). Of equal importance is the management of the natural environment. As resources are overexploited through forest removal, overgrazing and poor farming practices, soil stability is reduced. Soils lose their ability to absorb rainfall,

© GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

increasing runoff and sometimes triggering flash flooding. Furthermore, the removal of vegetation can lead to landslides as slopes lose their cohesion. Several methods can help mitigate these factors, such as improved agricultural practices and increased intensity and stability of forested areas. These methods often require both government intervention and local buy-in (Shrestha, 2008a).

4.3.2 GLACIAL LAKE OUTBURST FLOODS

The dangers of GLOF can be mitigated through two main avenues: monitoring and engineered solutions. In some cases, glacial lakes do not pose enough of a threat to warrant complex and costly engineering solutions. However, flood outcomes improve with adequate warning through early warning systems and flood monitoring.

Studies throughout AHM have used remotely sensed data to monitor the formation and growth of glacial lakes (e.g., Ives et al., 2010; Fukui et al., 2008; Bolch et al., 2011; Narama et al., 2010b). Though their methods differ, they each provide a valuable lake inventory over a wide spatial range, and provide data that would be very difficult to obtain through ground surveys. These surveys provide a valuable "first pass" to identify potentially dangerous lakes for more intensive monitoring. Lakes identified in this way can be tracked more closely with lake-level monitors, downstream flood gauges, or real-time camera or GPS monitoring tools.

Any early warning system must be accompanied by education efforts. Some progress has been made towards educating downstream populations and setting up early warning systems in vulnerable communities. However, there is still much progress to be made, especially in areas where floods are trans-national. For example, a flood occurring in China that flows downstream into India (e.g., through the Sutlej) requires international coordination to provide early warning (e.g., the Parechu flood described in Wulf et al., 2012). In many cases, that bilateral cooperation is not yet in place. Furthermore, systems with potential for false alarms raise the possibility of reduced community buy-in to early warning systems, as well as reduced efficacy.

In the cases of extremely dangerous lakes, such as Lake Sarez in Tajikistan (Stone, 2009), engineering projects to lower the lake level have been proposed. These lakes are typically rapidly growing, or have large human settlements or infrastructure developments in their downstream path. In lowering the lake level, the possibility of a breach due to seasonal precipitation, landslides into the lake, or other overtopping of the dam, is reduced. The most common method is to dig a channel in the glacial dam, or around the glacial dam, to relieve some of the water pressure. These methods have been in use in other high mountain areas (e.g., Peru) for the past few decades (Leslie, 2013). Disturbing a glacial lake dam during construction of mitigation measures carries the risk of indirectly causing a GLOF and must be approached cautiously. These mitigation projects are also expensive and difficult to maintain. Channels in some very large lake dams – such as the dam containing Lake Sarez – could also be used for hydroelectric power generation, somewhat offsetting the cost of mitigating GLOF risk (Stone, 2009). The feasibility of this type of adaptation is limited in AHM by lack of road access to many GLOF risk areas, as well as lack of technical capacity and resources for such major interventions.

4.3.3 LANDSLIDES

Though landslides can be caused by a range of factors unrelated to climate, such as earthquakes and human activities, they are also often caused by extreme precipitation, particularly in combination with poor land management practices. Thus, management plans that take into account the possible effects of rapid precipitation or flooding should also take into account the risks of landslides. In many cases, interventions that reduce flood risk can also serve to reduce landslide risk.

An important factor in landslide risk is vegetation cover (Shrestha et al., 2012). As noted above, vegetation cover also plays an important role in runoff control, and can help mitigate flood risk. Vegetation serves as both a mechanical support to slopes, and a controlling factor in water buildup through evapotranspiration, increased infiltration and absorption, and reduced surface runoff. Shrestha et al. (2012) published an excellent review of structural measures to mediate risk of flash flooding, including terracing, retaining walls and slope coatings.[5] Terracing involves the splitting of slopes into stacked terraces. This method reduces overland flow velocity, and has the added benefit of increasing cultivation area. It can both slow landslides and reduce the incidence of flooding. Retaining walls can protect vulnerable areas by diverting landslides or floods, but are often not cost effective in stopping entire landslides (Shrestha et al., 2012). Slope coatings often involve covering hillsides in cement, wire fencing or other strong materials; the coatings can improve slope cohesion and effectively stabilize slopes, but often introduce ecological problems stemming from increased runoff and removal of vegetated area (Shrestha et al., 2012).

Another significant driver of landslides in the region is poor rural road design (Mulmi, 2009). When roads are cut into the side of hills, they reduce hillslope stability by steepening stretches of the hillside and creating areas for water to stagnate and saturate soils. Blasting used in road construction can also destabilize precarious slopes. One potential approach is constructing “green roads,” or low-cost and low-volume roads built with local labor (Mulmi, 2009). This building approach explicitly focuses on the protection of local ecology and vegetation cover through both preservation of near-road ecology and introduction of additional vegetation when necessary.

5 For more information and techniques, refer to Shrestha et al. (2012) in “Resource Manual on Flash Flood Risk Management - Module 3: Structural Measures.”

4.4 Adaptation by Mountain Range

Communities across the individual mountain ranges face different climate-induced hazards, and have adapted in different ways based on situational contexts. This section provides a range-by-range analysis of known interventions.

4.4.1 THE HINDU KUSH–KARAKORUM–HIMALAYA REGION

The HKH region has a wealth of case studies on climate adaptation (e.g., Pradhan et al., 2012; Tiwari and Joshi, 2012; 2013; Shrestha and Bajracharya, 2013; Shrestha et al., 2012). They can be grouped into two broad categories: flood risk and water stress.

4.4.1.1 FLOOD RISK

Ives et al. (2010) reported on early warning systems implemented in several basins in the region with varying degrees of success (Ives et al., 2010). In one case in the Tsho Rolpa and Tamakoshi valleys of Nepal, an early warning system was implemented that coupled automated flood detection with an audible downstream warning system. However, after only four years in operation, the system was no longer in use. Despite the sustainability of the technical implementation, lack of community buy-in, false alarms, and the view that the lake was no longer a danger led to the dismantling of the early warning system's monitors to be used for other local projects.

Another intervention in Nepal's Upper Bhote Koshi valley is limited by a warning system that extends only to the Nepal-China border. As floods often start further upstream in China, this is a serious limitation, and leaves just six minutes of warning time from the Nepal-China border before a flood would hit a downstream hydroelectric station (Ives et al., 2010). Though this is not necessarily a maladaptation, its efficacy clearly suffers from the lack of trans-boundary cooperation.

In Bhutan, several lakes that have been deemed severely hazardous have been manually lowered through expanding outflow channels (Ives et al., 2010). These methods had at the time of publication proved effective at mitigating the risk of flooding, and created minimal environmental impacts. Similarly, in Nepal, several dangerous glacial lakes have been drained through a combination of spillway construction and mechanical siphoning (Ives et al., 2010).

Shrestha and Bajracharya (2013) report on several studies in Pakistan, Nepal and India. In the Chitral District of Pakistan, a partnership between Focus Humanitarian Assistance Pakistan and local communities led to a primarily educational investment. A three-step plan involving risk assessment, capacity building and awareness building phases led to increased adaptive capacity without significant infrastructural development. The main outcomes were increased awareness of flash flood risks and mitigation measures, the establishment of an early warning system using cell phones and mosques, and the formation of natural resource management committees. This community-based approach to flood risk management represents a low-cost and low environmental impact adaptation measure. The authors note that although these non-structural interventions are effective, they would be more useful in conjunction with limited structural measures (Shrestha and Bajracharya, 2013).

Similar projects in Nepal and India have also produced effective early warning systems, as well as hazard maps. These maps were distributed throughout the communities and increased adaptive capacity by informing community members of the best evacuation routes and what to do in an emergency (Shrestha and Bajracharya, 2013). Several studies also performed landslide and LLOF risk modeling, and showed that in all cases, risk can be mitigated through improved warning systems and community education. Shrestha and Bajracharya (2013) also note government investments have focused largely on relief and recovery, as opposed to mitigation strategies such as improved land management techniques (Shrestha and Bajracharya, 2013).

One study in Nepal found that some structural investments actually increase vulnerability (Shrestha et al., 2012). The authors found that growing dependence on embankments to mitigate flood risk has reduced community willingness to adapt to floods. They also found that floods caused by breached embankments were more extreme than those caused naturally (ICIMOD, 2013). The construction investments can also serve to divide towns into protected and unprotected areas. These divisions are sometimes used to allocate aid money and other investments. As such, they can be mechanisms of maladaptation by reducing people's willingness to adapt and disproportionately burdening the vulnerable communities that do not have the protection of embankments. However, Shrestha et al. (2012) emphasize that embankments can be important adaptation mechanisms if they are properly implemented and undergo regular repairs.

These case studies highlight the significant gains that can be made using non-structural methods, such as community education, development and dissemination of hazard maps, establishment of community organizations for natural resource management and disaster planning, and implementation of low-tech solutions for early warning systems. In some cases, structural methods, such as spillways to reduce GLOF risk, were implemented with varying degrees of success. These structural interventions suffer a higher risk of maladaptation, mainly due to the larger economic investment, which could limit investment in other climate adaptation projects, though they can also have negative impacts on river ecosystems by reducing biologically active bank areas and thus reducing food supplies for aquatic life.

4.4.1.2 WATER STRESS

Tiwari and Joshi (2012) present a case study at the headwaters of the Koshi River (Nepal and India), which ultimately drains into the Ganges Basin. This region has seen 36% of groundwater springs go dry in a single catchment over the last 20 years. Tiwari and Joshi (2012) recommended a combined plan of land resource management and water conservation, with the goal of recharging depleted groundwater reserves and increasing adaptive capacity to reduced flow and drought conditions. The primary objective of the land use planning exercise was to increase forest cover with the aim of increasing water absorption and reducing landslide risk. The increase in community forest cover would also discourage the degradation of state forest by providing more readily available fuel and other forest goods Community water management schemes would then receive updated recommended allotments based on newly analyzed water inputs and outputs. This scheme aimed to allocate limited irrigation resources equitably and in a more sustainable manner. (Tiwari and Joshi, 2012).

Another assessment in the Indrawati sub-basin of the Koshi River in Nepal suggests the development of a spring-source conservation plan, introduction of drought-resistant seeds and varietals, and adoption of various water conservation methods such as afforestation, water storage structures, and rainwater collection (Bartlett et al., 2011). These methods mesh well with the water management strategy recommended by Tiwari and Joshi (2012) which focused on both restoring headwaters and using downstream resources more effectively. Tiwari and Joshi (2012) recommend that headwaters be improved by the planting of water-conserving trees, as well as the construction of tanks and ponds for seasonal water storage. Some examples of these types of water storage ponds come from WWF Nepal, where community resource management committees have helped draw community labor and funding for cement water storage tanks in the villages of Tamang and Ramchebesi, as well as for smaller projects throughout Nepal using simple plastic-lined pits (WWF Nepal, 2012). These methods do not require a significant capital investment, but increase community adaptive capacity to low-flow periods.

Under the plan proposed by Tiwari and Joshi (2012), community water management systems would then receive updated recommended allotments based on newly analyzed water inputs and outputs. This plan aimed to allocate limited irrigation resources equitably, and in a more sustainable manner.

4.4.2 THE PAMIR RANGE

Though the Pamir Range is less well studied than the HKH region, some specific case studies have been published on the Pamir. In addition to these cases, adaptation methods are very similar to those employed in the western areas of the HKH.

4.4.2.1 FLOODING

The Pamir Range is under threat of GLOFs, LLOFs, and other flooding due to increases in extreme weather; lack of effective monitoring tools in much of the region; and both glacial retreat and surges. One particular case has drawn significant attention due to the potentially massive flooding it could cause. Lake Sarez, formed by an earthquake-triggered landslide in 1911, currently stores more than 17 billion m3 of water (Stone, 2009). Soon after the formation of the lake, a five-person team was established to keep constant watch over the lake. This team serves the dual purposes of early warning and monitoring the lake for any significant changes. Furthermore, an early warning system has been installed downstream, giving the nearest village a full 17 minutes of forewarning before any flood would reach the population (Stone, 2009). At the time of publication, the early warning system did not extend further downstream, and populations further along the Sarez drainage were potentially in danger from a flood sourced in Lake Sarez.

Structural measures have also been proposed to drain some of the water out of Lake Sarez to reduce the danger to local communities (Stone, 2009). At the time of publication, the preferred solution was to drill a tunnel through the side of the valley adjacent to the natural dam to allow some water to drain from the lake, potentially through a hydropower plant. However, this would require very careful engineering, and a massive $500 million investment. It would, on the other hand, provide a large new source of income in the region, and free up significant amounts of water for downstream uses. In this case, the costs of the project are potentially offset by the benefits of increased access to clean electricity and water in the region.

Due to its high visibility and potential for a catastrophic flood event, Lake Sarez draws significant public attention. However, there are numerous glacial lakes in the Pamir Range that pose similar, if less extreme, hazards, but which are not well documented because they are difficult to access and un-monitored (Haritashya et al., 2009). The lack of glacial lake monitoring, when coupled with poor weather monitoring in the region, means that the Pamir Range is vulnerable to both GLOFs and cloudburst floods.

4.4.2.2 WATER AND HEAT STRESS

The Pamir Range is at risk from shifting atmospheric patterns and increasing aridity in the region (Lioubimtseva and Henebry, 2009). One successful adaptation in the Pamir Range has been the introduction of new drought-resistant crop species, including tree species (Pradhan et al., 2012). In parts of Pakistan, losses in tree crops due to erratic weather and climate change were much lower than those from more traditional crops. In particular, walnut trees older than three to four years were highly resistant to drought. Tree crops such as walnuts thus represent a relatively secure investment against changing weather patterns and uncertainty about which crops are suitable for a changed climate.

Another study on the impacts of climate change on wheat crops in Pakistan indicates that planting earlier can offset some of the impacts of climate change in the region (Sultana et al., 2009). This benefit is primarily due to avoiding the negative impacts of hot and dry days on wheat during the summer. Shifts of a few days in summer onset should be matched by farmers in their planting strategies.

4.4.3 THE KUNLUN RANGE

The Kunlun Range is almost entirely contained within China. At the time of this review, there were no English language publications available on explicitly climate-driven adaptation efforts in the Kunlun Range. In the adjacent Tibetan Plateau, reports have noted that high rangelands have experienced severe degradation over the past few decades (WWF China, 2010; Harris, 2009). However, reports indicate that anthropogenic factors such as overgrazing are more important in rangeland degradation than climate factors. Further research is needed to quantify the impacts of climate change in the region, and to suggest mechanisms to adapt to changing climate.

4.4.4 THE TIEN SHAN–ALTAI REGION

Several studies have shown that the Tien Shan–Altai Region is at risk from both GLOFs and water stress. Melting glaciers and poor monitoring capacity in the region mean that GLOFs present an important risk, despite the fact that glacial lakes in the Tien Shan–Altai Region are typically slower-growing and hold less water than those in the HKH Region. Of more immediate concern in the region is water stress, particularly with the heavy focus on irrigated croplands in much of Central Asia. However, there is relatively little information on climate adaptation measures being pursued in the Tien Shan–Altai region.

4.4.4.1 FLOODING

A recent study has identified two potentially dangerous glacial lakes in part of the Tien Shan in Kazakhstan. An unnamed lake adjacent to the Manshuk Mametova Glacier was identified as very dangerous, as it would drain straight into the city of Almaty (Bolch et al., 2011). This lake is currently being controlled through spillways, which have lowered the lake level by 6.6 meters between 2010 and 2011. In this case, a structural measure is likely the most prudent investment, as the potential infrastructure and livelihood damage of a large flood into Almaty far outweighs the investment in flood prevention methods. Monitoring efforts are sufficient for the second unnamed lake, situated in a side valley of the Chon-Kemin River, which has no settlements in its flood path.

GLOFs are much less common in the Tien Shan–Altai region than in the HKH or Pamir Ranges (Narama et al., 2010b). Furthermore, they tend to be smaller in scale and potentially less destructive. This lowered risk profile lends itself to more non-structural measures, such as hazard mapping, early warning, and flood preparedness measures. These adaptation measures are low-impact and do not pose a severe burden on communities. Thus, they are generally positive adaptations, if they are properly implemented and communities are effectively engaged.

These same non-structural measures are applicable to broader flooding risks, such as those posed by cloudbursts. Accurate weather forecasting, community education, hazard mapping and early warning systems can be applied equally well to mediate other potential flood risks.

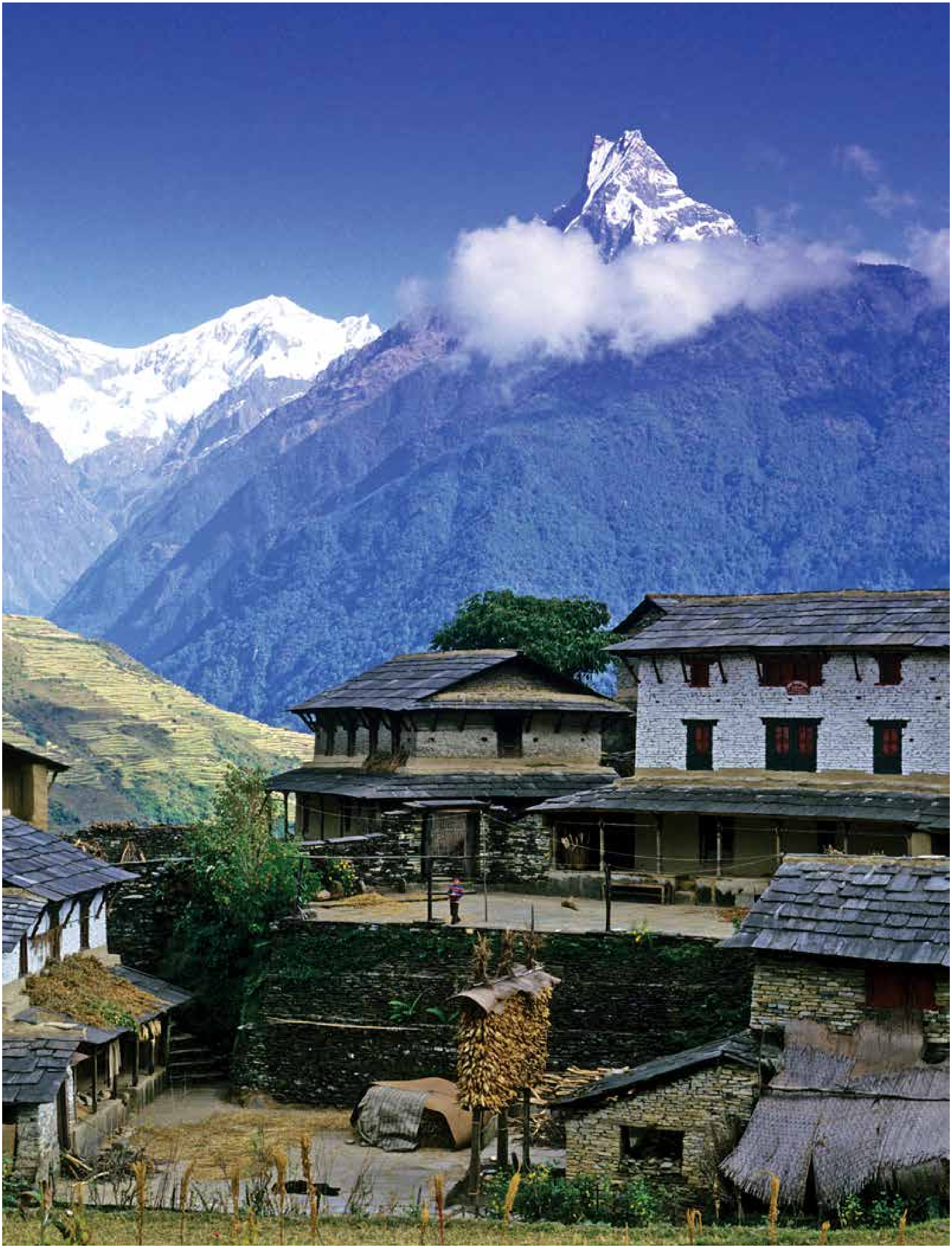
4.4.4.2 WATER STRESS

Due to increasing temperature trends, rivers in the Tien Shan–Altai region are likely to lose some of the seasonal water storage provided by snowmelt, exacerbating current trends in water availability, particularly during the summer months (Sorg et al., 2012). This is mainly driven by reduced winter snowfall, which instead falls as rain under higher temperatures. As there is less available snow to melt during dry summers, river flows will shrink.

Central Asia has a long history of structural approaches to reducing water scarcity, including those constructed during the Soviet era (Lioubimtseva and Henebry, 2009). These water management strategies, such as the massive irrigation projects in large parts of Central Asia, were undertaken to support agricultural development, but are now exacerbating the region's water stress related to climate change.[6]

Pilot programs in the region have seen success with intercropping of trees and drip irrigation systems to adapt to water stress (Lioubimtseva and Henebry, 2009). However, overhauls to irrigation systems in the region require a massive investment of finances and technical expertise. It remains to be seen whether these are viable options in the region or if the necessary investment would divert too much capital from other projects, such as livelihood diversification or other sustainable interventions. These water management strategies are designed to cope with water stress, which predates many of the more recent and rapid effects of climate change. Although they are not explicitly related to changing climate, they are included here because of the dearth of published literature on climate adaptation in this range, and the fact that many existing water management strategies, if modified to account for changing climate, can be effective in building community and ecosystem resilience.

6 Another unintended side effect of massive irrigations systems is the spread of vector-borne disease (Lioubimtseva and Henebry, 2009). The positive gains in crop production through irrigation often come hand-in-hand with increased mosquito and malaria presence, as well as other diseases such as schistosomiasis. Combating these disease vectors allows chemical insecticides to work their way into food webs and ultimately have an impact on human health and livelihoods in the region (Lioubimtseva and Henebry, 2009).



VILLAGE OF GANDRUNG NESTLED IN THE HIMALAYAS; © GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

SECTION V
Limitations of Current Evidence and Recommendations for Key Research Needs

This section presents current data gaps and shortcomings, and identifies key research needs. Given the paucity of data in the region relative to its vast size and remoteness, the Section also discusses the uses and limitations of satellite remotely sensed data in mitigating current data needs, focusing on use of available free or inexpensive imagery. This discussion of satellite imagery techniques is expanded by presentation of a small-scale case study illustrating the utility of freely available imagery for remote glacial monitoring in AHM.

5.1 Data Needs

The IPCC has identified significant data gaps throughout much of AHM, particularly gaps in direct observational knowledge (IPCC, 2013b). Data collection has been limited by the vast size of AHM; the remote, rugged and high elevation terrain; poor roads; sparse population; and, in many regions, political instability. These factors have placed severe limits on the scope of many studies, which often rely on few in-situ or observed data points.

5.1.1 GLACIER DATA

Glaciers can be monitored via direct field measurements, measurement of downstream impacts, remote sensing, and regional modeling. Due to access and data limitations, much of the current work focuses on remotely sensed data collection, which is not sufficient to constrain glacier character and climate change impacts (Bookhagen and Burbank, 2010). Most glacial change estimates in the region have been derived from temperature and precipitation data collected well below glaciers, regional climate models, or assumptions about snowlines and glacial altitudes (National Research Council, 2012). High elevation snowfall, avalanche- and wind-redistribution of snow, and subsurface glacial movements are all known to impact glacier character, but there are few direct measurements in the region. It is unclear how these factors impact glacial response to climate change, due primarily to lack of data.

Many glacial studies in the region have focused on monitoring glacial termini. These studies do not capture essential information on glacial mass balances (e.g., Aizen et al., 2007; Narama et al., 2006; 2010; Khromova et al., 2006; Malone, 2010). It is very possible for glaciers to retreat while gaining mass, or conversely, to advance while thinning and shedding mass. There are simply not enough in-situ glacial measurements to use glacier retreat or growth rates to estimate water storage capacity changes, which are important pieces of information for informing water management strategies under changing climate conditions.

Setting up new monitoring stations throughout the region, even if only short-term, would help immensely in calibrating GCM and remotely sensed datasets, which would reduce the need for future intensive on-site glacial monitoring data. Local participation in such projects, and engagement of local scientists and educators, would increase understanding of the factors controlling glacier change throughout AHM.

5.1.2 HYDROMETEOROLOGIC DATA

To properly constrain climate studies, accurate stream discharge and precipitation data are needed. However, very few places in AHM have kept consistent and long-term precipitation or stream monitoring records. Furthermore, there are few hydrometeorological stations above 1,000 meters in this region of elevations often exceeding 8,000 meters. Even when these records exist, they are not always available or easily accessible for analysis. For example, although Nepal's Department of Hydrology and Meteorology maintains a network of approximately 100 hydrometric stations and 280 climate/meteorological stations, it is unclear to what extent data from these stations are analyzed by the national program. The data from these stations are not freely available to researchers, though they can be obtained for a fee. More generally, the majority of scientific literature in the region is published by international researchers, and publications do not often reflect collaborations with government agencies directly responsible for monitoring data. Great strides could be made towards improved monitoring and analysis capacity through collaborations between scientists and monitoring agencies.

As many climate processes have multi-decadal variations that are unlikely to be expressed in shorter datasets, lack of continuous or temporally extensive data can severely limit analyses. As was noted by Cook et al. (2013), trends in river discharge often operate at decadal and centennial timescales, and can not be sufficiently constrained by the limited datasets available in AHM. This problem is particularly difficult to remedy, although longer-term data could be derived from weather records stored by the UK's Met Office or through local institutions such as monasteries. While older climatic records are often of lower quality, the increased temporal resolution they provide is valuable to predictive modeling in the region.

Measurement error has also been cited as a limiting factor on analyses in the region (e.g., National Research Council, 2012). Aging infrastructure, improper monitoring station construction techniques, and inadequate training can all contribute to poor data quality. Poor data quality is particularly evident in the case of snow measurements, as many older or bucket-type precipitation gauges seriously and variably underestimate snowfall. Vandalism or repurposing of weather stations is also a problem in parts of AHM (Ives et al., 2010). This could be somewhat mitigated through additional local engagement and training of "citizen scientists," with the added benefit of training on-the-ground data collection teams in remote locations. Measurement errors are often exacerbated in AHM through lack of regional coordination or cooperation in data standardization, collection and management. Without a regional data collection or quality standard, data collected in individual countries cannot necessarily be pooled for predictive modeling encompassing broader regions of AHM.

5.1.3 DEMOGRAPHIC DATA

Current demographic data in the region are sparse, and do not provide high enough spatial resolution for many studies (National Research Council, 2012). Available demographic data are also often unsuitable for projecting demographic changes in specific climatic or elevation zones. These deficiencies result in poor understanding of water resources use and of the potential changes in that use over the coming years. Key questions that these data might inform are: (1) How will populations change in areas with water abundance versus those areas with water scarcity?; (2) How do demographic trends affect water supply, demand and management?; (3) What infrastructure developments are planned, and how will they affect water management and regional hydrology?; and (4) How can international and national climate assessments be incorporated into regional and local water management policy?

Demographic data can in some cases be obtained through satellite imagery, although AHM pose additional challenges in satellite data collection due to steep topography and the resultant shadows and cloud cover. Increased national and international collection of demographic data, such as India's recently published 2011 census, will provide key information to inform the implementation and formation of climate adaptation policies in the region. [7]

5.2 Research Needs

The complex nature of AHM creates a vast array of possible research avenues. Viviroli et al. (2011) present a suite of research needs for mountain environments in general, which is supplemented in this report by additional research needs sourced from studies in the region (e.g., Bookhagen and Burbank, 2010; Jacob et al., 2012; Miller et al., 2012).

5.2.1 BLACK CARBON

Black carbon has been implicated in surface warming, weather pattern changes and glacier melting (International Resources Group, 2010). However, the impacts of black carbon on these three areas are still hotly debated, and no real consensus has been reached on the impacts of black carbon in AHM. Further

7 http://censusindia.gov.in/

studies are particularly needed to assess the direct effects of black carbon, and rate of those effects, on glacial melting in the region.

5.2.2 PERMAFROST

Detailed analyses of the effects of changing permafrost on climate and water budgets are scarce, though studies have shown that permafrost is decreasing throughout AHM as temperatures increase (e.g., Cheng and Wu, 2007; Bookhagen and Burbank, 2010). It is not well understood what the short- and long-term effects of reduced permafrost will be on AHM and their inhabitants.

One recent study has implicated permafrost changes in degradation of high rangelands (Harris, 2010), positing that the increasing depth of the active layer – the area which freezes and thaws each year – has led to enhanced erosion potential. This increased erosion potential, when combined with increasingly heavy grazing, has resulted in degraded high pasture lands. Further research is required to identify the influence of each of these factors on rangeland degradation in AHM.

A WWF study (WWF China, 2010) posited that increasing permafrost depth could increase the infiltration of groundwater, and reduce surface water availability. This would lead to the desiccation of many streams, springs and lakes, and drastically change the types and amounts of vegetation that could be supported in many high areas. It is unclear how rapidly such a process might occur, and what the spatial extent of the effects could be.

5.2.3 GROUNDWATER STORAGE

Changing water regimes throughout AHM, as well as population and agricultural growth, will likely stress groundwater reservoirs. However, detailed data are lacking on the effects of groundwater-surface water interactions, land use changes and vegetation-water interactions (Viviroli et al., 2011). Groundwater storage could become particularly important where seasonal flow is likely to decrease (such as areas in which glaciers have disappeared). Active recharge of groundwater aquifers could be an alternative water storage mechanism in these areas.

5.2.4 MODEL DOWNSCALING AND PRECIPITATION PROJECTIONS

Most regional and global climate models present data in large spatial resolution (300 x 300 km cells) (Viviroli et al., 2011). These models are insufficient to predict climate impacts at smaller scales, and are particularly unreliable in steep and varied topography. The same is true for precipitation projections, which are often given at rough spatial scales and do not represent on-the-ground conditions. There are research opportunities both in statistical downscaling of large-scale models, and in improving regional modeling techniques that incorporate topography, which are often extremely computationally intensive.

5.2.5 SATELLITE DATA CALIBRATION

Satellite data can be a powerful tool in remote and hard-to-access environments. However, satellite data do not always accurately capture ground conditions, particularly when variations in the environment are smaller than the resolution of the data captured. These variations can be both spatial, such as land cover variations over a one km^2 pixel, and temporal, such as changes in snow cover between daily, monthly or yearly satellite image acquisitions. Thus, satellite data must be calibrated with ground data points to give a more accurate picture of actual ground conditions. In addition, there are research opportunities in calibrating remotely sensed datasets in less difficult and varied terrain, such as the European Alps, to improve data quality for predictions in regions such as AHM where ground data are scarce.

The AHM region is data-poor, and accurately calibrated satellite data can provide important insight into conditions in parts of the region where direct monitoring is infeasible due to rough terrain, political instability or lack of road access. For monitoring of remote regions, satellite data are the most cost-effective solution, particularly given the lack of investment in AHM in ground monitoring efforts.

5.2.6 SNOW-WATER EQUIVALENT

Snow-Water Equivalent (SWE) is a measurement of the amount of water contained in snow pack. Estimates of spatially distributed SWE require complex data, including precipitation, air temperature and stream runoff. A recent model for SWE in the Swiss Alps included more than 11,000 direct measurements from 37 sites over a 50-year period (Viviroli et al., 2011). This model now allows SWE estimations using simple temperature sensors, as well as snow distribution, which can be fairly easily obtained via satellite imagery. The development of such a model, or a series of models, would be of great use in estimating water budgets in AHM.

Preliminary work has been conducted by Bookhagen (unpublished), and is illustrated in Figure 14 below. This work is limited in AHM by lack of sufficient ground stations, diversity of terrain and varied weather patterns. As such, the work should be treated as provisional, and in need of further development before it is usable as a program planning mechanism in AHM.

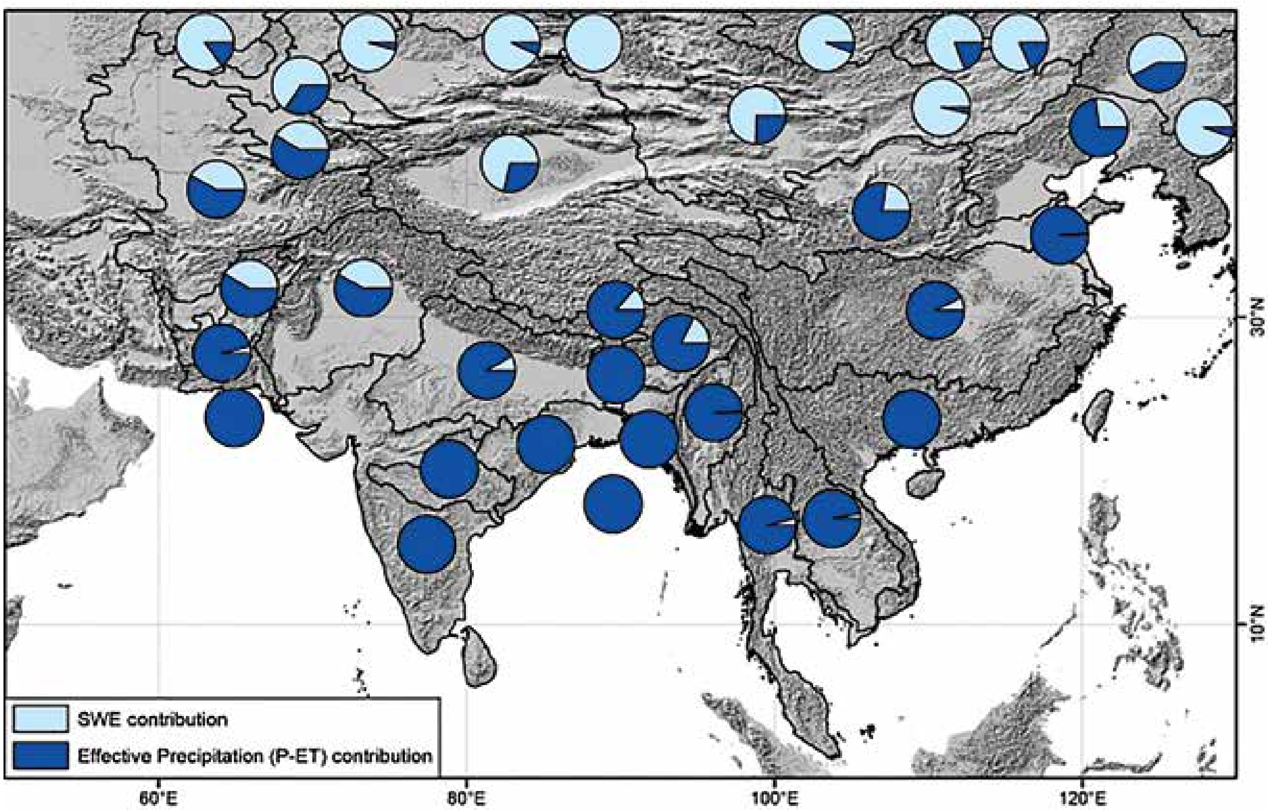


Figure 14 - Annual contribution of Snow-Water Equivalent (SWE) and effective precipitation (Precipitation minus Evaporation), showing clear trends of higher glacial contribution in the northern and western areas of AHM. Data from TRMM 3B42 V7 (rainfall), MODIS (evapotranspiration), SWE from compiled passive microwave data. All quantities are based on calibrated remote-sensing data and not on snowmelt modeling. Source: Bookhagen (Unpublished)

Figure 14 illustrates the potential for varied response of watersheds to climate change. Circles dominated by light blue (high SWE contribution) represent areas that are more likely to see slight increases in water availability from glacial melt, and then lower water availability as glaciers disappear. Circles dominated by dark blue (high precipitation contribution) represent areas that respond to changes in seasonal monsoon patterns, and do not draw as much moisture from glacial runoff. Such models, though rough in scale, can help inform future water budgets and assess the variable impacts of climate change throughout the region. Further research integrating additional ground stations will help improve these models so that they may be used in regional planning.

5.2.7 SOIL PARAMETERS

Soils are very important factors in any hydrologic model, as they are a strong control on surface water absorption. The complex topography of AHM, as well as the wide range of source rocks, creates highly heterogeneous soil profiles. The heterogeneity of source rocks, coupled with inaccessibility of many regions, means that soil maps in AHM are very rough, and data are generally limited to broad soil type classifications. Improved soil data would both greatly inform groundwater flux models and give a better indication of soil moisture and infiltration rates for water management in AHM.

5.2.8 ENHANCED WARMING AND FEEDBACK MECHANISMS

A decrease in snow- and ice-cover reduces surface albedo, and can lead to increased heat absorption. This cycle will likely accelerate as smaller glaciers continue to shrink, and could exacerbate warming trends. However, these changes are spatially diverse, and are not well represented in global or regional models of climate change. The factors controlling these feedback loops are not well understood, and further research is needed to quantify their effect on climate in AHM.

5.2.9 GLOF RISK MONITORING

Many glacial lakes are found high above inhabited areas in AHM. These remote lakes can grow undisturbed until they burst and flood downstream areas. Though some automated risk detection techniques have been proposed (e.g., Ives et al., 2010; Narama et al., 2010b; Bolch et al., 2011), these methods are not yet well established and require significant manual input. Better algorithms for assessing GLOF risk over wide areas are needed throughout AHM.

5.2.10 ACCURATE LAND COVER DATA

Global land cover datasets are products derived from satellite imagery, and usually have spatial resolutions no better than 1 km^2. The satellite imagery from which they are derived, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Very High Resolution Radiometer (AVHRR), provide land cover classifications, vegetation index measures, albedo and several other measurements. However, these data are by necessity averaged over many image cycles, as weather patterns often disrupt data collection. More accurate calibration, when combined with ground control data, could help with regional land management and planning.

5.3 Satellite Remote Sensing

Satellite data are powerful tools for studying rugged environments, and can provide valuable data on hard-to-access regions. Individual satellite data sources are useful for specific applications, and each also comes with drawbacks and limitations. This section presents some possible uses of remotely sensed data in AHM through case studies, and discusses their limitations.

5.3.1 GLACIER INVENTORY

Narama et al. (2010a) present a wide-area study of changes in glacier area in the Tien Shan range from 1968 through 2008, using only remotely sensed data. They were most concerned with understanding the spatial extent of glaciers and rate of retreat in the region, and did not provide any mass balance estimates. Using declassified Corona imagery from 1968-1971, they were able to digitize the original boundaries of glaciers in the region. Between 1999 and 2002, they used Landsat imagery to assess glacial extent, and for the period 2002-2008, they used Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) and Advanced Visible and Near Infrared Radiometer (AVNIR) data.

Corona imagery provides high-resolution black and white photography, and is one of the oldest high-resolution (1.8-5 m) data sets available. However, Corona imagery is challenging to work with, and mapping glacier extents from black and white images is particularly so. Landsat imagery provides multiple spectral bands which can be used to more readily identify glacial extent, although its 30 m resolution still leads to large errors in glacial extent. AVNIR provides 10 m resolution, which allows for fairly accurate glacial extent mapping.

Using these three data sources, glacial extents were manually digitized, and areas calculated within a geographic information system (GIS). The three main limitations of this study are: (1) lack of mass balance or volume estimates; (2) labor intensity of manually digitizing glacial outlines; and (3) possible errors associated with snow cover and image resolution. Unfortunately, there are no well-defined algorithms for extracting glacial area from older images, as they vary greatly in their spectral characteristics, particularly between data sources. Narama et al.'s (2010a) study presents a state-of-the art glacial inventory methodology, and despite the labor-intensity, a few similar studies have been performed throughout AHM to assess glacial extent and change (e.g., Narama et al., 2006; Shangguan et al., 2007; Haritashya et al., 2009; Shahgedanova et al., 2010).

In addition to small-scale studies, there are several global glacier datasets available, which vary in their scale, application and accuracy. The GLIMS database is generally the most extensive, and includes user-contributed data for much of the world (Raup et al., 2007). It has been continuously updated by the scientific community since its inception, and remains a widely used tool (Racoviteanu et al., 2009). However, as it is generally populated by hand-digitized glacial outlines, there are potential errors which can make it inappropriate for detailed analyses (Paul et al., 2013).

The implications of these studies are that glacier area estimates from large datasets and studies are inherently limited by both image resolution and potential for human error in digitizing glacier boundaries. Thus, natural resource management plans that include glacial monitoring or cover areas impacted by glacial runoff should consider the potential sources of error in glacial measurements when making management decisions.

5.3.2 GLACIER MASS BALANCE MEASUREMENTS

Berthier et al. (2007) present a suite of mass balance estimates for Himachal Pradesh in the western Himalaya. They use three primary data sources: (1) Satellite pour l'Observation de la Terre (SPOT) imagery; (2) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery; and (3) Shuttle Radar Topography Mission (SRTM) digital elevation models (DEM).

Using a pair of SPOT images at 2.5 m resolution, and shot from different view angles, the researchers were able to create a "stereo" image, which interpolates between two view angles to create a DEM. By using ASTER imagery, the researchers were able to digitize the boundaries of the glaciers at 15 m resolution. By assuming that the non-glaciated areas would not change between the 2000 SRTM elevation data and the 2004 stereo-DEM, they could correct for elevation bias between the two datasets. Further statistical corrections were then applied based on data collection problems inherent in the SPOT satellite. With this technique, they were then able to directly compare the elevations of the digitized glacial zones in 2000 from the SRTM and 2004 from the stereo-DEM.

Though this methodology can provide valuable mass-balance estimates, there are several limitations. First, the SRTM-DEM has been shown to be less accurate in steep terrain than in flat terrain (Nuth and Kääb, 2011; Smith and Sandwell, 2003). Furthermore, the stereo-DEM and SRTM-DEM are at different spatial resolutions, and use different data capture techniques, and thus comparing them directly is inherently error prone. Lastly, a lack of direct field measurements means that it is very difficult to assess uncertainty in results produced using this methodology. The methodology presented by Berthier et al. (2007) has been replicated using other satellite sources and is generally accepted as a useful technique for assessing mass balances, especially over large areas, despite the inherent shortcomings and inaccuracies in the methodology (e.g., Nuth and Kääb, 2011; Gardelle et al., 2012). It does not serve as a replacement for field-based mass balance measurements, but can support wider-scale glacier mass balance estimates, especially in hard-to-access terrain.

The main implication of this type of study from a management perspective is in interpreting mass balance estimates derived using satellite techniques. Though estimates are fairly low in error in aggregate, they cannot necessarily identify where mass is being shed from a glacier. Thus, potential for glaciers to calve or avalanche into glacial lakes may be misestimated when satellite techniques are used. Estimates of water gain or loss should be substantiated through field surveys when possible.

5.3.3 HYDROLOGIC MODELING

Bookhagen and Burbank (2010) use a suite of remote sensing tools, as well as ground validation data, to define a complete Himalayan hydrologic budget. They

© ROEL A. BURGLER / WWF-CANON

use four main datasets in their analysis: (1) the SRTM-DEM; (2) Tropical Rainfall Measurement Mission (TRMM) rainfall data; (3) TRMM LIS (Lightning Imaging Sensor); and (4) MODIS data to parameterize evapotranspiration, snow-cover area and surface temperature.

SRTM data were used both in calculating incoming solar radiation and in calculating hydrological flow of water throughout the region. The investigators used TRMM rainfall estimates at a 5 x 5 km^2 resolution, with additional ground calibration through a network of 1,741 monitoring stations to create robust instantaneous, seasonal and yearly precipitation measurements. Using the TRMM LIS, they linked high intensity storms with their resultant rainfall both through ground gauges and precipitation estimates from satellite data. Finally, using two MODIS products, they mapped surface snow cover and temperature at 5 x 5 km^2 resolution. In this way they estimated both the inputs (rain and snowfall), and outputs (outbound stream flow) throughout their study region.

Their model was shown to successfully predict both rain and snow input into the hydrologic system through validation with stream flow records in the region. However, there are several important shortcomings in the use of remotely sensed data in the study: (1) The model can operate only on fairly large watersheds, as the resolution of precipitation data is 5 x 5 km^2. (2) The data are not collected continuously, and must instead be averaged over the measurement timeframe of the satellite, which may miss some short-lived storms. (3) MODIS data are unreliable during high cloud cover and in the context of high water-vapor content, and thus these data must also be averaged over several image acquisitions. However,

© GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

due to lack of in-situ data, a remote modeling approach is one of the best ways to approach large-scale hydrologic questions in AHM.

Though large-scale hydrologic budgets can be constructed, they are not often downscaled to individual catchments. This implies that estimates created through regional modeling, however well they match up to stream flow records, should be applied with caution as they may not reflect local context.

5.3.4 AEROSOL MONITORING

Gautam et al. (2009) used the Nimbus 7 satellite (1979-1992), Total Ozone Mapping Spectrometer (TOMS) (1997-2001), Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), and MODIS to analyze aerosol loading over the ISM region.

Although Nimbus 7, TOMS, and MODIS have fairly low spatial resolution, Gautam et al. (2009) were able to extract regional trends, and show that aerosol content is highly consistent with regional weather patterns. The CALIOP sensor was used to measure both the vertical distribution of aerosols in the region, and the type. The sensor is able to distinguish between spherical (sulfate) and non-spherical (dust) particles, which allows the authors to derive a measure of anthropogenic contribution to aerosol loading in the region.

While the spatial resolution of the datasets used was quite large, this is not a problematic limitation due to the spatial scale of the processes involved. The limits on the accuracy of absorption spectra in the region, which allow the investigators to distinguish between anthropogenic particles and dusts, are more important, and could be improved by in-situ measurements and more advanced calibration techniques.

Techniques such as the one presented in Gautam et al. (2009) open the interesting possibility of applying aerosol distribution patterns in weather prediction. As the authors noted, aerosol loading is likely a major driver of earlier ISM rainfall, followed by a relatively drier period. Though their modeling results focus on a multi-year time series, their methodology could help inform agricultural practices which rely on the timing and volume of rainfall.

5.3.5 GLOF RISK ASSESSMENT

Bolch et al. (2011) undertook a semi-automated GLOF risk assessment in the northern Tien Shan using a suite of remote sensing datasets. Their study used (1) Corona imagery, (2) Landsat imagery, (3) ASTER imagery, and (4) the SRTM-DEM.

Bolch et al. (2011) first registered all of their data to a common reference image, and then used the spectral properties of water to perform an automated delineation of lakes in each image, with manual corrections for shadowed areas. Glaciers were then tracked between each scene using image tracking software to quantify glacial changes and speeds of change. Using the SRTM-DEM, the authors quantified glacier slope, as well as other near-lake characteristics such as propensity for landslides and avalanche risk. Finally, using the SRTM-DEM, they used flow routing algorithms, based on the estimated volume of each glacial lake, to assess total downstream area that would be affected by a GLOF. By combining each of these pieces of information, an automated risk assessment algorithm was created, and risk of flooding assessed. This methodology could be further combined with infrastructure and population data to perform a rudimentary impact analysis on downstream populations, although Bolch et al. (2011) did not incorporate this step.

The main drawbacks of the imagery used in the Bolch et al. (2011) study are temporal resolution and the difficulty in accurately assessing lake area and volume from satellite data. This study used six images over the period of 1999-2008, which does not provide a complete picture of rates of change. Another study in the region noted that some of the most dangerous glacial lakes grow quite quickly (on a scale of weeks to months), and that these lakes are unlikely to be captured by imagery with repeat times of multiple months to years (Narama et al., 2010b). Furthermore, using an automated process to delineate lake boundaries often creates misclassifications, particularly in areas of shadow which have similar spectral characteristics as lakes. Thus, manual intervention is needed, rendering the analysis less appropriate for large-scale studies. Despite these shortcomings, Bolch et al. (2011) present a useful methodology for quickly delineating a large number of glacial lakes and assessing their downstream hazard potential.

Using automated lake-mapping methodologies, resource managers can both assess lake hazards and make a rough assessment of water storage in lakes in a region. For simple inventory purposes, the methods presented in Bolch et al. (2011) could be simplified by including only one set of images, though this would fail to capture some of the dynamic activities of lakes that make them dangerous to downstream populations.

5.3.6 IMAGERY AVAILABILITY TO USAID AND IMPLEMENTING PARTNERS

USAID recently established a Center for the Application of Geospatial Analysis for Development (GeoCenter) to provide technical assistance to missions, bureaus and projects. The GeoCenter maintains a database of geographically oriented data that may be useful for project implementation. In coordination with SERVIR,[8] the GeoCenter also assists in the acquisition of satellite imagery for implementing partners. These services could be leveraged in the design of project activities worldwide, but particularly in AHM, as SERVIR maintains a presence inside of the International Centre for Integrated Mountain Development (ICIMOD).

8 https://www.servirglobal.net/

TERRACED HILLSIDES FOR FARMING, GANDRUNG; © GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

SECTION VI
Current Policy Initiatives Supporting Climate Change Adaptation and Resilience

This section (1) provides a regional perspective on climate change policy; (2) describes interstate policy initiatives underway in AHM; and (3) presents country-specific policy initiatives for regional states home to project field sites or important implementation (Bhutan, India, Kyrgyzstan, Mongolia, Nepal, Pakistan and Tajikistan). Many regional policy initiatives focus on the effects of changing water quantity and quality, although changes in agriculture and ecosystems also play an important role.

6.1 Regional Perspective on Climate Change Policy

As has been presented in the previous sections, climate change has serious implications for human and ecosystem welfare in AHM. In addition to local effects due to water and other resource changes, climate change could have geopolitical and security effects, exacerbating resource conflicts and driving migrations which could destabilize both individual countries and entire regions (Matthew, 2012). Matthew (2012) cites one example in Nepal, where flood victims were resettled among communities already struggling to survive in a resource-poor region. The tensions between the two groups quickly escalated and fueled anti-government sentiments, ultimately resulting in violent clashes between police and community members. Examples such as this illustrate the need for coherent and environmentally sound practices in responding to climate change.

Regional cooperation is imperative in managing cross-boundary climate impacts and mitigation strategies. Floods that begin in upstream areas of China often proceed downstream into Nepal. Data collected in the upper reaches of the Indus River in India are critical to the management of the river's downstream reaches in Pakistan. However, there is a marked lack of regional cooperation on climate issues. There are a range of political and economic reasons that robust regional cooperation on climate change has not occurred in AHM. International development and donor agencies have committed financial and technical resources to supporting interstate policy and cooperation (e.g. Appendix A), but sustainable and long-term solutions to the climate problems faced by AHM must be home-grown, and developed within the cultural, political, and environmental context of each country.

6.2 Interstate Policy Initiatives

Despite limited regional cooperation on climate change in AHM, there are notable exceptions and mechanisms for continued progress. One is the development of regional knowledge hubs, such as ICIMOD, which has demonstrated many potential areas where interstate policy measures could have positive impacts on regional climate adaptation. Others include the Indus Water Treaty, the Thimphu Statement on Climate Change, and the Climate Summit for a Living Himalayas, described below.

6.2.1 THE INDUS WATER TREATY

Established in 1960, the Indus Water Treaty (IWT) is one of the oldest water sharing treaties in the modern world, and governs the flow of water from the headwaters of the Indus in India downstream into Pakistan (Figure 15). Since the establishment of the IWT, populations have grown dramatically in the region, and the effects of climate change on the river basin have become more pronounced.

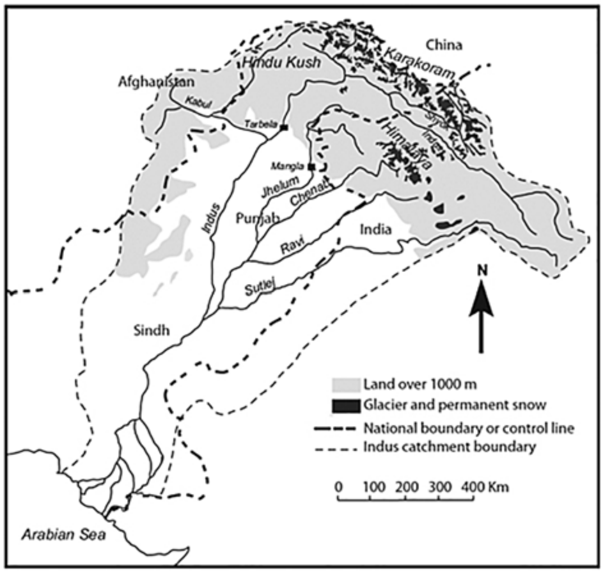


Figure 15 - Indus Basin, showing national boundaries, catchment boundaries, mountainous areas and major tributaries (Archer et al., 2010).

One of the major shortcomings of the IWT is that climate variability and uncertainty are not addressed in the treaty (Sarfraz, 2013). As atmospheric patterns shift, and other climate-induced threats – such as GLOF – become more prevalent, there is a need for enhanced cooperative management and climate adaptation strategies between India and Pakistan. Furthermore, the IWT does not take into account "environmental flows," or flows necessary to maintain a certain level of ecosystem health. It also does not account for groundwater storage, which, under growing population pressure, has dramatically fallen. The construction of additional upstream dams and reservoirs may positively affect extraction and local use, but can have quite drastic impacts on downstream populations which rely on seasonal recharge of groundwater for year-round water availability.

Despite its shortcomings, the IWT has functioned with relatively few issues throughout the last 50 years, even through periods of interstate conflict. In fact, only two disputes have been referred to third parties during the lifetime of the IWT (Sarfraz, 2013). The treaty provides an important base of communication and cooperation between India and Pakistan, and, with amendments to reflect environmental changes and protections, could continue to function through periods of shifting climate.

6.2.2 THE THIMPHU STATEMENT ON CLIMATE CHANGE

Although the South Asian Association for Regional Cooperation (SAARC)[9] does not include Kyrgyzstan or Mongolia, SAARC can be considered one of the few multi-state organizations operating in AHM. Its charter does not explicitly encompass environmental or climate issues, but recent focus on environmental health and sustainable development encouraged SAARC to issue the 2010 Thimphu Statement on Climate Change. This statement recognizes that climate change is a multi-national issue, and that mitigation and adaptation methods should be formulated at a regional and international level.

SAARC resolved to (1) establish an inter-governmental expert group on climate change; (2) promote the use of green technology and best practices; (3) incorporate science-based materials in education; (4) plant 10 million trees in a regional reforestation campaign; (5) enhance knowledge and data sharing within the region; (6) commission studies on both glacial and monsoon patterns; and (7) commission an inter-governmental climate-related disasters initiative in coordination with the SAARC Disaster Management Center. Though these declarations lack the force of law, they illustrate that climate change and its impact on human populations in the region are a growing concern, and that timely and well-informed interventions should be implemented. Although SAARC does not cover the entirety of AHM, avenues of regional cooperation defined and implemented could and should be extended to other regions of Asia impacted by climate change.

In the three years since the Thimphu Statement was signed, the SAARC Intergovernmental Group on Climate Change has been formed. The group has met at least three times (June 2011, April and December 2012) to review implementation progress, but reports from these meetings have not been released to the public. Information available through public sources

9 Member countries are Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka and Afghanistan. Observers include Australia, China, the European Union, Japan, Iran, Mauritius, Myanmar, South Korea and the United States.

indicates that the SAARC Disaster Management Center in Delhi, India, recently commissioned a comprehensive study of the policy and institutional landscape and resource allocation for climate change adaptations and disaster risk reduction in the eight SAARC countries (Chandra, 2013).

6.2.3 THE CLIMATE SUMMIT FOR A LIVING HIMALAYAS

In 2011, the Royal Government of Bhutan convened the Climate Summit for a Living Himalayas, which included environment ministers from Bangladesh, Bhutan, India and Nepal, as well as academics and representatives of civil society (Bhutan Climate Summit Secretariat, 2011). The outcomes of this summit included a declaration to adopt a "Framework of Cooperation," including four broad objectives: food security, freshwater systems, biodiversity and energy security. The summit had a particular focus on regional knowledge sharing and capacity building, particularly in regards to climate-related issues such as climate-induced natural disasters and climate resiliency in energy systems.

6.3 Country-Specific Policy Initiatives

Each country in the region has responded to climate change through policies informed by distinct geographic, political and climatic influences. These measures are diverse in their scale and scope, as well as in how they are implemented. This section reviews important policies within each partner state relevant to climate change adaptation and mitigation. Each partner country has ratified the United Nations Framework Convention on Climate Change (UNFCCC), and has taken steps to fulfill obligations under the convention.

6.3.1 BHUTAN

Bhutan submitted its second communication to the UNFCCC in 2011 (Narngyel et al., 2011), which detailed several target sectors for adaptation policy: water resources, energy, forest and biodiversity, agriculture, health, and glaciers and GLOF.[10] This communiqué provides a fairly comprehensive set of adaptation priorities, many of which require significant outside technical or financial assistance. The report notes that current priorities should be the development of a comprehensive climate change strategy, capacity development on climate change issues, improved communication between stakeholders and donor agencies, media and educational awareness efforts, and additional institutional authority for the National Environment Commission.

6.3.2 INDIA

In India's second communication to the UNFCCC (Government of India, 2012), eight National Missions are identified which comprise the National Action Plan on Climate Change (NAPCC). These missions are (1) National Solar Mission – to significantly increase solar energy percentage; (2) National Mission for Enhanced Energy Efficiency; (3) National Mission on Sustainable Habitat – to promote environmentally sound urban development strategies; (4) National Water Mission; (5) National Mission on Green India – to enhance carbon sinks in forests and other ecosystems; (6) National Mission for Sustaining the Himalayan Ecosystem; (7) National Mission for Sustainable Agriculture; and (8) National Mission on Strategic Knowledge for Climate Change.[11] Mission 6 – the National Mission for Sustaining the Himalayan Ecosystem – is particularly interesting for this report. It proposes to network knowledge institutions to develop a coherent database on geological, hydrological, biological and socio-cultural dimensions of conserving the ecosystem; detect and decouple natural and anthropogenic causes of environmental change; assess the socio-economic and environmental consequences of global environmental change; study traditional knowledge systems for community participation in adaptation, and evaluate sustainable tourism and resource development; raise awareness among stakeholders in the region; assist states in the Indian Himalaya region with informed actions; and develop regional cooperation with neighboring countries (Government of India, 2010).

Each of India's 35 states and union territories has been asked to prepare a state-level action plan as an

10 For a more complete list of adaptation measures, see Bhutan's Second Communication to the UNFCCC (Narngyel et al., 2011).

11 For more detail, see India's Second Communication to the UNFCCC (Government of India, 2012).

extension of the NAPCC contextualized within local governance constraints. India has also commissioned a national climate change assessment, which was published in 2010 (Indian Network for Climate Change Assessment, 2010).

These national- and state-level action plans rarely trickle down to city or community level planning (Revi, 2008). A few cities have undertaken climate risk assessments (i.e., Tanner et al., 2009; Laukkonen et al., 2009), but it is unclear whether those assessments have motivated policy changes.

6.3.3 KYRGYZSTAN

The Government of Kyrgyzstan ratified the UNFCCC in 2000 and the Kyoto Protocol in 2003, implying a political awareness of the implications of climate change. Under their UNFCCC and Kyoto commitments, Kyrgyzstan has implemented a detailed survey of greenhouse gas emissions, modeled expected national climate impacts through 2100, undertaken qualitative assessments in a range of environments throughout Kyrgyzstan, and implemented adaptation and mitigation measures (Zholdosheva, 2010).

In 2007, Kyrgyzstan established a legal basis at the national level for the execution of obligations under the UNFCCC through the national parliament. Furthermore, a series of executive orders have created a National Committee on Climate Change, as well as legislation specific to the improvement of forest management in Kyrgyzstan (Zholdosheva, 2010).

In the Second National Communication of Kyrgyzstan to the UNFCCC, Kyrgyzstan noted that it was developing a climate change adaptation strategy for the health sector, as well as an inter-agency group tasked with the development of a national climate change adaptation strategy (Iliasov and Yakimov, 2009). Both of these initiatives were started in 2009.[12]

6.3.4 MONGOLIA

Mongolia's Second National Communication to the UNFCCC in 2010 identified several policy measures implemented relative to climate change in the country (Ministry of Nature, Environment and Tourism 2010). At an international level, Mongolia has joined 14 environment-related UN conventions, such as the UNFCCC, the Convention on Biological Diversity, and the Convention to Combat Desertification. At a national level, the Mongolia National Action Programme on Climate Change aims to not only meet UNFCCC obligations, but to integrate climate change adaptation across multiple sectors. These include (1) introduction of new plant varieties resistant to droughts and pests, (2) modifying plant sowing periods to adapt to climate shifts, (3) construction of water reservoirs to harvest glacier and snowmelt, (4) expanding tree-planting initiatives and afforestation, (5) insulation and energy usage efficacy improvements, (6) limitation on number of livestock in the agricultural sector, and (7) water reuse and recycling measures. These policies span a wide range of adaptation strategies across multiple sectors, and represent a fairly comprehensive approach to climate change adaptation.[13]

A WWF report notes that despite the numerous national policy documents in line with global climate change commitments, many of these commitments have not evolved into practical actions (WWF Mongolia, 2007b). Further hindrances to implementation are lack of cross-sectoral coordination, which results in piecemeal and often ineffective interventions, and lack of interactive dialogue or involvement of key stakeholders, such as local communities. Finally, the report cites non-enforcement of many pieces of legislation as a major roadblock to effective climate change policy in Mongolia (WWF Mongolia, 2007b).

6.3.5 NEPAL

Nepal submitted its first communication to the UNFCCC in 2004 (Government of Nepal, 2004), which indicates that at the time, climate change was a growing issue, although not one addressed through extensive policy measures. The Nepal Environmental Policy and Action Plan (Government of Nepal, 2010) focused on sustainable management of natural resources; population, health and sanitation, and poverty alleviation; safeguarding national heritage; mitigating adverse environmental impact; and legislation, institutions, education and public awareness.

12 For more information, see the Second National Communication of Kyrgyzstan to the UNFCCC (Iliasov and Yakimov, 2009).

13 A more complete description of adaptation methods can be found under Mongolia's Second Communication to the UNFCCC (Ministry of Nature, Environment and Tourism, 2010).

© GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

More recently, Nepal has created the Nepal Climate Change and Development Portal,[14] as part of its National Adaptation Programme for Action (sponsored under the UNFCCC) (National Research Council, 2012). This action plan specifies several combined program areas under which adaptations should be planned, such as "promoting community-based adaptation through integrated management of agriculture, water, forest, and biodiversity sectors," and "GLOF monitoring and disaster risk reduction."[15] Nepal has also taken steps to institute Local Adaptation Plans for Action to contextualize national plans into regional contexts.

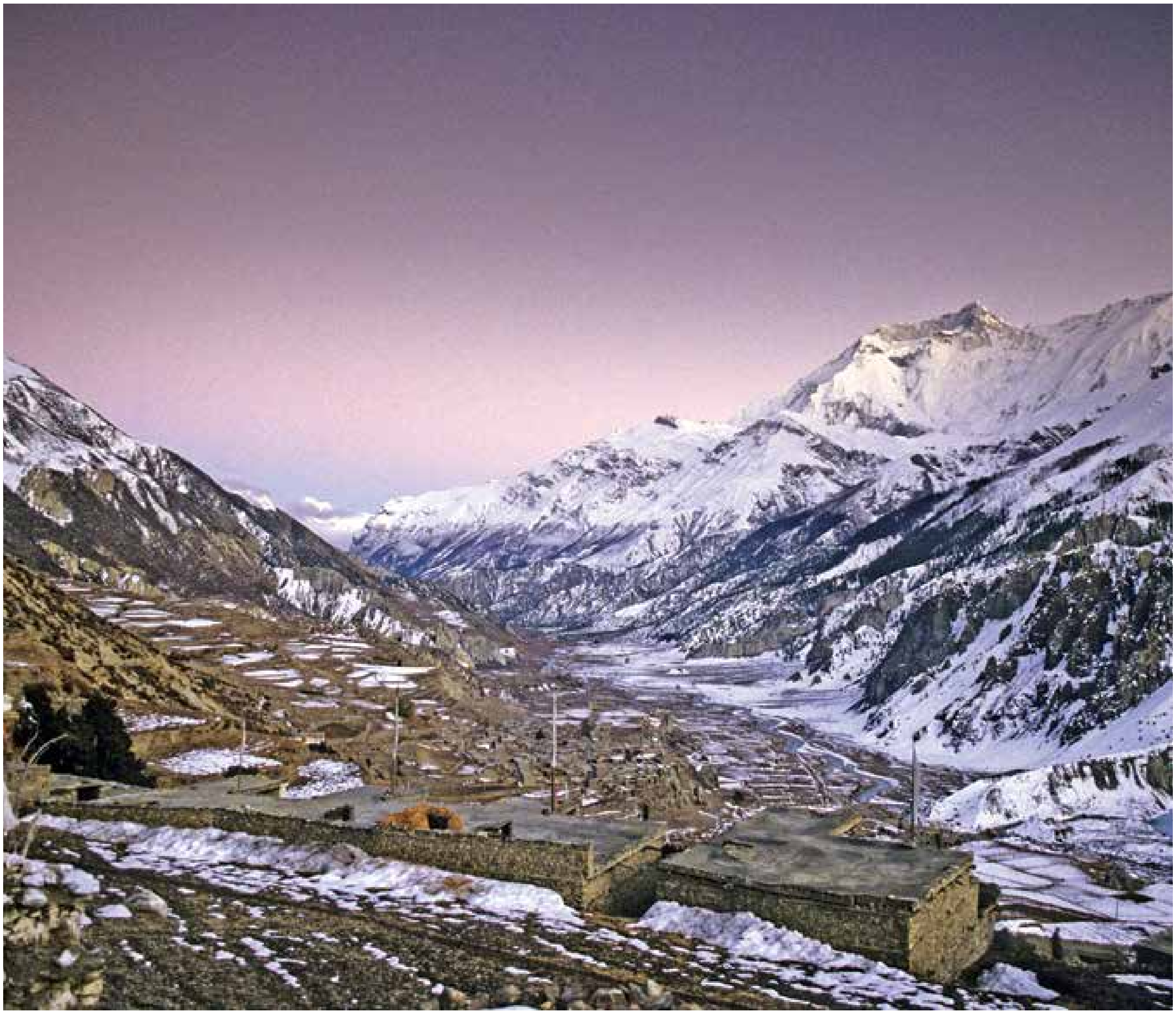
14 http://www.climatenepal.org.np/main/

15 For a more complete list, see the Nepal National Adaptation Programme of Action (Government of Nepal, 2010)

A 2011 Asian Development Bank (ADB) report identifies "overlapping mandates of district agencies, inadequate coordination, and weak resource allocation mechanisms" as major issues confronting climate change policy in Nepal (ADB, 2011). Furthermore, lack of knowledge on climate change risk in key agencies, particularly among junior staff, limits the efficacy of policy measures (ADB, 2011).

6.3.6 PAKISTAN

Pakistan submitted its first communication to the UNFCCC in 2003 (Iqbal, 2003), and has yet to submit an updated report. Pakistan's environmental policy is based on the Pakistan Environment Protection Act of 1997, which addresses development and implementation of clean air, clean water, solid waste management and ecosystem management projects.



© GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

With support from the Pakistan Environmental Protection Agency, a range of adaptation methods have been implemented, such as improved water system efficiency, flood mitigation strategies, and modified cropping patterns in response to water availability.

In 2012, Pakistan established a Ministry on Climate Change (National Research Council, 2012). This new authority coincided with the release of an updated climate change strategy (Government of Pakistan, 2012), which presents a coherent framework for the implementation of climate change adaptation policy.[16] These policy initiatives fall under the umbrellas of water storage and infrastructure improvements, water conservation strategies, integrated water resource management, improved legislative framework, enhanced technical capacity, and enhanced public awareness of conservation and sustainable resource use. At least one major city within Pakistan (Karachi) has also drafted a city-specific climate change adaptation plan (Anwar, 2012). Recently, improved

16 A more complete description can be found under Pakistan's National Climate Change Policy (Government of Pakistan, 2012).

environmental guidelines for near-road slope stabilization have been issued and made mandatory for the construction of roads in mountainous areas (Muhammad Ibrahim Khan, personal communication, May 2014).

6.3.7 TAJIKISTAN

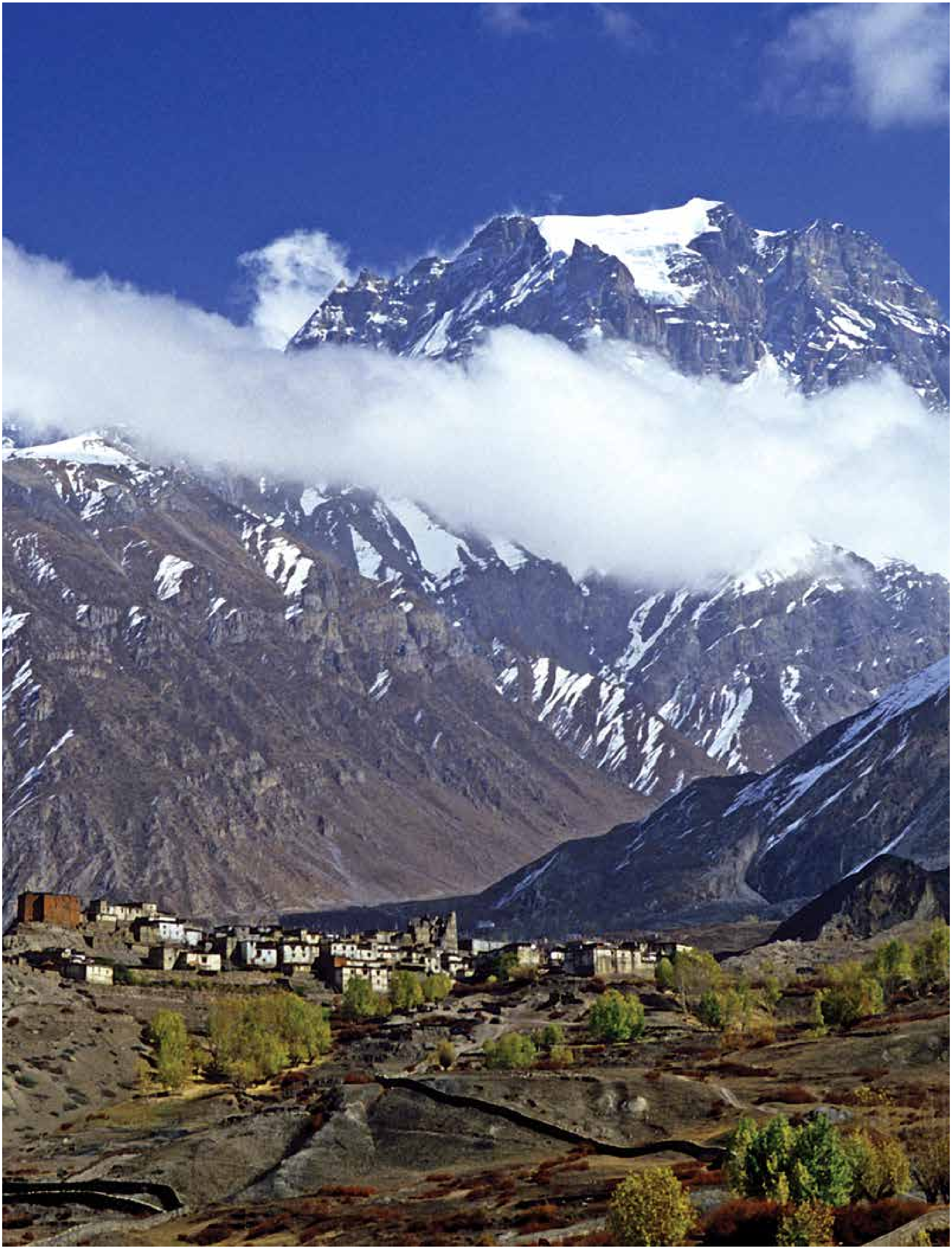
Tajikistan submitted its first communication to the UNFCCC in 2002 (Government of Tajikistan, 2002), and has submitted a second updated report in 2008 (Government of Tajikistan, 2008). As of October 2008, Tajikistan has ratified the Kyoto Protocol and developed a National Action Plan for Climate Change mitigation, which was ratified by the government of Tajikistan in 2003. Much of the focus of Tajikistan's policy is on the development of hydropower, as Tajikistan has an estimated 18 billion kWh of hydroelectric potential (Government of Tajikistan, 2008).

The national law "On Nature Protection" forms the legislative basis of Tajikistan's environmental policy, which was established in 1994, though this law governs only the atmosphere, energy and transportation sectors, and does not include provisions for sectors such as agriculture and forestry (Government of Tajikistan, 2008). Several actions have been undertaken in regards to the Tajikistan National Action Plan for Climate Change, such as supporting new hydropower construction, upgrading industrial complexes, and upgrading irrigation structures and water reservoirs. Many, if not all, of these actions should be more properly classified as 'mitigation', where the focus of policy is on reducing greenhouse gas emissions and environmental impacts. Minimal effort has been directed towards climate change adaptation. [17]

6.3.8 SUMMARY

Though each of the seven countries have taken preliminary steps towards mitigating climate change impacts, these steps have rarely materialized as concrete interventions. Some of this is due to limitations in capital and human resources, as well as poorly defined jurisdiction over climate-related issues. Most, if not all, of the countries studied have multiple overlapping ministries and regional or local governments in charge of inter-related sectors of ecosystem management. These factors combined have made it difficult for national-level policy on climate change to impact local land governance or climate change adaptation activities.

17 A more complete description can be found under Tajikistan's Second Communication to the UNFCCC (Government of Tajikistan, 2008).



JHARKOT MONSTERY NEAR MUKTINAH. MANANG DISTRICT, ANNAPURNA AREA, NEPAL; © © GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

SECTION VII
Recommendations for Future Adaptation Efforts

This final section recommends future adaptation efforts for consideration in AHM, building on recommendations made in the 2010 USAID report *Changing Glaciers and Hydrology in Asia* (Malone, 2010). Section 8 assesses new avenues of collaboration and regional-scale climate impact planning, contextualized within both a regional framework and a range-specific scientific, climatic and vulnerability setting. The Section identifies synergies between range-specific recommendations and region-wide efforts where appropriate.

This section will first illustrate general recommendations for activities and methods pertinent throughout AHM, followed by recommendations for regional-scale activities and methods, and finally methods specific to individual mountain ranges.

7.1 General Recommendations

Some strategies and methods are common to the entirety of AHM. These include such broad methods as community education, locally driven water management strategies, and drawing on traditional and local knowledge in the design and implementation of interventions. Malone (2010) presents a range of programmatic options to address climate change vulnerability at the national, sub-national, local and community level using an integrated development approach. Some suggestions include providing support to community-based water management groups, implementing zero-till farming practices, introducing small-scale irrigation systems, and establishing water and sanitation programs directly tied to improved water management practices.[18]

7.1.1 COMMUNITY EDUCATION

Several case studies, particularly in the relatively well-studied HKH region, have shown that community education is an essential factor in the implementation of many climate change adaptation measures. In some cases, such as in the implementation of GLOF or cloudburst flood early warning systems, education is as, if not more, important than the actual structural intervention. Flood early warning systems without community understanding have led to deaths from ignored warnings, and in some cases, cannibalization of equipment that locals did not understand the importance of. Implementing systems without sufficient local education can result in a large loss on investment, and can reduce adaptive capacity if warning systems provide a false sense of security to locals.

As has been illustrated throughout AHM, lack of data is a serious detriment to effective planning and mitigation efforts. Often, those best equipped to gather data are the local populations who know and can manage the often harsh terrain, and who have a vested interest in understanding the changes in their environment. Activities could be planned to build monitoring capacity throughout the region through the training of “citizen-scientists.” These citizens could fulfill the role of both data gatherer in hard-to-reach locations, and point of contact to disseminate further knowledge about climate change and its potential impacts. With the spread of text messaging, the Internet and social media, some communities within AHM are delegating weather monitoring in remote regions to individuals, often younger and more tech-savvy, who can gather data using existing stations or through rudimentary tools such as stream flow gauges and rain meters (Singh et al., 2011). As these individuals are already engaged with monitoring their environment, they serve as perfect “ambassadors” for providing up-to-date news and best practices related to climate adaptation to remote communities.

7.1.2 LOCALLY DRIVEN WATER MANAGEMENT

Many reports throughout AHM have noted that farmers are the first to notice changes in water availability. This is not surprising given how intimately their livelihoods are tied to changes in the landscape. Many communities

18 For more complete discussion of potential interventions, see *Changing Glaciers and Hydrology in Asia* (Malone, 2010).

throughout AHM recognize changing water availability and have started to implement coping strategies. One important strategy that could be supported through outside intervention is the creation and support of Village Resource Management Committees (VRMCs). These committees could consist of herders, farmers, educated youth, women, school teachers or other representatives of the communities. Using a mix of local knowledge and outside technical support, they could implement and maintain resource management solutions, of which water is likely to be the most important. However, legal frameworks supporting these types of committees are somewhat weak, and enforcing water management strategies remains difficult (Bartlett et al., 2011). It is also important that these committees remain flexible, and have a framework to adapt to changing climate patterns (FAO, 2011).

These committees can also address another important issue in water management in the region: scale. Most water policies operate on a regional or watershed level, which often engenders conflicts when watersheds cross national, or even sub-national, boundaries (FAO, 2011). Problems of jurisdiction are compounded when watershed-level policies do not apply or make sense for sub-catchment community use (FAO, 2011). By providing a unified voice for individual villages, VRMCs can convey the village's needs to higher-level policy makers, and help contextualize and tailor natural resource management strategies to local contexts. Though VRMCs as presented here are a somewhat idealized solution, any successful framework for water management in the region must engage with local participants.

7.1.3 CLIMATE-SMART RESTORATION OF NATURAL ECOSYSTEMS

Although standard ecosystem restoration is insufficient in addressing major long-term climate changes such as shifts in seasonality, water regimes and species succession, it is nevertheless important in building resilience to the impacts of climate change by reducing anthropogenic influence on climate vulnerability. Throughout AHM, ecosystem restoration has been shown to have positive and direct impacts on climate-induced problems such as flood risk, water quality, and depleted groundwater resources, with the co-benefits of reducing atmospheric carbon dioxide, providing alternative livelihoods, and safeguarding ecosystem biodiversity. As Section 4 illustrates, reforestation and restoration of degraded landscapes, such as overgrazed or over-farmed pastures, can drastically increase rainwater infiltration and slope stability, and decrease the impacts of erosion on infrastructure.

Reforestation activities have been supported under Reducing Emissions from Deforestation and Forest Degradation (REDD) – part of the 2009 Copenhagen Accord of the UNFCCC – and REDD+ activities, typically funded by outside donors. REDD activities in the region should be targeted to have the highest impact on climate-vulnerable and high-impact landscapes, such as refugia forests, denuded hillslopes, and areas vulnerable to plant succession. The 2010 USAID report *Changing Glaciers and Hydrology in Asia* presents several programmatic interventions to address ecosystem restoration under these mechanisms (Malone, 2010). Because logging is not a major issue in sparsely forested high-elevation areas, smaller-scale interventions should be supported. These could include tree and vegetation planting on denuded hillslopes, afforestation of degraded or semi-degraded land that is not economically feasible to farm or use for pasture, or improved management of conserved landscapes, especially those that provide essential resources such as pastures, fiber, medicinal plants and proteins (e.g., wild nuts) to local communities.

7.1.4 DRAWING ON LOCAL AND TRADITIONAL KNOWLEDGE

Irrigation systems have been in use in much of AHM for thousands of years, some of which have remained intact and in use, having been repaired with knowledge handed down from generation to generation. In some cases, these traditional methods are nearly as efficient as modern solutions, but require less technical expertise to implement. Important gains in resource management could be made by collecting and sharing regional solutions, and using modern technology to improve their implementation. For example, a pilot program in Pakistan helped villages design irrigation systems using traditional methods, supported in part by modern survey equipment. Project managers found that village methods were sound and sustainable, but the increased efficiencies brought on by accurate maps of slope and elevation, as well as creating trenches with fewer dips and bumps, created a useful synergy of traditional and modern techniques (Groenfeldt, 1991).

Another example of a traditional technique comes from Nepal, where several villages have invested in both plastic-lined and cement water holding tanks as a means to combat seasonal water scarcity and increased water variability (WWF, 2011; WWF Nepal, 2012). These projects used modern techniques and materials to improve on traditional holding pools, which have long been in use in the Himalaya. Some farmers have even identified a use for cattle urine, which is collected and mixed with several plants, as well as rotten fruits and vegetables, to create a bio-pesticide which doubles as fertilizer. This mixture combines traditional knowledge on bio-pesticides with more modern knowledge on building cattle sheds designed to collect cow urine, as well as modern improvements on traditional pesticide recipes (WWF, 2011).

In many flood-prone regions of AHM, communities have adapted to the threat of flooding by building on higher elevations and understanding the weather signs that indicate a flood is likely. The influx of new populations, as well as increased reliance on and trust in engineered flood management solutions, has made many remote communities more susceptible to flooding. Activities could be planned throughout much of AHM that integrate traditional flood management techniques with modern hazard assessments to give communities sustainable flood management plans.

Pastoral populations in some areas of AHM have adapted to changing climate through modified migration patterns and livelihood diversification (Joshi et al., 2013; Fernández-Gimenez et al., 2012). These adaptations could be supported by integrating pastoral grazing strategies, as well as traditional resource management techniques, into policy development and intervention planning. One potential strategy is herd diversification to lower the impact of excessive grazing of single favored species (FAO, 2011). As the links between climate change, overgrazing and livestock health are not fully understood in AHM, reducing pressure on the natural ecosystem in the face of changing climate is essential. This could also be accomplished in many cases through grazing rotation, which was common among nomadic and semi-nomadic herders until the past few decades. Grazing rotation could also entail controlling the timing of grazing, where grazing of summer pastures is delayed until grass has sprouted and more biomass has been generated (FAO, 2011).

In some cases, the only fuel available to herders is dried dung from their herds, which is collected from the fields. This represents a removal of essential nutrients from rangelands, and could be curtailed through the promotion of solar heating or cooking stoves. Under slightly colder and wetter conditions in many parts of AHM, drying of dung will be increasingly difficult, and dung will become a decreasingly useful fuel source. Replacing dung as fuel represents a move away from traditional techniques, recognizing that certain practices are no longer sustainable under climate change. Replacing dung-fired stoves with solar stoves could also have co-benefits on human health and in mitigation of black carbon emissions.

7.1.5 SYNCHRONIZING NATIONAL, REGIONAL AND LOCAL CLIMATE CHANGE POLICY

Each of the field-site states in AHM (Bhutan, Nepal, India, Pakistan, Kyrgyzstan and Mongolia) is a signatory to the UNFCCC, and each has implemented several national-level policy initiatives. While the scope and efficacy of their respective policy initiatives differ, a common problem throughout AHM is that local- and regional-level policies do not always mesh with national climate change plans, or that region-specific climate change plans have yet to be drafted (National Research Council, 2012; ADB, 2011; Lefèvre, 2012). Often, the language governing national development, or even development of large urban centers such as capital cities, explicitly mentions climate change, and has provisions for the management of its effects (e.g., Anwar, 2012). However, rapidly growing regional hubs rarely have such language in their development plans (National Research Council, 2012).

There is also a significant gap between adaptation being planned at local village levels, and their relationship to national or regional climate management policy. Technical capacity in dealing with water variability may exist in the context of small, village-level projects, where local communities have implemented and maintained water management solutions independently or with the help of outside technical expertise. This knowledge does not readily translate to, or is not widely disseminated in, regional- or national-level planning (National Research Council, 2012). Conversely, technical capacity in regional or national hubs may not filter down to local implementation of climate adaptation projects. Supporting top-to-bottom knowledge sharing and integrating climate policy at differing levels of government will help illustrate possible collaborations, and help disseminate lessons learned in disparate regions. The mechanisms for such knowledge sharing are poorly defined in AHM, but could be supported through work exchanges or climate-related workshops in the region.

7.2 Regional Recommendations

Many of the issues facing AHM cannot be tackled at the individual country or range level. Global climate systems and changes therein affect broad regions regardless of political divisions. Furthermore, the problems associated with climate change, and the solutions to those problems, are often bigger than is reasonable for a single country to approach, in terms of both financial and technical investments. Many of the country-level communications to the UNFCCC mention lack of technical capacity as one of the most pressing issues in dealing with climate change. This section presents a suite of possible avenues for regional cooperation on disaster risk management, natural resource management, technical capacity building and data sharing.

7.2.1 DISASTER RISK MANAGEMENT

Several countries in AHM have implemented national disaster risk management networks, which often serve as knowledge banks, monitoring centers and preparedness planning hubs. The effectiveness of network efforts is limited by the trans-boundary nature of many disasters, funding deficiencies, lack of proactive management and complex geography; regional networks could help address these important limitations.

The SAARC Disaster Management Centre[19] provides an example of a disaster working group that provides technical expertise and policy guidance, and facilitates data sharing and monitoring efforts. A similar organization or working group focused on issues specific to AHM would support sharing of knowledge and technical expertise, and of wider and more robust monitoring data. Such an organization or working group could be supported through an organization like ICIMOD, which has worked extensively gathering data and producing analyses on mountain ecosystems in the region, or SERVIR-Himalaya, which is a USAID-funded organization based at ICIMOD.

Several reports have also suggested that a regional GLOF risk-monitoring network be established (e.g., Viviroli et al., 2011; Mool et al., 2011; Ives et al., 2010). As many potential GLOFs are trans-boundary, regional data sharing and the pooling of technical expertise are essential. A regional group focused on GLOFs would facilitate sharing of data and methods, and could provide technical support throughout the region.

7.2.2 REGIONAL RESOURCE MANAGEMENT

As with natural disasters, resource management problems often occur across national boundaries. A perfect example of a multi-national resource management agreement is the Indus Water Treaty, where the upper reaches of the Indus in India control the flow of water into Pakistan. However, most trans-boundary natural resources in AHM are not governed by such formalized agreements.

Water resources are coming under increased stress throughout the region, both from climate change and demographic shifts. As rivers continue to be further modified for human use, particularly through irrigation diversions and hydropower plants, attention must be paid to both the upstream and downstream uses of water, to ensure equitable resource distribution across a wide range of water users. Although these problems of resource distribution are not often likely to require regional-level collaboration, improved bi-lateral communication and natural resource management could aid in more equitable and efficient allocation of water for optimal outcomes for all users.

Another trans-boundary resource that is problematic in AHM is air quality. As demonstrated in Section 2, the effects of anthropogenic air pollution on climate systems are not fully understood. However, there is a growing body of research linking atmospheric aerosol content to shifting weather patterns and storm seasonality. These problems are caused by, and affect, multiple countries in the region, and thus collaboration on policy changes and direct interventions should be a regional-scale effort. These efforts should include multi-national non-governmental organizations, such as the Global Alliance for Clean Cookstoves,[20] who are already working in the region.

There is also room for regional collaboration in strategic data investments, monitoring networks, and environmental evaluations which are often trans-national. For example, an assessment of ecosystem

19 Website available at http://saarc-sdmc.nic.in/index.asp

20 http://www.cleancookstoves.org/

© WWF NEPAL, HARIYO BAN PROGRAM/ JYOTI SHRESTHA.

A resident of Kristinachnechaur in central Nepal drinks from a new communal tap, installed to combat increasing drought and water scarcity by WWF and local community forestry organization FECOFUN, with funding from USAID. Such relatively simple water supply interventions can significantly reduce climate vulnerability in isolated high mountain communities.

health in the Kanchanjunga region of India should also incorporate data from the Kanchanjunga region of Nepal. These resource assessments, which form the basis for environmental policy in the region, will be more robust if resource use on both sides of political divides is considered. Furthermore, as Section 5 demonstrated, there are many knowledge gaps that affect multiple countries in the region. An improved understanding of the hydrologic cycle in Nepal will also benefit downstream areas in India which rely on waters sourced in the Himalaya.

7.2.3 TECHNICAL CAPACITY BUILDING

Meeting the needs for local expertise in remote sensing, GIS, disaster preparedness and management, and water management should be supported through home-grown networks, such as ICIMOD. Outside technical expertise must address needs while also building capacity in local scientists to lead climate change science in the region. Degree programs in technical fields related to climate change science could be supported in regional higher education institutions, or training workshops facilitated through trans-boundary knowledge banks. The USAID-funded project “Contribution to High Asia Runoff from Ice and Snow” (CHARIS) is an example of a project in the region aiming to build technical capacity in climate adaptation and management among local universities. Increased local technical capacity in addressing climate-related issues will provide more adaptation options and increase regional resilience to climate change. Previous work by WWF has also generated benefits through co-sponsored scientific missions. For example, in Nepal, the High Altitude Wetlands Project helped fund a scientific research study through Kathmandu University, with the dual goals of understanding the freshwater ecosystem at Gokyo and improving in-country technical capacity (WWF Nepal, 2011).

Increased technical capacity for structural interventions must be coupled with increased training on when and where these interventions are appropriate. In many cases, currently planned infrastructure will make adapting to modified climate harder (Le Quesne et al., 2010). Truly climate-adaptive infrastructure should be conservative and functional under multiple flow scenarios. Building technical capacity in the design and implementation of flexible and adaptable solutions, and training professionals who are comfortable designing adaptations for multiple climate futures, are imperative, particularly in AHM where the future effects of climate change are still poorly understood.

7.2.4 DATA SHARING AND DATA COLLECTION STANDARDIZATION

One of the major gaps identified in this report is the lack of adequate climate and environmental data in much of AHM (Section 6). To provide maximum benefits to both AHM and the broader scientific community, increased data collection should be supported under a regional framework. Data collected under a common framework could be designed with a collective purpose to maximize regional coverage, coverage of diverse ecosystems, and applicability to modeling efforts. A regional framework could also enforce data quality standards, and standardize results and procedures across a wide area. With standardized data across AHM, data collected in diverse areas could be applied in modeling and projection efforts of any individual country in AHM. As data are required across AHM, this data sharing and standardization would necessarily be a regional effort, and could be dovetailed onto other technical support or knowledge sharing frameworks.

7.3 Range-Specific Recommendations

There are certain interventions likely to be most effective in specific ranges. Often, these are simply more robust versions of interventions targeted at a village level, or scaled down versions of regional policy interventions.

7.3.1 THE HIMALAYA RANGE

The Himalaya Range is the least susceptible to changes in water availability due to glacier melt, as precipitation is driven primarily by the ISM. However, the effects of changing monsoon patterns will be most strongly felt in this region. With changing monsoon patterns, and increased incidence of extreme weather, floods, landslides, and water stress are the most critical risks in the Himalaya.

As was discussed in Section 4, early warning systems have been implemented in several basins in the Himalaya region. The most effective of those entailed community-wide education efforts and community buy-in in the construction and maintenance of the systems. Those systems sited away from population centers in remote or difficult terrain should be self-sufficient, though semi-regular use or maintenance by local communities could enhance ownership and sustainability. Early warning systems should be combined with some structural interventions such as spillways to mitigate GLOF risk, afforestation and restoration of marginal lands, and introduction of plants onto steep and erosion-prone slopes.

As with the threat of too much water, the threat of too little water should be managed with a combination of education and structural interventions. Land management plans should incorporate groundwater recharge areas, as well as natural spring protections via water-conserving plants and trees. Crop diversification, particularly into species such as apples which are likely to flourish at higher altitudes under continuing climate change, presents another method through which the communities of the Himalaya can increase their adaptive capacity to climate change. Diversification has the added benefit of increasing resilience to variable water flow and changing growing seasons, as crop diversification mitigates the risk of single-crop failure.

In the Manang district of Nepal, climate predictions are still rough, and predicted impacts of climate change are not well defined. Thus, several flexible solutions were proposed by Aase et al. (2009) to maintain adaptability to several climate scenarios. One specific suggestion for Manang district is to replace wheat with barley, which is a more resistant and flexible crop, requires less water, and thrives in cold and mountainous regions (Aase, 2009). A second suggestion for Manang is to reconsider the farming of lower elevation valleys that were previously susceptible to frosts, and thus traditionally unfarmed. Under warming scenarios, these valley bottoms may become suitable for a wider range of crops and provide important livelihood diversification options.

In the Indrawati catchment (a sub-basin of the Koshi River), WWF Nepal has helped implement Integrated Resource Management Committees to drive community engagement in project activities (WWF Nepal, 2012). These committees have helped draw community labor and funding for projects such as cement water storage tanks in the villages of Tamang and Ramchebesi. These projects will help safeguard the communities during periods of low flow, both natural and those exacerbated by climate change. Further projects in Nepal have used simple plastic-lined pits to accomplish the same goal, albeit in a slightly less permanent, but also less expensive, manner.

A perfect example of community engagement and the training of citizen scientists comes from Nepal, where several schools have started "Eco Clubs" tasked with maintaining and utilizing small weather stations, to both gather data and disseminate knowledge on climate change (WWF, 2011). These clubs have not only engaged students in the study of climate change, but also drawn the wider community's attention to issues surrounding climate change.

7.3.2 THE KARAKORUM RANGE

The Karakorum Range occupies a unique place in AHM, as some glaciers are advancing, bringing with them a higher risk of jökulhlaups. Between 1826 and 1982, there have been at least 35 disastrous jökulhlaups in the region, more than anywhere else in the world with the exception of Alaskan-Yukon glaciers (Hewitt, 1982). GLOFs are also a risk, particularly under low-elevation glaciers. Early warning systems, coupled with structural measures to reduce the risk of GLOFs, as well as increased monitoring and predictive capacity in the region, are likely to somewhat mitigate these threats. These initiatives could be pursued at the village level, or at the regional level through increased international cooperation on weather monitoring, storm tracking and GLOF risk assessments.

Water scarcity is likely to be more of an issue for the Karakorum than for the other ranges in the HKH, as it does not receive significant moisture from the ISM, and summer glacier melt accounts for a much larger portion of discharge. As mass balance for some Karakorum glaciers has been shown to be positive (glaciers are growing), there has been a slight decrease in discharge from rivers in the region as more water is stored seasonally in glaciers (Gardelle et al., 2012). As the downstream areas of the Karakorum are highly dependent on melt water for irrigation, even small changes can pose serious problems. The implementation of water management strategies, such as land use planning systems, crop diversification and more efficient irrigation, will help offset some of the risk of reduced water availability.

One example of efficient irrigation in Pakistan involved the development of irrigation systems following traditional designs (using local materials and packed-earth canals), but that were drafted using modern tools such as survey equipment and topographic maps, creating effective, sustainable and community-driven irrigation mechanisms (Groenfeldt, 1991). This intervention was not motivated by climate change, but rather sustainable development. If such sustainable development projects are modified to suit current and future climate conditions, for example by considering flood hazard maps in the placement of new irrigation systems or accounting for possible severe or frequent droughts in designing water storage tanks, they can provide a valuable interface between modern technology and traditional techniques.

7.3.3 THE HINDU KUSH RANGE

The Hindu Kush Range has more small-area glaciers than the other ranges in AHM. As such, its glaciers are more likely to melt and disappear than those in its neighbors the Karakorum and Pamir Ranges. The Hindu Kush should receive strategic interventions in GLOF risk management, both through early warning and monitoring systems, and through structural measures where appropriate to individual glacial lakes. Furthermore, though many studies examine the Hindu Kush region as part of the HKH ranges, there is very little ground data in the Hindu Kush, some of which is due to political instability in the region. Additional monitoring data would help improve predictive models both for flooding and for increasingly scarce water in the region.

Increasing water availability from shrinking glaciers is likely to be offset and overcome by increasing human use in the region, which has a rapidly growing population and a large agricultural sector. Thus, as with the Karakorum and Himalaya Ranges, water management strategies such as land use planning changes, irrigation updates and water policy changes are likely to increase the region's adaptive capacity to low-flow periods. Increasing human use, however, is mostly located in downstream areas. Upstream areas may see improved hydropower potential, which could help provide clean electricity to growing economies in the region, though any investment in hydropower must take climate change context into account, protect against the negative impact for the ecology of the river system and on potential for sedimentation, and also provide for possibilities of low flow in the future. Recently, India's Supreme Court put a moratorium on the construction of new hydroelectric plants in Uttarakhand in response to a potential link between proliferation of hydroelectric dams and catastrophic flooding and landslides in June 2013 which left more than 5,000 people dead or missing (Kumar, 2013). Such flooding highlights the potential risks of constructing hydroelectric plants under uncertain climate scenarios.

7.3.4 THE PAMIR RANGE

Glaciers in the Pamir Range are characterized as "low-precipitation," and tend to grow slowly over many seasons of limited precipitation, though recent studies have noted a propensity for glacial surging (e.g., Gardelle et al., 2013; Kotlyakov et al., 2008). Melting of these glaciers has increased the possibility of GLOFs while also increasing hydropower resources in the region. The Pamir Range also sits in one of the most tectonically active regions of AHM, and thus sees more earthquake-driven landslides than the other ranges. This seismic activity leads to increased risk of LLOFs, such as the potential danger of Lake Sarez, which stores more than 17 billion m^3 of water, as well as to significant risks associated with hydropower investments. Addressing these dangers requires education of at-risk communities, as well as some structural interventions such as spillways, depending on the character of individual glacial lakes and hydroelectric dams.

Even with slightly increased flows due to melting glaciers, studies have shown that the region is at risk of increasing aridity due to shifting climate patterns. There has been success in the region in introducing drought-resistant crop species, including some tree species such as walnuts that are more resistant to changing climate patterns than other crops (Pradhan et al., 2012). As with the other ranges in AHM, water management techniques, particularly those indigenous to the region, should be supported.

Another suggested intervention for the Pamir Range is the introduction of community-owned greenhouses (WWF Pakistan, 2011). These greenhouses could form a buffer against climate-induced natural hazards by providing the community with both vegetables which are hard to grow in the wild in much of Pakistan, and a community fund raised from selling some of the vegetables. This would function as an insurance system for repairs to villages in the aftermath of flooding, crop failure due to drought or storm, or other natural disasters such as earthquakes.

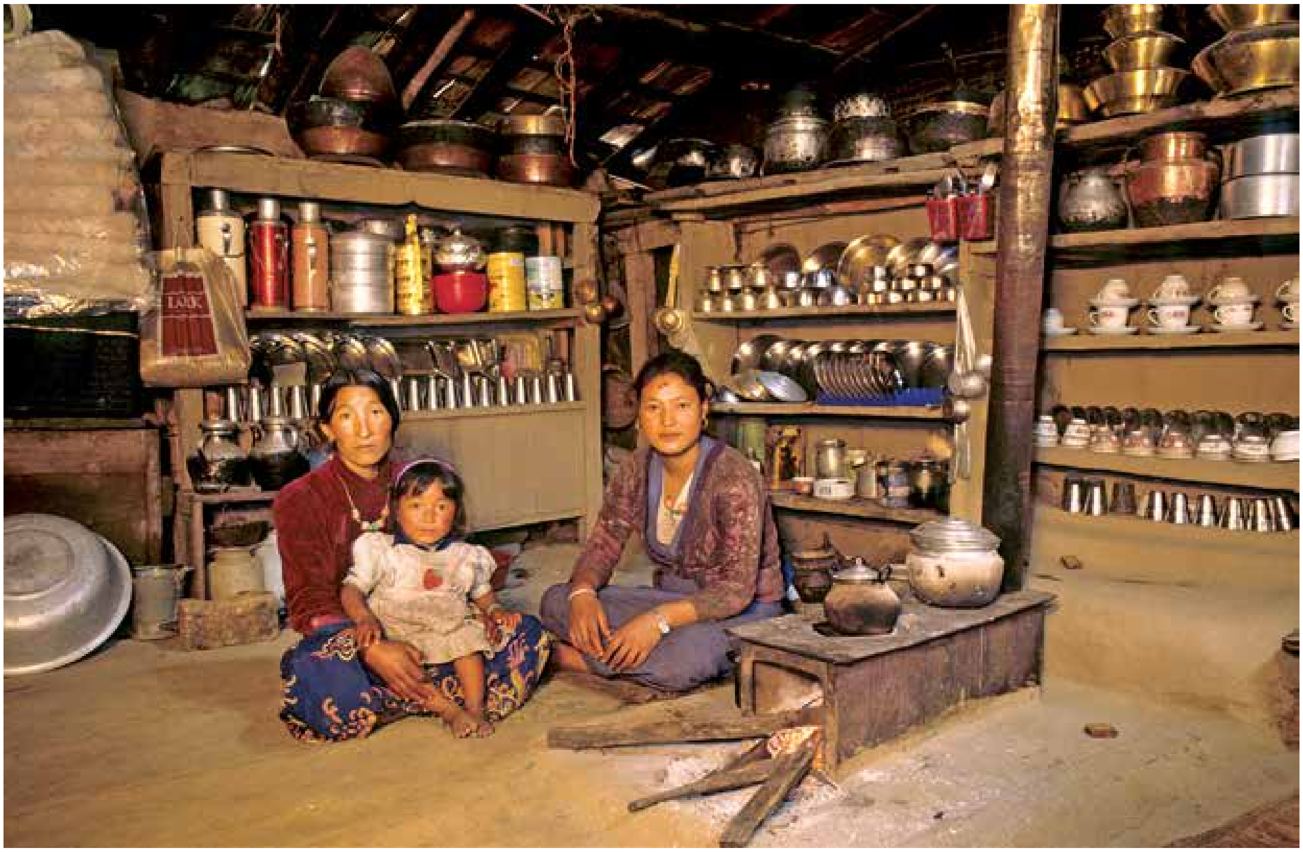
7.3.5 THE TIEN SHAN RANGE

Although GLOFs are less common in the Tien Shan Range than in other ranges of AHM, they are still a risk. Current monitoring and response capacity is low, and could be increased through regional technical assistance, installation of additional monitoring stations, and early warning systems. However, the relatively low risk in the region means that non-structural measures, such as hazard mapping and community preparedness, are more appropriate and cost-effective interventions in most cases than structural measures such as spillways and diversions.

As summer temperatures continue to climb, the Tien Shan will lose more of its seasonal water storage capacity. Quicker snowmelt early in the melting season will likely be followed by more frequent droughts during the hot summer months. The region is also characterized by massive and inefficient Soviet-era irrigation systems. Updating and improving these systems, which currently lose a significant amount of water in transit due to evaporation and leaks, and modifying water allocations based on climate projections, are likely to improve the regional water situation. Though structural updates and improvements would require significant capital investments, modifying allocations can be done relatively cheaply through policy changes regarding dam operations and environmental flows. Alternative approaches are similar to those suggested for other ranges of AHM: intercropping of new species, switching agricultural lands from water-intensive crops such as cotton to cereals such as wheat and maize, improved water management policies, and introduction of drought resistant species.

7.3.6 THE KUNLUN RANGE

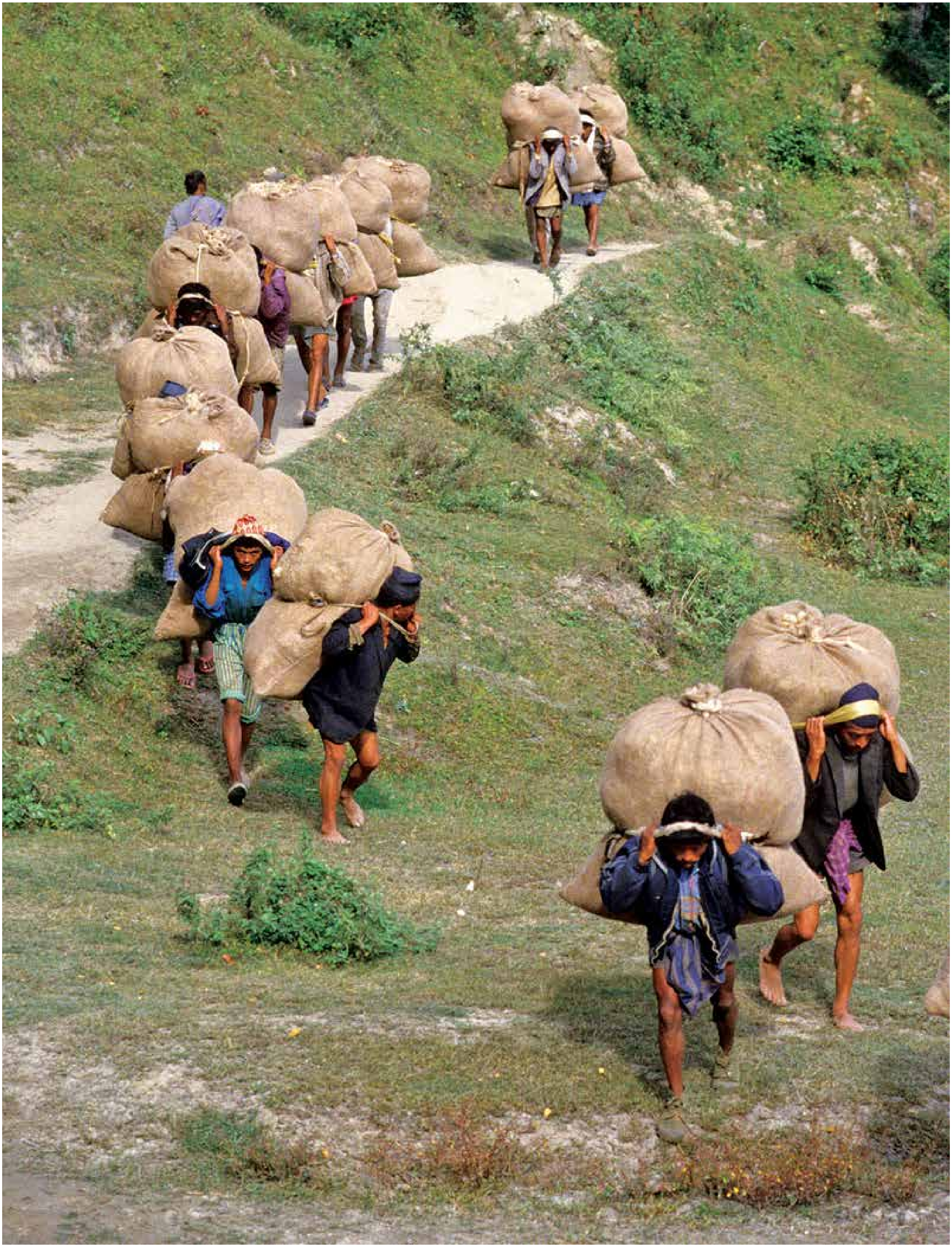
While the Kunlun Range has suffered the fewest ill effects of climate change of all of the ranges in AHM, it will continue to experience problems related to rising temperatures. As with the nearby Tien Shan Range, rising temperatures are likely to increase the incidence of summer and autumn heat waves and seasonal water shortages related to earlier snowmelt. These effects can be mitigated through the introduction of water-saving measures, as well as modified cropping patterns to increase drought resistance.



Some of the high rangeland that adjoins the Kunlun Range along the Tibetan Plateau has experienced severe degradation over the past few decades (WWF China, 2010). However, it is unclear to what extent this degradation is driven by climate changes as opposed to anthropogenic factors such as overgrazing. More information is needed on the effects of climate change on rangeland degradation, and particularly on the effects of changing permafrost depth and structure, as permafrost changes have the potential to seriously decrease rangeland productivity. As the dual influences of overgrazing and climate change are linked, effective management of pastureland through herd diversification and modified grazing patterns could help both in restoring natural environments and in increasing community resiliency to shifts in climate.

7.3.7 THE ALTAI RANGE

The Altai Range is characterized as "low-precipitation," with the primary glacial growth season in the summer, which implies low seasonal water storage in the form of snowfall and glaciers in the region. Reports have noted that the primary changes in climate patterns in the region are related to increasingly extreme droughts, heat waves and cold waves, and that extreme storms have not been as evident in the Altai as in other ranges of AHM. In many pastoral regions of the Altai, improved land-management systems can be used to increase community adaptability by more efficiently allocating ecosystem resources to stakeholders. As many communities in the region have transitioned towards a more sedentary lifestyle, near-settlement natural resources have become overexploited (Kokorin, 2011). These changes have led to invasive species and increased competition between livestock and wild animals. Effective techniques to combat this include introduction of hay fields to supplement grazing in low-productivity months, introduction of land-management techniques focused on sustaining ecosystem services across multiple climate scenarios, and increasing groundwater recharge and reducing runoff through bioengineering and afforestation (FAO, 2011).



RICE PORTERS; DUMRE, MARSYANGDI. ANNAPURNA REGION, NEPAL; © GALEN ROWELL/MOUNTAIN LIGHT / WWF-US

REFERENCES

A

Aase, Tor, R P Chaudhary, and O R Vetaas. "Farming flexibility and food security under climatic uncertainty: Manang, Nepal Himalaya." *Area* (2009).

Adger, Neil, N W Arnell, and E. Tompkins. "Successful adaptation to climate change across scales." *Global environmental change* 15.2 (2005): 77-86.

Aggarwal, Pramod K, S N Kumar, and H Pathak. "Impacts of Climate Change on Growth and Yield of Rice and Wheat in the Upper Ganga Basin." WWF-India, 2010.

Agrawala, Shardul, Vivian Raksakulthai, Maarten van Aalst, Peter Larsen, Joel Smith, and John Reynolds. "Development and Climate Change in Nepal: Focus on Water Resources and Hydropower." *Organization for Economic Cooperation and Development, Paris* (2003): 64.

Ahmad, Ali Jan, Ayaz Asif, Ashfaq Ahmed Khokar, Imtiaz Ahmed, and Tasleem Akhtar. "The Phenomenon of Formation and Breaking of Alpine Lakes: A Report on Khalti Lake in District Ghizer, Northern Areas of Pakistan." Unpublished.

Aizen, Vladimir. B., E. M. Aizen, and S. A. Nikitin. "Glacier regime on the northern slope of the Himalaya (Xixibangma glaciers)." *Quaternary International* 97 (2002): 27-39.

Aizen, Vladimir B., V A Kuzmichenok, A B Surazakov, E M Aizen. "Glacier changes in the central and northern Tien Shan during the last 140 years based on surface and remote-sensing data." *Annals of Glaciology* 43.1 (2006): 202-213.

Aizen, Vladimir B., V A Kuzmichenok, A B Surazakov, E M Aizen. "Glacier changes in the Tien Shan as determined from topographic and remotely sensed data." *Global and Planetary Change* 56.3 (2007a): 328-340.

Aizen, Vladimir B., E M Aizen, and V Kuzmichonok. "Glaciers and Hydrological Changes in the Tien Shan: Simulation and Prediction." Environmental Research Letters 2.4 (2007b): 045019.

Akthar, Shamshad. "The south Asiatic monsoon and flood hazards in the Indus river basin, Pakistan." J. Basic Appl. Sci 7 (2011): 101-115.

Alford, D., and R. Armstrong. "The role of glaciers in stream flow from the Nepal Himalaya." The Cryosphere Discuss 4 (2010): 469-494.

Andermann, Christoff, A Crave, R Gloaguen, P Davy, S Bonnet. "Connecting source and transport: Suspended sediments in the Nepal Himalayas." Earth and Planetary Science Letters 351 (2012a): 158-170.

Andermann, Christoff, S Bonnet, A Crave, P Davy, L Longuevergne, R Gloaguen. "Sediment transfer and the hydrological cycle of Himalayan rivers in Nepal." Comptes Rendus Geoscience (2012b).

Andermann, Christoff, L Longuevergne, S Bonnet, A Crave, P Davy, and R Gloaguen. "Impact of transient groundwater storage on the discharge of Himalayan rivers." Nature Geoscience 5.2 (2012c): 127-132.

Anwar, Farhan. "Karachi City Climate Change Adaptation Strategy - A Roadmap." 2012. http://preventionweb.net/go/27915

Araral, Eduardo, and David J. Yu. "Comparative water law, policies and administration in Asia: Evidence from 17 countries." Water Resources Research (2013).

Archer, D. R., N. Forsythe, H. J. Fowler, and S. M. Shah. "Sustainability of Water Resources Management in the Indus Basin Under Changing Climatic and Socio Economic Conditions." Hydrology and Earth System Sciences Discussions 7 (2010).

Armstrong, Richard. "The glaciers of the Hindu Kush-Himalayan region: a summary of the science regarding glacier melt/retreat in the Himalayan, Hindu Kush, Karakoram, Pamir, and Tien Shan mountain ranges." International Centre for Integrated Mountain Development (ICIMOD), 2010.

Armstrong, Richard, B. Raup, S.J.S. Khalsa, R. Barry, J. Kargel, C. Helm, and H. Kieffer. 2005, updated 2013. GLIMS glacier database. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Aryal, Kamal P, Pashupati Chaudhary, and Kamal P Aryal. "Imperatives Global Warming in Nepal : Challenges and Policy Imperatives." (2009)

Asian Development Bank (ADB). "Technical Assistance Report – Nepal: Mainstreaming Climate Change Risk Management in Development." (2011). http://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/Approval_by_mail_Nepal_Mainstreaming_Climate_Change_Risk_Management_in_Development_technical_assistance_report_0.pdf

B

Bajracharya, Samjwal R., and Basanta Shrestha. "The status of glaciers in the Hindu Kush-Himalayan region." International Centre for Integrated Mountain Development (ICIMOD), 2011.

Bajracharya, Samjwal R., Pradeep K. Mool, and Basanta Raj Shrestha. "Impact of climate change on Himalayan glaciers and glacial lakes: case studies on GLOF and associated hazards in Nepal and Bhutan." International Centre for Integrated Mountain Development (ICIMOD), 2007.

Balk, D., and G. Yetman. "The Global Distribution of Population: Gridded Population of the World Version 3 (GPWv3)." *Center for International Earth Science Information Network (CIESIN), New York* (2005).

Baqir, Maryam, Zain a Sobani, Amyn Bhamani, Nida Shahab Bham, Sidra Abid, Javeria Farook, and M Asim Beg. "Infectious Diseases in the Aftermath of Monsoon Flooding in Pakistan." *Asian Pacific Journal of Tropical Biomedicine* 2. (2012).

Barlow, Mathew, M Wheeler, B Lyon, and H Cullen. "Modulation of daily precipitation over southwest Asia by the Madden-Julian oscillation." *Monthly weather review* 133.12 (2005): 3579-3594.

Barnard, Patrick L., L Owen, M Sharma, and R Finkel. "Natural and human-induced landsliding in the Garhwal Himalaya of northern India." *Geomorphology* 40.1 (2001): 21-35.

Barnett, Jon and Saffron J. O'Neill. "Minimizing the Risk of Maladaptation: A Framework for Analysis". Palutikof, Jean, ed. *Climate Adaptation Futures*. 2013.

Barry, Roger G. "The Status of Research on Glaciers and Global Glacier Recession: a Review." *Progress in Physical Geography* 30.3 (2006): 285–306.

Bartlett, Ryan, L Bharati, D Pant, H Hosterman, and P McCornik. *Climate Change Impacts and Adaptation in Nepal*. Colombo, Sri Lanka: International Water Management Institute (IWMI), 2010.

Bartlett, Ryan, S Freeman, J Cook, B S Dongol, R Sherchan, M Shrestha, and P G McCornick. "Freshwater Ecosystem Vulnerability Assessment: The Indrawati Sub-Basin, Nepal." Nicholas Institute for Environmental Policy Solutions: 2011.

Batima, P., L Natsagdorj, P Gombluudev, B Erdenetsetseg. "Observed climate change in Mongolia." *New York: AIACC Working Paper* 12 (2005).

Batnasan N. "Overview of Climate Change Issues in Mongolia." WWF-Mongolia: 2006.

Berthier, Etienne, A Yves, K Rajesh, A Sarfaraz, W Patrick, and C Pierre. "Remote sensing estimates of glacier mass balances in the Himachal Pradesh (Western Himalaya, India)." *Remote Sensing of Environment* 108.3 (2007): 327-338.

Bhambri, Rakesh, and Tobias Bolch. "Glacier mapping: a review with special reference to the Indian Himalayas." *Progress in Physical Geography* 33.5 (2009): 672-704.

Bhutan Climate Summit Secretariat. "Adoption of Ministerial Declaration." Thimphu, Bhutan. (2011). http://wwf.panda.org/what_we_do/where_we_work/eastern_himalaya/solutions2/climate_summit_for_living_himalayas/

Bhutiyani, M. R., V. S. Kale, and N. J. Pawar. "Climate change and the precipitation variations in the northwestern Himalaya: 1866–2006." *International Journal of Climatology* 30.4 (2010): 535-548.

Bishkek Recommendations on the Conservation of Snow Leopards and Their High-Mountain Ecosystems. Conference Proceedings, Dec 3, 2012. (2012). http://bigcats.ru/newsfiles/others/20121218/SL_Bishkek_Recommendations_Adopted_eng.pdf

Bocchiola, Daniele, and Guglielmina Diolaiuti. "Recent (1980–2009) Evidence of Climate Change in the Upper Karakoram, Pakistan." *Theoretical and Applied Climatology*. (2012).

Bohner, Jurgen. "General climatic controls and topoclimatic variations in Central and High Asia." *Boreas* 35.2 (2006): 279-295.

Bolch, Tobias, T Yao, S Kang, M F Buchroithner, D Scherer, F Maussion, E Huintjes, and C Schneider. "A glacier inventory for the western Nyainqentanglha Range and the Nam Co Basin, Tibet, and glacier changes 1976–2009." *The Cryosphere* 4.3 (2010): 419-433.

Bolch, Tobias, J Peters, A Yegorov, B Pradhan, M Buchroithner, and V Blagoveshchensky. "Identification of Potentially Dangerous Glacial Lakes in the Northern Tien Shan." *Natural Hazards* 59.3 (2011): 1691–1714.

Bolch, Tobias., A Kulkarni, A Kaab, C Huggel, F Paul, J G Cogley, H Frey, J S Kargel, K Fujita, M Scheel, S Bajracharya, and M Stoffel. "The state and fate of Himalayan glaciers." *Science* 336.6079 (2012): 310-314.

Bookhagen, Bodo. "Appearance of extreme monsoonal rainfall events and their impact on erosion in the Himalaya." *Geomatics, Natural Hazards and Risk* 1.1 (2010): 37-50.

Bookhagen, Bodo. "Himalayan groundwater." (2012). *Nature Geoscience*.

Bookhagen, Bodo, Rasmus C. Thiede, and Manfred R. Strecker. "Abnormal monsoon years and their control on erosion and sediment flux in the high, arid northwest Himalaya." Earth and Planetary Science Letters 231.1 (2005a): 131-146.

Bookhagen, Bodo, Rasmus C. Thiede, and Manfred R. Strecker. "Late Quaternary intensified monsoon phases control landscape evolution in the northwest Himalaya." *Geology* 33.2 (2005b): 149-152.

Bookhagen, Bodo and D W. Burbank. "Topography, relief, and TRMM-derived rainfall variations along the Himalaya." *Geophysical Research Letters* 33.8 (2006).

Bookhagen, Bodo and D W Burbank. "Toward a complete Himalayan hydrological budget: spatiotemporal distribution of snowmelt and rainfall and their impact on river discharge." J. Geophys (2010).

Bookhagen, Bodo. "Spatiotemporal hydrologic gradients in High Mountain Asia." Unpublished. http://www.evk2cnr.org/cms/files/evk2cnr.org/4_%20Bodo%20Bookhagen.pdf

Boos, William R., and Zhiming Kuang. "Dominant control of the South Asian monsoon by orographic insulation versus plateau heating." *Nature* 463.7278 (2010): 218-222.

Bouma, M. J., C. Dye, and H. J. Van der Kaay. "Falciparum malaria and climate change in the northwest frontier province of Pakistan." (1996).

Burbank, Douglas W., B Bookhagen, E J Gabet, and J Putkonen. "Modern climate and erosion in the Himalaya." *Comptes Rendus Geoscience* (2012).

C

Chandra, Swati. "BHU Scholars to Study Weather Changes in SAARC Countries." Times of India: 2013. http://articles.timesofindia.indiatimes.com/2013-06-06/varanasi/39787403_1_glacial-lake-outburst-floods-saarc-disaster-management-centre-vulnerable-countries

Charney, Jule. "Dynamics of deserts and drought in the Sahel." *Quarterly Journal of the Royal Meteorological Society* 101.428 (1975): 193-202.

Charney, Jule, W Quirk, S H Chow, and J Kornfield. "A comparative study of the effects of albedo change on drought in semi-arid regions." *Journal of the Atmospheric Sciences* 34.9 (1977): 1366-1385.

Chaudhary, Pashupati, and Kamal P. Aryal. "Global warming in Nepal: challenges and policy imperatives." *For. Livelihood* 8 (2009): 3-13.

Chen, Yaning, K Takeuchi, C Xu, Y Chen, and Z Xu. "Regional Climate Change and Its Effects on River Runoff in the Tarim Basin, China." *Hydrological Processes* 20.10 (2006): 2207–2216.

Cheng, Guodong, and Tonghua Wu. "Responses of Permafrost to Climate Change and Their Environmental Significance, Qinghai-Tibet Plateau." *Journal of Geophysical Research* 112.F2 (2007): F02S03.

Cohen, Judah and Dara Entekhabi. "Eurasian Snow Cover Variability and Northern Hemisphere Climate Predictability." *Geophysical Research Letters* 26.3 (1999): 345-348.

Collins, David N. "Climatic warming, glacier recession and runoff from Alpine basins after the Little Ice Age maximum." *Annals of Glaciology* 48.1 (2008): 119-124.

Conrad, Christopher, M Rahmann, M Machwitz, G Stulina, H Paeth, and S Dech. "Satellite based calculation of spatially distributed crop water requirements for cotton and wheat cultivation in Fergana Valley, Uzbekistan." *Global and Planetary Change* 110 (2013): 88-98.

Cook, Edward R., J G Palmer, M Ahmed, C A Woodhouse, P Fenwick, M U Zafar, M Wahab, and N Khan. "Five Centuries of Upper Indus River Flow from Tree Rings." *Journal of Hydrology* (2013).

Cook, Jonathan, S Freeman, E Levine, and M Hill. "Shifting Course: Climate Adaptation for Water Management Institutions." WWF-US: 2011.

Cretaux, Jean-François, R Letolle, and M Bergé-Nguyen. "History of Aral Sea level variability and current scientific debates." *Global and Planetary Change* 110 (2013): 99-113.

Cuffey, Kurt M., and W. S. B. Paterson. *The Physics of Glaciers*. Academic Press, 2010.

D

D'Agnes, Leona. "Adapting to Water Stress and Changing Hydrology in Glacier-dependent Countries in Asia: A Tool for Program Planners and Designers." Coastal Resources Center, University of Rhode Island: 2013.

Dahal, Ranjan Kumar, and Shuichi Hasegawa. "Representative rainfall thresholds for landslides in the Nepal Himalaya." *Geomorphology* 100.3 (2008): 429-443.

Dahe, Qin, Liu Shiyin, and Li Peiji. "Snow cover distribution, variability, and response to climate change in western China." *Journal of climate* 19.9 (2006): 1820-1833.

Dale, V H., L A Joyce, S McNulty, R P Neilson, M P Ayres, M D Flannigan, P J Hanson, L C Irland, A E Lugo, C J Peterson, D Simberloff, F J Swanson, B J Stocks, and B M Wotton. "Climate Change and Forest Disturbances." *BioScience* 51.9 (2001): 723.

Dang, Thi Ha, A Coynel, D Orange, G Blanc, H Etcheber, and L A Le. "Long-term Monitoring (1960-2008) of the River-sediment Transport in the Red River Watershed (Vietnam): Temporal Variability and Dam-reservoir Impact." *The Science of the total environment* 408.20 (2010): 4654–64.

Ding, Yongjian, S Liu, J Li, and D Shangguan. "The Retreat of Glaciers in Response to Recent Climate Warming in Western China." *Annals of Glaciology* 43.1 (2006): 97–105.

Dixit, A., K A Shukla, R Shrestha, J K.C., and D R Bishwakarma. (ed). "Proceedings of National

Seminar on Small Scale Irrigation: Experiences, Challenges, Opportunities and Pathways." Institute for Social and Environmental Transition-Nepal (ISET-Nepal). Kathmandu: 2013a.

Dixit, A, Y Subedi, T McMahon, and M Moench (eds). "Mainstreaming Climate Sensitive Indicators into an Existing Food Monitoring System: Climate Change and Food Security in Nepal." Institute for Social and Environmental Transition- Nepal, Kathmandu: 2013b.

Djanibekov, Nodir, K Frohberg, and U Djanibekov. "Income-based projections of water footprint of food consumption in Uzbekistan." *Global and Planetary Change* 110 (2013): 130-142.

E

Eichler, Anja, S Olivier, K Henderson, A Laube, J Beer, T Papina, H W Gaggeler, M Schwikowski. "Temperature Response in the Altai Region Lags Solar Forcing." *Geophysical Research Letters* 36.1 (2009): L01808.

F

Farrington, John D. "De-development in eastern Kyrgyzstan and persistence of semi-nomadic livestock herding." *Nomadic Peoples* 9.1-2 (2005): 1-2.

Farrington, John D. (ed). "Impacts of Climate Change on the Yangtze Source Region and Adjacent Areas." WWF China, 2009.

Fernández-Gimenez, María, B Batjav and B Baival. "Lessons from the Dzud: Adaptation and Resilience in Mongolian Pastoral Social-Ecological Systems." World Bank: 2012.

Ficke, Ashley D., Christopher a. Myrick, and Lara J. Hansen. "Potential Impacts of Global Climate Change on Freshwater Fisheries." Vol. 17. 2007.

Focus Humanitarian Assistance Pakistan and Eco-Conservation Initiatives. "Gilgit-Baltistan and Chitral Region: Report on the Impacts of Climate Change and the Capacity of Mountain People to Respond to Disasters." 2010

Food and Agriculture Organization (FAO). "Climate-Smart Agriculture Sourcebook." FAO: 2011.

Fu, Congbin. "Potential impacts of human-induced land cover change on East Asia monsoon." *Global and Planetary Change* 37.3 (2003): 219-229.

Fukui, Hiromichi, Ponthip Limlahapun, and Takaharu Kameoka. "Real time monitoring for Imja Glacial Lake in Himalaya—global warming front monitoring system." *SICE Annual Conference, 2008*. IEEE, 2008.

G

Gardelle, Julie, E Berthier, and Y Arnaud. "Slight mass gain of Karakoram glaciers in the early twenty-first century." *Nature geoscience* 5.5 (2012): 322-325.

Gardelle, Julie, E Berthier, Y Arnaud, and A Kaab. "Region-wide glacier mass balances over the Pamir-Karakoram-Himalaya during 1999-2011." *The Cryosphere Discussions* 7 (2013): 975-1028.

Gardner, Alex S., G Moholdt, J G Cogley, B Wouters, A A Arendt, J Wahr, E Berthier, R Hock, W T Pfeffer, G Kaser, S R M Ligtenberg, T Bolch, M J Sharp, J O Hagen, M R van den Broeke, and F Paul. "A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009." Science 340.6134 (2013): 852-857.

Gautam, R., N C Hsu, K M Lau, and M Kafatos. "Aerosol and rainfall variability over the Indian monsoon region: distributions, trends and coupling." *Annales geophysicae: atmospheres, hydrospheres and space sciences*. Vol. 27. No. 9. 2009.

Githeko, Andrew K., S W Lindsay, U E Confalonieri, and J A Patz. "Climate change and vector-borne diseases: a regional analysis." *Bulletin of the World Health Organization* 78.9 (2000): 1136-1147.

Government of China. "The second national communication on climate change of the People's Republic of China." Beijing, 2012. http://unfccc.int/resource/docs/natc/chnnc2e.pdf

Government of India. "National Mission for Sustaining the Himalayan Ecosystem." New Delhi: 2010. http://www.dst.gov.in/scientific-programme/NMSHE_June_2010.pdf

Government of India. "Second National Communication to the UN Framework Convention on Climate Change." New Delhi, 2012. http://moef.nic.in/downloads/public-information/2ndNational_Communication_2_UNFCCC.pdf

Government of Nepal. "Initial National Communication to the Conference of the Parties of the UN Framework Convention on Climate Change. Kathmandu: 2004. http://unfccc.int/resource/docs/natc/nepnc1.pdf

Government of Nepal. “National Adaptation Programme of Action (NAPA). Kathmandu, September 2010. http://www.napanepal.gov.np/

Government of Pakistan. “National Climate Change Policy.” Islamabad – September 2012. http://oneunjpe.org/NCCP.pdf

Government of Tajikistan. “The First National Communication of the Republic of Tajikistan to the United Nations Framework Convention on Climate Change.” Dushanbe, 2002. http://unfccc.int/resource/docs/natc/tainc1.pdf

Government of Tajikistan. “The Second National Communication of the Republic of Tajikistan to the United Nations Framework Convention on Climate Change.” Dushanbe, 2008. http://unfccc.int/resource/docs/natc/tainc2.pdf

Groenfeldt, David. “Building on tradition: Indigenous irrigation knowledge and sustainable development in Asia.” *Agriculture and Human Values* 8.1-2 (1991): 114-120.

Gupta, Anil K., and Sreeja S. Nair. “Ecosystem approach to disaster risk reduction.” *National Institute of Disaster Management, New Delhi* (2012).

Gupta, Vikram, and M. P. Sah. “Impact of the trans-Himalayan landslide lake outburst flood (LLOF) in the Satluj catchment, Himachal Pradesh, India.” *Natural Hazards* 45.3 (2008): 379-390.

Gurung, Deo Raj, A Giriraj, K S Aung, B Shrestha, and A V Kulkarni. *Snow-cover mapping and monitoring in the Hindu Kush-Himalayas*. International Centre for Integrated Mountain Development (ICIMOD), 2011.

H

Hagg, Wilfried, C Mayer, A Lambrecht, D Kriegel, and E Azizov. “Glacier changes in the Big Naryn basin, Central Tian Shan.” *Global and Planetary Change* 110 (2013a): 40-50.

Hagg, Wilfried, M Hoelzle, S Wagner, E Mayr, and Z Klose. “Glacier and runoff changes in the Rukhk catchment, upper Amu-Darya basin until 2050.” *Global and Planetary Change* 110 (2013b): 62-73.

Hahn, Micah B., Anne M. Riederer, and Stanley O. Foster. “The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique.” *Global Environmental Change* 19.1 (2009): 74-88.

Han, Yongxiang, X Fang, S Kang, H Wang, and F Kang. “Shifts of Dust Source Regions over Central Asia and the Tibetan Plateau: Connections with the Arctic Oscillation and the Westerly Jet.” *Atmospheric Environment* 42.10 (2008): 2358–2368.

Harding, R. J., E M Blyth, O A Tuinenburg, and A Wiltshire. “Land atmosphere feedbacks and their role in the water resources of the Ganges basin.” *Science of the Total Environment* (2013).

Haritashya, Umesh K., M P Bishop, J F Shroder, A B G Bush, and H N N Bulley. “Space-based assessment of glacier fluctuations in the Wakhan Pamir, Afghanistan.” *Climatic change* 94.1-2 (2009): 5-18.

Harris, Richard B. “Rangeland degradation on the Qinghai-Tibetan plateau: a review of the evidence of its magnitude and causes.” *Journal of Arid Environments* 74.1 (2010): 1-12.

He, Mengying, Hongbo Zheng, Bodo Bookhagen, Peter Clift. “Controls on Erosion Intensity in the Yangtze River Basin Tracked by Detrital U-Pb Zircon Dating.” 1–37. In Review.

Hewitt, Kenneth. “Natural dams and outburst floods of the Karakoram Himalaya.” IAHS 138 (1982): 259-269.

Hewitt, Kenneth. “The Karakoram anomaly? Glacier expansion and the elevation effect, Karakoram Himalaya.” *Mountain Research and Development* 25.4 (2005): 332-340.

Hewitt, Kenneth. “Glaciers of the Karakoram Himalaya.” *Encyclopedia of Snow, Ice and Glaciers*. Springer Netherlands, 2011. 429-436.

Hoermann, B, S. Banerjee, J.Y. Gerlitz. “Labour Migration as a Response Strategy to Water Hazards in the Hindu Kush-Himalayas.” ICIMOD: (2011).

Hu, Li, Wang Xiaofeng, and Gao Yaqi. “Analysis and Assessment of Land Desertification in Xinjiang Based on RS and GIS.” 2.1998510009 (2004): 159–166.

I

ICIMOD. *Glacial lakes and glacial lake outburst floods in Nepal*. Kathmandu: ICIMOD: 2011.

ICIMOD. *Policy and institutions in adaptation to climate change: Case study on flood mitigation Infrastructure in India and Nepal*. ICIMOD Working Paper 2013/4. Kathmandu: ICIMOD: 2013.

Iliasov, S and V Yakimov. "Second National Communication of the Kyrgyz Republic to the UN Framework Convention on Climate Change." – Bishkek: 2009. http://unfccc.int/resource/docs/natc/kyrnc2e.pdf

Immerzeel, Walter W., Ludovicus PH van Beek, and Marc FP Bierkens. "Climate change will affect the Asian water towers." *Science* 328.5984 (2010): 1382-1385.

Immerzeel, W. W., F. Pellicciotti, and M. F. P. Bierkens. "Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds." *Nature Geoscience* (2013).

Indian Network for Climate Change Assessment. "Climate Change and India: A 4x4 Assessment." Ministry of Environment and Forests: 2010.

Institute for Social and Environmental Transition. "Enabling Adaptation to Climate Change for Poor Populations in Asia through Research, Capacity Building and Innovation", Report from the Adaptation Study Team to the International Development Research Centre, Coordinated by ISET, Published by ISET-Nepal at Format Graphics, Kathmandu, July 2008, pp. 126

International Snow Leopard Trust, Panthera, Snow Leopard Network, Wildlife Conservation Society. 'Generalized Snow Leopard Range'. Beijing GIS Workshop, 2008.

Intergovernmental Panel on Climate Change (2007): Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Univ. Press, U.K.

Intergovernmental Panel on Climate Change (2013): Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the 5th Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Univ. Press, U.K.

Intergovernmental Panel on Climate Change (2013b): Climate Change 2013: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the 5th Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Univ. Press, U.K.

Intergovernmental Panel on Climate Change (2013c): Climate Change 2013: Mitigation of Climate Change, Contribution of Working Group III to the 5th Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Univ. Press, U.K.

International Resources Group. "Black Carbon Emissions in Asia: Sources, Impacts, and Abatement Opportunities." Washington: USAID, April 2010.

Iqbal, Tahir. "First National Communication of Pakistan to the UN Framework Convention on Climate Change" – Islamabad: 2003. http://unfccc.int/resource/docs/natc/paknc1.pdf

Issar, Rajeev, K Rapten, R Pandit, A Masud, and P Acharya. "GLOF Risk Reduction through Community-based Approaches." UNDP: 2012.

Ives, Jack D., Rajendra Shrestha, and Pradeep Mool. *Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment*. Kathmandu: ICIMOD, 2010.

J

Jacob, Thomas, J Wahr, W T Pfeffer, and S Swenson. "Recent contributions of glaciers and ice caps to sea level rise." *Nature* 482.7386 (2012): 514-518.

Jeelani, G., J J Feddema, C J van der Veen, and L Stearns. "Role of Snow and Glacier Melt in Controlling River Hydrology in Liddar Watershed (western Himalaya) Under Current and Future Climate." *Water Resources Research* 48.12 (2012): W12508.

Joshi, S., W A Jasra, M Ismail, R M Shrestha, S L Yi, and N Wu. "Herders' Perceptions of and Responses to Climate Change in Northern Pakistan." *Environmental management* (2013): 1-10.

K

Kääb, Andreas, E Berthier, C Nuth, J Gardelle, and Y Arnaud. "Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas." *Nature* 488.7412 (2012): 495-498.

Kadota, Tsutomu and Davaa Gombo. "Recent glacier variations in Mongolia." *Annals of Glaciology* 46.1 (2007): 185-188.

Kamp, Ulrich, Martin Byrne, and Tobias Bolch. "Glacier fluctuations between 1975 and 2008 in the Greater Himalaya Range of Zanskar, southern Ladakh." *Journal of Mountain Science* 8.3 (2011): 374-389.

Kang, Jung-Ho, S D Choi, H Park, S Y Baek, S Hong, and Y S Chang. "Atmospheric Deposition of Persistent Organic Pollutants to the East Rongbuk Glacier in the Himalayas." *The Science of the total environment* 408.1 (2009): 57–63.

Kargel, Jeffrey S., G Leonard, R Crippen, K B Delaney, S G Evans, and J Schneider. "Satellite Monitoring of Pakistan's Rockslide-Dammed Lake Gojal." *Eos, Transactions American Geophysical Union* 91.43 (2010): 394-395.

Kargel, Jeffrey S., J G Cogley, G J Leonard, U Haritashya, and A Byers. "Himalayan glaciers: The big picture is a montage." *Proceedings of the National Academy of Sciences* 108.36 (2011): 14709-14710.

Keck, Helmut, Roger Dekumbis, and Mirjam Sick. "Sediment Erosion in Hydraulic Turbines and Experiences with Advanced Coating Technologies." 2005.6 (2005): 2005.

Kehrwald, Natalie M., L G Thompson, Y Tandong, E Mosley-Thompson, U Schotterer, V Alfimov, J Beer, J Eikenberg, and M E Davis. "Mass loss on Himalayan glacier endangers water resources." *Geophysical Research Letters* 35.22 (2008): L22503.

Kelly, R.E. and Alfred T Chang. "A Prototype AMSR-E Global Snow Area and Snow Depth Algorithm." *IEEE Transactions on Geoscience and Remote Sensing* 41.2 (2003): 230–242.

Khadka, Dibesh, M S Babel, S Shrestha, and N K Tripathi. "Climate Change Impact on Glacier and Snow Melt and Runoff in Tamakoshi Basin in the Hindu Kush Himalayan (HKH) Region." *Journal of Hydrology* (2014).

Khromova, T. E. "Late-twentieth Century Changes in Glacier Extent in the Ak-shirak Range, Central Asia, Determined from Historical Data and ASTER Imagery." *Geophysical Research Letters* 30.16 (2003): 1863.

Khromova, T. E., G B Osipova, D G Tsvetkov, M B Dyurgerov, and R G Barry. "Changes in glacier extent in the eastern Pamir, Central Asia, determined from historical data and ASTER imagery." *Remote sensing of environment* 102.1 (2006): 24-32.

Kitoh, Akio, H Endo, K K Kumar, I F A Cavalcanti, P Goswami, and T Zhou. "Monsoons in a changing world: a regional perspective in a global context." *Journal of Geophysical Research: Atmospheres* (2013).

Kokorin, A. O. (ed.). "Assessment Report: Climate change and its impact on ecosystems, population and economy of the Russian portion of the Altai-Sayan Ecoregion." Moscow: WWF-Russia: 2011.

Konagai, Kazuo, and A Sattar. "Partial breaching of Hattian Bala landslide dam formed in the 8th October 2005 Kashmir earthquake, Pakistan." *Landslides* 9.1 (2012): 1-11.

Kotlyakov, V. M., G. B. Osipova, and D. G. Tsvetkov. "Monitoring surging glaciers of the Pamirs, central Asia, from space." *Annals of Glaciology* 48.1 (2008): 125-134.

Kovats, Sari, and Rais Akhtar. "Climate, climate change and human health in Asian cities." *Environment and Urbanization* 20.1 (2008): 165-175.

Kriegel, David, C Mayer, W Hagg, S Vorogushyn, D Duethmann, A Gafurov, and D Farinotti. "Changes in glacierisation, climate and runoff in the second half of the 20th century in the Naryn basin, Central Asia." *Global and Planetary Change* (2013).

Kumar, Sanjay. "Indian Court Halts Projects in Wake of Calamitous Monsoon." Nature newsblog (2013). http://blogs.nature.com/news/2013/08/indian-court-halts-projects-in-wake-of-calamitous-monsoon.html

Kumar, Rajesh, G Areendran, and Prakash Rao. "Witnessing Change: Glaciers in the Indian Himalayas." WWF India: 2009.

L

Lako, P., H Eder, M de Noord, and H Reisinger. "Hydropower development with a focus on Asia and Western Europe. Overview in the framework of VLEEM 2." 2003.

Lang, Timothy J., and Ana P. Barros. "Winter storms in the central Himalayas." *Journal of the Meteorological Society of Japan. Ser. II* 82.3 (2004): 829-844.

Larson, Christina. "'Third Pole' Glacier Research Gets a Boost From China." *Science*, 334. 2011.

Lau, K. M., and Song Yang. "Climatology and interannual variability of the Southeast Asian summer monsoon." *Advances in Atmospheric Sciences* 14.2 (1997): 141-162.

Lau, K. M., M. K. Kim, and K. M. Kim. "Asian summer monsoon anomalies induced by aerosol direct forcing: the role of the Tibetan Plateau." *Climate Dynamics* 26.7-8 (2006): 855-864.

Laukkonen, Julia, et al. "Combining climate change adaptation and mitigation measures at the local level." *Habitat International* 33.3 (2009): 287-292.

Lefèvre, Benoit. "Incorporating cities into the post-2012 climate change agreements." *Environment and Urbanization* 24.2 (2012): 575-595.

Lehner, Bernhard, Kristine Verdin, and Andy Jarvis. "New global hydrography derived from spaceborne elevation data." *EOS, Transactions American Geophysical Union* 89.10 (2008): 93-94.

Le Quesne, Tom, J H Matthews, C Von der Heyden, A.J. Wickel, R Wilby, J Hartmann, G Pegram, E Kistin, G Blate, G K de Freitas, E Levine, C Guthrie, C McSweeney, and N Sindorf. "Flowing Forward: Freshwater Ecosystem Adaptation to Climate Change in Water Resources Management and Biodiversity Conservation." World Bank: 2010.

Leslie, Jacques. "A Torrent of Consequences." World Policy Institute, Summer 2013. http://www.worldpolicy.org/journal/summer2013/torrent-consequences

Lhendub, P, E Wikramanayake, S Freeman, N Sindorf, K Gyeltshen, and J Forrest. "Climate Change Vulnerability Assessment of Wangchuck Centennial Park." WWF-Bhutan: 2011.

Lioubimtseva, E., R Cole, J M Adams, and G Kapustin. "Impacts of climate and land-cover changes in arid lands of Central Asia." *Journal of Arid Environments* 62.2 (2005): 285-308.

Lioubimtseva, Elena, and Geoffrey M. Henebry. "Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations." Journal of Arid Environments 73.11 (2009): 963-977.

Luckman, Adrian, Duncan Quincey, and Suzanne Bevan. "The potential of satellite radar interferometry and feature tracking for monitoring flow rates of Himalayan glaciers." *Remote Sensing of Environment* 111.2 (2007): 172-181.

M

Macchi, Mirjam, A M Gurang, B Hoermann, and D Choudhury. *Climate variability and change in the Himalayas: community perceptions and responses*. International Centre for Integrated Mountain Development (ICIMOD), 2011.

Malik, Sadia Mariam, Haroon Awan, and Niazullah Khan. "Mapping vulnerability to climate change and its repercussions on human health in Pakistan." *Globalization and Health* 8.1 (2012): 31.

Malone, E. "Changing Glaciers and Hydrology in Asia: Addressing Vulnerabilities to Glacier Melt Impacts." Washington: USAID, November (2010).

Mannig, Birgit, M Müller, E Starke, C Merkenschlager, W Mao, X Zhi, R Podzun, D Jacob, and H Paeth. "Dynamical downscaling of climate change in Central Asia." *Global and Planetary Change* 110 (2013): 26-39.

Mathison, Camilla. A Wildshire, A P Dimri, P Falloon, D Jacob, P Kumar, E Moors, J Ridley, C Siderius, M Stoffel, and T Yasunari. "Regional Projections of North Indian Climate for Adaptation Studies." *The Science of the total environment* (2013).

Matsuo, Koji, and Kosuke Heki. "Time-variable Ice Loss in Asian High Mountains from Satellite Gravimetry." *Earth and Planetary Science Letters* 290.1-2 (2010): 30–36.

Matthew, Richard. "Environmental Change, Human Security, and Regional Governance: The Case of the Hindu Kush/Himalaya Region." Global Environmental Politics 12.3 (2012): 100-118.

Matthew, Richard. "Climate Change and Security." *Environmental Security*. Ed Rita Floyd and Richard Matthew. Routledge (2013): 264-278.

Mayewski, Paul A., and Peter A. Jeschke. "Himalayan and Trans-Himalayan glacier fluctuations since AD 1812." *Arctic and Alpine Research* (1979): 267-287.

McCarthy, Thomas M., and Guillaume Chapron. "Snow leopard survival strategy." International Snow Leopard Trust, 2003.

McDowell, G., J D Ford, B Lehner, L Berrang-Ford, and A Sherpa. "Climate-related hydrological change and human vulnerability in remote mountain regions: a case study from Khumbu, Nepal." *Regional Environmental Change* (2012): 1-12.

Menon, Arathy, A Levermann, and J Schewe. "Enhanced Future Variability During India's Rainy Season." *Geophysical Research Letters* 40. May (2013).

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.

Miller, James D., Walter W. Immerzeel, and Gwyn Rees. "Climate Change Impacts on Glacier Hydrology and River Discharge in the Hindu Kush–Himalayas." *Mountain Research and Development* 32.4 (2012): 461–467.

Miner, Mary, G Patankar, S Gamkhar, and D J Eaton. "Water sharing between India and Pakistan: a critical evaluation of the Indus Water Treaty." *Water International* 34.2 (2009): 204-216.

Ministry of Nature, Environment and Tourism, Monglia. "Mongolia's Second National Communication to the UNFCCC." Ulanbaatar: 2010. http://unfccc.int/resource/docs/natc/mongnc2.pdf

Mohan, Divya and Shirish Sinha. "Vulnerability Assessment of People, Livelihoods, and Ecosystems in the Ganga Basin." WWF-India: 2011a.

Mohan, Divya and Shirish Sinha. "Facing the Facts: Ganga Basin's Vulnerability to Climate Change." WWF-India: 2011b.

Mölg, Thomas, F Maussion, and D Scherer. "Mid-latitude westerlies as a driver of glacier variability in monsoonal High Asia." *Nature Climate Change* (2013).

Mool, Pradeep. "Some examples of Landslide Dammed Lakes Outburst Floods (LDOF) in the HKH region." ICIMOD, 2012.

Morton, Katherine. "Climate change and security at the third pole." *Survival* 53.1 (2011): 121-132.

Mulmi, Abhiman Das. "Green road approach in rural road construction for the sustainable development of Nepal." *Journal of Sustainable Development* 2.3 (2009): P149.

N

Narama, Chiyuki. "Late Holocene variation of the Raigorodskogo Glacier and climate change in the Pamir–Alai, central Asia." *Catena* 48.1 (2002): 21-37.

Narama, Chiyuki, Y Shimamura, D Nakayama, and K Abdrakhmatov. "Recent changes of glacier coverage in the western Terskey-Alatoo range, Kyrgyz Republic, using Corona and Landsat." *Annals of Glaciology* 43.1 (2006): 223-229.

Narama, Chiyuki, A Kaab, M Duishonakunov, and K Abdrakhmatov. "Spatial variability of recent glacier area changes in the Tien Shan Mountains, Central Asia, using Corona (~ 1970), Landsat (~ 2000), and ALOS (~ 2007) satellite data." *Global and Planetary Change* 71.1 (2010a): 42-54.

Narama, Chiyuki, M Duishonakunov, A Kaab, M Daiyrov, and K Abdrakhmatov. "The 24 July 2008 Outburst Flood at the Western Zyndan Glacier Lake and Recent Regional Changes in Glacier Lakes of the Teskey Ala-Too Range, Tien Shan, Kyrgyzstan." *Natural Hazards and Earth System Science* 10.4 (2010b): 647–659.

Narngyel, Thinley, S Dagay, T Tashi, S L Khandu, and K Tshering. (2011). "Second National Communication to the UNFCCC." Thimphu, 2011. http://unfccc.int/resource/docs/natc/bhunc2.pdf

National Research Council. "Himalayan Glaciers: Climate Change, Water Resources, and Water Security." Washington, DC: The National Academies Press, 2012.

Nawaz, Shuja. "Leaders Call for Modernizing Indus Water Treaty." Atlantic Council. April 3, 2013. http://www.acus.org/press/leaders-call-modernizing-indus-water-treaty

Nie, Yong, Q Liu, and S Liu. "Glacial Lake Expansion in the Central Himalayas by Landsat Images, 1990–2010." *PloS one* 8.12 (2013): e83973.

Nogués-Bravo, D., M B Araujo, M P Errea, and J P Martinez-Rica. "Exposure of Global Mountain Systems to Climate Warming During the 21st Century." *Global Environmental Change* 17.3-4 (2007): 420–428.

Nuth, C., and A. Kääb. "Co-registration and bias corrections of satellite elevation data sets for quantifying glacier thickness change." *The Cryosphere, Volume 5, Issue 1, 2011,* pp. 271-290 5 (2011): 271-290.

O

Organisation for Economic Co-operation and Development. "Paris Declaration on Aid Effectiveness: Ownership, Harmonisation, Alignment, Results and Mutual Accountability." *High Level Forum on Joint Progress Toward Enhanced Aid Effectiveness: Harmonization, Alignment and Results. 2nd High level Forum on Aid Effectiveness. Paris, France*. 2005.

P

Palazzi, E., J. Hardenberg, and A. Provenzale. "Precipitation in the Hindu-Kush Karakoram Himalaya: Observations and future scenarios." *Journal of Geophysical Research: Atmospheres* (2013).

Palmer, Margaret, C A R Liermann, C Nilsson, M Florke, J Alcamo, P S Lake, and N Bond. "Climate Change and the World's River Basins: Anticipating Management Options." *Frontiers in Ecology and the Environment* 6.2 (2008): 81–89.

Pandey, Arvind C., Swagata Ghosh, and M. S. Nathawat. "Evaluating patterns of temporal glacier changes in Greater Himalayan Range, Jammu & Kashmir, India." *Geocarto International* 26.4 (2011): 321-338.

Patz, J. A., A K Githeko, J P McCarty, S Hussein, U Confalonieri, and N de Wet. "Climate change and infectious diseases." *Climate change and human health: risks and responses* (2003): 103-37.

Paul, Frank, N E Barrand, S Baumann, E Berthier, T Bolch, K Casey, H Frey, S P Joshi, V Konovalov, R Le Bris, N Mölf, G Nosenko, C Nuth, A Pope, A Racoviteanu, P Rastner, B Raup, K Scharrer, S Steffen, and S Winsovold. "On the accuracy of glacier outlines derived from remote-sensing data." *Annals of Glaciology* 54.63 (2013): 171-182.

Paul, S. K., S K Bartarya, P Rautela, and A K Majajan. "Catastrophic mass movement of 1998 monsoons at Malpa in Kali Valley, Kumaun Himalaya (India)." *Geomorphology* 35.3 (2000): 169-180.

Penna, Anthony N. and Jennifer S. Rivers. Natural *Disasters in a Global Environment*. 2013.

Pieczonka, Tino, T Bolch, W Junfeng, and L Shiyin. "Heterogeneous mass loss of glaciers in the Aksu-Tarim Catchment (Central Tien Shan) revealed by 1976 KH-9 Hexagon and 2009 SPOT-5 stereo imagery." *Remote Sensing of Environment* 130 (2013): 233-244.

Poudel, Laxman, B Thapa, B P Shrestha, R Shrestha, B K.C, and N K Shrestha. (2006). "Erosive Effect on Hydro Mechanical Components : A Case Study of Roshi Khola in Nepal." 1–9.

Pradhan, NS; Khadgi, VR; Schipper, L; Kaur, N; Geoghegan, T. "Role of Policy and Institutions in Local Adaptation to Climate Change – Case studies on responses to too much and too little water in the Hindu Kush Himalayas." Kathmandu: ICIMOD, (2012).

Priya, Satya, G Laganda, F Woodhams, S Kai, S Foruna, N Hansen, H Inagaki, R Rakshit, and K Jihyun. "Practitioners and Policy-makers Exchange on Climate Change Adaptation in Agriculture." (2011).

R

Racoviteanu, Adina E., R Armstrong, and M W. Williams. "Evaluation of an ice ablation model to estimate the contribution of melting glacier ice to annual discharge in the Nepal Himalaya." *Water Resources Research* 49.9 (2013): 5117-5133.

Racoviteanu, Adina E., F Paul, B Raup, S J S Khalsa, and R Armstrong. "Challenges and recommendations in mapping of glacier parameters from space: results of the 2008 Global Land Ice Measurements from Space (GLIMS) workshop, Boulder, Colorado, USA." Annals of Glaciology 50.53 (2009): 53-69.

Raina, V.K. "Himalayan Glaciers." Ministry of Environment and Forests (MOEF) Discussion Paper, New Delhi, India (2009).

Ramanathan, V., C Chung, D Kim, T Bettge, L Buja, J T Kiehl, W M Washington, Q Fu, D R Sikka, and M Wild. "Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle." *Proceedings of the National Academy of Sciences of the United States of America* 102.15 (2005): 5326-5333.

Rasul, G, A Mahmood, A Sadiq, and S I Khan. 2012. "Vulnerability of the Indus Delta to Climate Change in Pakistan." *Pakistan Journal of Meteorology* 8 (16): 89–107.

Rasul, Ghulam, Muhammad Afzal, Maida Zahid, and Syed Ahsan Ali Bukhari. 2012. *Climate Change in Pakistan Focused on Sindh Province. Pakistan Meteorological Department Technical Report No. PMD-25/2012*. Islamabad.

Raup, Bruce, A Racoviteanu, S J S Khalsa, C Helm, R Armstrong, and Y Arnaud. "The GLIMS geospatial glacier database: A new tool for studying glacier change." *Global and Planetary Change* 56.1 (2007): 101-110.

Redford, Kent H., and William M. Adams. "Payment for ecosystem services and the challenge of saving nature." *Conservation Biology* 23.4 (2009): 785-787.

Rees, H. Gwyn and David N. Collins. "Regional differences in response of flow in glacier-fed Himalayan Rivers to Climatic Warming." *Hydrological processes* 20.10 (2006): 2157-2169.

Revi, Aromar. "Climate change risk: an adaptation and mitigation agenda for Indian cities." *Environment and Urbanization* 20.1 (2008): 207-229.

Ridley, Jeff, Andrew Wiltshire, and Camilla Mathison. "More frequent occurrence of westerly disturbances in Karakoram up to 2100." *Science of the Total Environment* (2013).

Rodell, Matthew, Isabella Velicogna, and James S. Famiglietti. "Satellite-based estimates of groundwater depletion in India." *Nature* 460.7258 (2009): 999-1002.

Rudenko, I.,M Bekchanov, U Djanibekov, and J P A Lamers. "The added value of a water footprint approach: Micro-and macroeconomic analysis of cotton production, processing and export in water bound Uzbekistan." *Global and Planetary Change* 110 (2013): 143-151.

S

Sarfraz, Hamid. "Revisiting the 1960 Indus Waters Treaty", Water International, 38:2, 204-216. (2013)

Scherler, Dirk, Bodo Bookhagen, and Manfred R. Strecker. "Hillslope-glacier coupling: The interplay of topography and glacial dynamics in High Asia." *Journal of Geophysical Research* 116.F2 (2011a): F02019.

Scherler, Dirk, Bodo Bookhagen, and Manfred R. Strecker. "Spatially variable response of Himalayan glaciers to climate change affected by debris cover." *Nature Geoscience* 4.3 (2011b): 156-159.

Schöne, T, C Zech, K Unger-Shayesteh, V Rudenko, H Thoss, H-U Wetzel, A Gafurov, J Illingner, and A Zubovich. "A new permanent multi-parameter monitoring network in Central Asian high mountains-from measurements to data bases." *Geoscientific Instrumentation, Methods and Data Systems Discussions* 2 (2012): 301-336.

Schlüter, Maja, G Khasankhanova, V Talskikh, R Taryannikova, N Agaltseva, I Joldasova, R Ibragimov, and U Abdullaev. "Enhancing resilience to water flow uncertainty by integrating environmental flows into water management in the Amudarya River, Central Asia." *Global and Planetary Change* 110 (2013): 114-129.

Shahgedanova, Maria, G Nosenko, T Khromova, and A Muraveyev. "Glacier Shrinkage and Climatic Change in the Russian Altai from the Mid-20th Century: An Assessment Using Remote Sensing and PRECIS Regional Climate Model." *Journal of Geophysical Research* 115.D16 (2010): D16107.

Shangguan, Donghui. "Monitoring the Glacier Changes in the Muztag Ata and Konggur Mountains, East Pamirs, Based on Chinese Glacier Inventory and Recent Satellite Imagery." 43.1 (2006): 79–85.

Shangguan, Donghui, S Liu, Y Ding, J Li, Y Zhang, L Ding, X Wang, C Xie, and G Li. "Glacier changes in the west Kunlun Shan from 1970 to 2001 derived from Landsat TM/ETM+ and Chinese glacier inventory data." *Annals of Glaciology* 46.1 (2007): 204-208.

Sherchan, Roshan, Ryan Bartlett, and Bhawani Dongol. "Climate Change Vulnerability Assessment: The Tamor River Sub-Basin, Nepal." WWF-Nepal: 2013.

Shi, Yafeng, Y Shen, E Kang, D Li, Y Ding, G Zhang, and R Hu. "Recent and future climate change in northwest China." *Climatic Change* 80.3-4 (2006): 379-393.

Shrestha, A. B., M Eriksson, P Mool, P Ghimire, B Mishra, and N R Khanal. "Glacial lake outburst flood risk assessment of Sun Koshi basin, Nepal." *Geomatics, Natural Hazards and Risk* 1.2 (2010): 157-169.

Shrestha, A. B., S H Shah, and R Karim. "Resource Manual on Flash Flood Risk Management – Module 1: Community-based Management." ICIMOD: (2008a).

Shrestha, A. B. "Resource Manual on Flash Flood Risk Management – Module 2: Non-Structural Measures." ICIMOD: (2008b).

Shrestha, A. B., E GC, R P Adhikary , and S K Rai. "Resource Manual on Flash Flood Risk Management – Module 3: Structural measures." Kathmandu: ICIMOD: (2012).

Shrestha, A. B., and S. R. Bajracharya. "Case Studies on Flash Flood Risk management in the Himalayas: In Support of Specific Flash Flood Policies." International Centre for Integrated Mountain Development (ICIMOD), 2013.

Simonov, E A and T D Dahmer. "Amur-Heilong River Basin Reader." Ecosystems Ltd: 2008.

Singh, Surender P., I Bassignana-Khadka, B S Karky, and E Sharma. *Climate change in the Hindu Kush-Himalayas: the state of current knowledge*. International Centre for Integrated Mountain Development (ICIMOD), 2011.

Smith, Bridget and David Sandwell. "Accuracy and resolution of shuttle radar topography mission data." *Geophysical Research Letters* 30.9 (2003).

Sorg, Annina, T Bolch, M Stoffel, O Solomina, and M Beniston. "Climate change impacts on glaciers and runoff in Tien Shan (Central Asia)." *Nature Climate Change* 2.10 (2012): 725-731.

South Asian Association for Regional Cooperation (SAARC). "Thimphu Statement on Climate Change." SAARC, Thimphu: April 2010.

Stone, Richard. "Peril in the Pamirs." *Science* 326.5960 (2009): 1614-1617.

Sultana, Humaira, N Ali, M. M Iqbal, and A M. Khan. "Vulnerability and Adaptability of Wheat Production in Different Climatic Zones of Pakistan Under Climate Change Scenarios." *Climatic Change* 94 (1-2) (2009): 123–142.

Surazakov, A. B., V B Aizen, E M Aizen, and S A Nikitin. "Glacier changes in the Siberian Altai Mountains, Ob river basin,(1952–2006) estimated with high resolution imagery." *Environmental Research Letters* 2.4 (2007): 045017.

T

Tennigkeit, T. and A Wilkes. "An Assessment of the Potential for Carbon Finance in Rangelands." Working Paper no. 68: 2008.

Thapa, Bhola, R Shrestha, P Dhakal, and B S Thapa. "Problems of Nepalese hydropower projects due to suspended sediments." *Aquatic Ecosystem Health & Management* 8.3 (2005): 251-257.

Theile, Stephanie. "Fading Footprints: The Killing and Trade of Snow Leopards." TRAFFIC, Cambridge, UK: 2003.

Tiwari, P.C. and Joshi, B. "Environmental Changes and Sustainable Development of Water Resources in the Himalayan Headwaters of India. *Water Resource Management* (2012). 26(4), 883-907.

Tiwari, P.C. and Joshi, B. "Changing Monsoon Pattern and Its Impact on Water Resources in Himalaya: Responses and Adaptation". Palutikof, Jean, ed. *Climate Adaptation Futures*. 2013.

U

Unger-Shayesteh, Katy, S Vorogushyn, D Farinotti, A Gafurov, D Duethmann, A Mandychev, and B Merz. "What do we know about past changes in the water cycle of Central Asian headwaters? A review." *Global and Planetary Change* 110 (2013): 4-25.

UN-Water. "Climate Change Adaptation: The Pivotal Role of Water." (2010). http://www.unwater.org/policyclimate.html

USAID. "USAID Water and Development Strategy 2013-2018." Washington: USAID, (2013). http://www.usaid.gov/sites/default/files/documents/1865/USAID_Water_Strategy_3.pdf

V

Valentin, C., F Agus, R Alamban, A Boosaner, J P Bricquet, V Chaplot, T de Guzman, A de Rouw, J L Janeau, D Orange, K Phachomphonh, D D Phai, P Podwojewski, O Ribolzi, N Silvera, K Subagyono, J P Thiebaux, T D Toan, T Vadari. "Runoff and Sediment Losses from 27 Upland Catchments in Southeast Asia: Impact of Rapid Land Use Changes and Conservation Practices." *Agriculture, Ecosystems & Environment* 128.4 (2008): 225–238.

Viviroli, D., D R Archer, W Buytaert, H J Fowler, G B Greenwood, A F Hamlet, Y Huang, G Koboltschnig, M I Litaor, J I Lopez-Moreno, S Lorentz, B Schadler, H Schreier, K Schwaiger, M Vuille, and R Woods. "Climate change and mountain water resources: overview and recommendations for research, management and policy." *Hydrology and Earth System Sciences* 15.2 (2011): 471-504.

W

Waage, S., C. Bracer, and M. Inbar. "Payments for ecosystem services: getting started. A primer." (2008).

Wang, Houjie, Y Saito, Y Zhang, N Bi, X Sun, and Z Yang. "Recent changes of sediment flux to the western Pacific Ocean from major rivers in East and Southeast Asia." *Earth-Science Reviews* 108.1-2 (2011): 80-100.

Wang, Shengjie, M Zhang, N C Pepin, Z Li, M Sun, X Huang, and Q Wang. "Recent changes in freezing level heights in High Asia and their impact on glacier changes." *Journal of Geophysical Research: Atmospheres* (2014).

Wang, Shih-Yu, R E Davies, W R Huang, and R R Gillies. "Pakistan's two-stage monsoon and links with the recent climate change." *Journal of Geophysical Research: Atmospheres* (1984–2012) 116.D16 (2011).

Wang, Xiao-ping, Tan-dong Yao, Peng-ling Wang, Wei-Yang, and Li-de Tian. "The Recent Deposition of Persistent Organic Pollutants and Mercury to the Dasuopu Glacier, Mt. Xixiabangma, Central Himalayas." *The Science of the total environment* 394.1 (2008): 134–43.

Warner, Koko. “Climate Change Induced Displacement: Adaptation Policy in the Context of the UNFCCC Climate Negotiations.” (2011). PPLA/2011/02.

Warraich, Haider, Anita KM Zaidi, and Kavita Patel. “Floods in Pakistan: a public health crisis.” *Bulletin of the World Health Organization* 89.3 (2011): 236-237.

Webster, P. J., V. E. Toma, and H.-M. Kim. “Were the 2010 Pakistan Floods Predictable?” *Geophysical Research Letters* 38.4 (2011).

WHO (2011). “Gender, Climate Change, and Health.” World Health Organization, Geneva.

WHO (2012). “Atlas of Health and Climate.” World Health Organization, Geneva.

Wilkes, Andreas. “Towards Mainstreaming Climate Change in Grassland Management Policies and Practices on the Tibetan Plateau.” World Agroforestry Centre – Working paper: 2008.

Winkler, Daniel. “Yartsa Gunbu (Cordyceps sinensis) and the fungal commodification of Tibet’s rural economy.” *Economic Botany* 62.3 (2008): 291-305.

World Bank. “Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience.” A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. Washington, DC: 2013.

Worni, Raphael, C Huggel, and M Stoffel. “Glacial Lakes in the Indian Himalayas - From an Area-wide Glacial Lake Inventory to On-site and Modeling Based Risk Assessment of Critical Glacial Lakes.” *The Science of the total environment* (2012).

Wulf, Hendrik, Bodo Bookhagen, and Dirk Scherler. “Seasonal precipitation gradients and their impact on fluvial sediment flux in the Northwest Himalaya.” *Geomorphology* 118.1 (2010): 13-21.

Wulf, H., B. Bookhagen, and D. Scherler. “Climatic and geologic controls on suspended sediment flux in the Sutlej River Valley, western Himalaya.” Hydrology and Earth System Sciences 16 (2012): 2193-2217.

WWF China. “Climate Change Vulnerability Assessment for the Mekong Source Region – Qinghai Province, China.” September, 2010.

WWF International. “Feature Advisory: Human-Wildlife Conflict.” Gland, Switzerland: 2003.

WWF International. “Best Practices – Adapting to Climate Change.” 2011.

WWF Mongolia. “Mongolia Takes First Steps Towards PoWPA Implementation.” Ulaanbaatar, Mongolia: 2007a.

WWF Mongolia. “Freshwater Issues in Mongolia and WWF Mongolia’s Planned Contribution towards a Solution.” Ulaanbaatar, Mongolia: 2007b.

WWF Mongolia. “Annual Review Fiscal Year 2010.” Ulaanbaatar, Mongolia: 2010.

WWF Mongolia. “Buyant River Basin Modeling: Results of Hydraulic and Hydrological Modeling.” Ulaanbaatar, Mongolia: 2012.

WWF Nepal. “Integrated Study on Hydrology and Meteorology of Khumbu Region with Climate Change Perspectives.” Kathmandu, Nepal: 2008.

WWF Nepal. “High Altitude Wetlands Project: A Retrospective.” Kathmandu, Nepal: 2011.

WWF Nepal. “Towards Sustainable Utilization of Water and Natural Resources in the Indrawati Basin.” Kathmandu, Nepal: 2012.

WWF Pakistan. “Disaster Risk and Management Planning for UC Koh and Broze Chitral District.” WWF-Pakistan: 2011.

WWF Russia. “Altai-Sayan Ecoregion Project.” 2007.

WWF Russia. “WWF-Russia Conservation Strategy 2013-2017.” Moscow: 2013.

X

Xu, Jianchu, R E Grumbine, A Shrestha, M Eriksson, X Yang, Y Wang, and A Wilkes. “The Melting Himalayas: Cascading Effects of Climate Change on Water, Biodiversity, and Livelihoods.” *Conservation biology: the journal of the Society for Conservation Biology* 23.3 (2009): 520–30.

Y

Yohe, Gary, E Malone, A Brenkert, M Schlesinger, H Meij, X Xing, and D Lee. "A synthetic assessment of the global distribution of vulnerability to climate change from the IPCC perspective that reflects exposure and adaptive capacity." *CIESIN (Center for International Earth Science Information Network), Columbia University, Palisades*. (2006).

Z

Zahid, Maida, and Ghulam Rasul. "FREQUENCY OF EXTREME TEMPERATURE & PRECIPITATION EVENTS IN PAKISTAN 1965-2009." 23.4 (2011): 313–319.

Zemp, M, I Roer, A Kääb, M Hoelzle, F Paul, and W Haeberli. *WGMS (2008): global glacier changes: facts and figures*. (2008).

Zhang, Leilei, et al. "Discharge regime and simulation for the upstream of major rivers over Tibetan Plateau." *Journal of Geophysical Research: Atmospheres* (2013).

Zholdosheva, Elnura. "Review of the existing information, policies and proposed or implemented climate change measures in Kyrgyzstan." FAO, (2010). www.fao.org/docrep/014/k9589e/k9589e10.pdf

Zongtai, Wang, and Yang Huian. "Characteristics of the distribution of glaciers in China." *Annals of Glaciology* 16 (1992): 17-20.

APPENDIX A

Current and Ongoing Scientific Research Efforts on Climate Change and Glacier Melt in AHM

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
MAJOR DONORS						
Changing Glaciers and Hydrology in Asia: Addressing Vulnerabilities to Glacier Melt Impacts	USAID	Heather D'Agnes, Health Advisor. Mary Melnyk, Senior Advisor, NRM. Kristian Yarrow, Health Advisor	hdagnes@usaid.gov, mmelnyk@usaid.gov, kyarrow@usaid.gov		Central Asia, South Asia, China	
Global Climate Change in the Asia Pacific Region: An analysis and roadmap in 2008, Asia-Pacific Regional Climate Change Adaptation Assessment, and Black Carbon Emissions in Asia	USAID	Winston Bowman, RDMA	wbowman@usaid.gov			
Supported the Tajikistan weather and water forecasting agency to improve the collection, analysis, and exchange of data critical to water resource management, including the installation of a meteorological station at Fedchenko Glacier.	USAID	Andrei Barannik, Regional Environmental Advisor for Asia	abarannik@usaid.gov		Central Asia	
	USAID	Ayse Sezin Tokar (OFDA)	stokar@usaid.gov		Pan Asia	Disaster preparedness and hydro-meteorological hazards
CHARIS	USAID	Richard Armstrong, CIRES	rlax@nsidc.org	http://nsidc.org/charis/	Pan Asia	
	USAID	LeAnna Marr(Asia Bureau Education)			Pan Asia	
	USAID	Ricki Gold (Asia Bureau DG)			Pan Asia	

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
	USAID	Neil Adlai Levine (DCHA/CMM)			Pan Asia	
	USAID	Dan Henry (DCHA/OTI)			Pan Asia	
	USAID	Pat Piere (DCHA/DG/G)			Pan Asia	
	USAID	Jim Franckiewicz, Dan Deeley, Richard Volk (Water team)			Pan Asia	
	USAID	Tjip Walker (DCHA/CMM)			Pan Asia	
	US State Dep't	Joseph M Bracken (Population and International Migration)			Pan Asia	Climate change impacts
	US State Dep't	Maria Placht	plachtmt@state.gov			
	US State Dep't	Ingrid Specht	spectik@state.gov			
	US State Dep't	Sumreen Mirza (EOS)				
Bhutan Biological Conservation Complex	WWF				Bhutan	
Climate Change & High Altitude Wetlands	WWF				Bhutan	
Climate Change and Energy	WWF				India	
Freshwater ecosystem conservation	WWF				Mongolia	
REDD	WWF				Nepal	
Climate Change Adaptation	WWF				Nepal	
Renewable Energy for Rural Livelihood (RERL)	UNDP	Anupa Rimal Lamichhane	registry.np@undp.org	http://www.undp.org/content/nepal/en/home/operations/projects/environment_and_energy/rerl/	Nepal	Environment and Energy
Conservation and Sustainable Use of Wetlands in Nepal (CSUWN)	UNDP	Mr. Vijay Singh	vijay.singh@undp.org	http://www.undp.org/content/nepal/en/home/operations/projects/environment_and_energy/csuwn.html	Nepal	Environment and Energy
Ecosystem based Adaptation (EbA) in mountain ecosystem in Nepal	UNDP	Mr. Vijay Singh	vijay.singh@undp.org		Nepal	Environment and Energy
Comprehensive Disaster Risk Management Programme (CDRMP)	UNDP	Jenty Kirsch-Wood	registry.np@undp.org	http://www.undp.org/content/nepal/en/home/operations/projects/crisis_prevention_and_recovery/cdrmp.html	Nepal	Crisis Prevention and Recovery

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
Strengthening National Capacity for Disaster Risk Management in Bhutan	UNDP				Bhutan	
Reducing Climate Change-induced Risks and Vulnerabilities from Glacial Lake Outburst Floods in the Punakha-Wangdi and Chamkhar Valleys	UNDP	Anne Erica Larsen		http://www.undp.org.bt/150.htm	Bhutan	
National Environmental Information Management System (NEIMS)	UNDP	Munazza Naqvi	munazza.naqvi@undp.org	http://undp.org.pk/national-environmental-information-management-system-neims.html	Pakistan	
Institutional Strengthening for Implementation of Montreal Protocol Project (Phase V)	UNDP	Munazza Naqvi	munazza.naqvi@undp.org	http://undp.org.pk/institutional-strengthening-for-implementation-of-montreal-protocol-project-phase-v.html	Pakistan	
Protection and Management of Pakistan Wetlands Project	UNDP	Munazza Naqvi	munazza.naqvi@undp.org	http://undp.org.pk/protection-and-management-of-pakistan-wetlands-project.html	Pakistan	
Sustainable Land Management to Combat Desertification in Pakistan Project	UNDP	Naveeda Nazir	naveeda.nazir@undp.org	http://undp.org.pk/sustainable-land-management-to-combat-desertification-in-pakistan-project.html	Pakistan	
Glaciers Lake Outburst Flood Project	UNDP	Mr. Bilal Ali Qureshi	bilal.qureshi@unp.org	http://undp.org.pk/glaciers-lake-outburst-flood-project.html	Pakistan	
Climate Risk Management in Kyrgyzstan	UNDP	Daniyar Ibragimov	daniar.ibragimov@undp.org	http://www.undp.kg/en/resources/project-database/article/1-projects/1884-climate-risk-management	Kyrgyzstan	
Ecosystem Based Adaptation Approach to Maintaining Water Security in Critical Water Catchments in Mongolia	UNDP				Mongolia	
Sustainable Land Management for Combating Desertification in Mongolia	UNDP	Bunchingiv.B	bunchingiv.bazartseren@undp.org	http://www.undp.mn/snrm-slmcd.html	Mongolia	
Strengthening Environmental Governance in Mongolia	UNDP	Bunchingiv.B	bunchingiv.bazartseren@undp.org	http://www.undp.mn/snrm-segm.html	Mongolia	
Strengthening the protected area network in Mongolia	UNDP	Onno van den Heuvel	tungalag@undp.org	http://www.undp.mn/snrm-span.html	Mongolia	
Integrated Land and Ecosystem Management to Combat Land Degradation and Deforestation in Madhya Pradesh	UNDP	Ms. Lianchawii		http://www.in.undp.org/content/india/en/home/operations/projects/environment_and_energy/integrated_land_andecosystemmanagementtocombatlanddegradationand.html	India	

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
Climate Change Community of Solution Exchange	UNDP	Ramesh Jalan		http://www.in.undp.org/content/india/en/home/operations/projects/environment_and_energy/climate-change-community-of-solution-exchange.html	India	
Ecosystem Based Adaptation in Mountain Ecosystems	UNEP	Musonda Mumba	musonda.mumba@unep.org)	http://www.unep.org/climatechange/adaptation/EcosystemBasedAdaptation/EcosystemBasedAdaptationinMountainEcosystems/tabid/51980/Default.aspx	Nepal	Environment
Sustainable Financing for Biodiversity Conservation and Natural Resources Management	World Bank	Genevieve Boyreau	gboyreau@worldbank.org		Bhutan	
Strengthening the Enabling Environment for Biodiversity Conservation and Management in India	World Bank	Sunita Malhotra	indiapic@worldbank.org		India	
Bihar Flood Management Information System Phase II	World Bank	Sunita Malhotra	indiapic@worldbank.org		India	
Water Management Improvement Project (WMIP)	World Bank		bishkek_office@worldbank.org		Kyrgyzstan	
Second Rural Water Supply & Sanitation	World Bank		bishkek_office@worldbank.org		Kyrgyzstan	
Building Resilience to Climate Related Hazards	World Bank		nepalpic@worldbank.org		Nepal	
Nepal Agriculture and Food Security Project	World Bank		nepalpic@worldbank.org		Nepal	
Zoonoses Control Project (ZCP)	World Bank		nepalpic@worldbank.org		Nepal	
Irrigation & Water Resources Management Supplemental	World Bank		nepalpic@worldbank.org		Nepal	
Development of a program for Hazard and Risk Assessment in Urban Areas	World Bank		mariamaltaf@worldbank.org	http://www.worldbank.org/projects/P110099/water-sector-capacity-buildling-advisory-services-project-wcap?lang=en	Pakistan	
Water Sector Capacity Building and Advisory Services Project (WCAP)	World Bank		mariamaltaf@worldbank.org		Pakistan	
Capacity Building for Emerging Infectious Disease Preparedness	World Bank		eastasiapacific@worldbank.org	http://www.worldbank.org/projects/P131204/capacity-builiding-emerging-infectious-disease-preparedness?lang=en	Mongolia	
Improving Disaster Risk Management in Mongolia	World Bank		eastasiapacific@worldbank.org	http://www.worldbank.org/projects/P129541/improving-disaster-risk-management-mongolia?lang=en	Mongolia	

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
High Mountain Agribusiness and Livelihood Improvement Project	ADB	Arun S Rana	arunrana@adb.org	http://www.adb.org/projects/search/499	Nepal	Agriculture
Water Resources Project Preparatory Facility	ADB	Ahsan Tayyab	atayyab@adb.org		Nepal	Agriculture and natural resources
High Mountain Agribusiness and Livelihood Improvement Project	ADB	Arun S Rana	arunrana@adb.org		Nepal	Agriculture and natural resources
Community Irrigation Project	ADB	Deepak Bahadur Singh	dbsingh@adb.org		Nepal	Agriculture and natural resources
Building Climate Resilience of Watersheds in Mountain Eco-Regions	ADB	Cynthia (Cindy) Malvicini	cmalvicini@adb.org		Nepal	Multisector
Support for Government Planning in Climate Resilience	ADB	Cynthia (Cindy) Malvicini	cmalvicini@adb.org		Nepal	Not yet classified
Strengthening Capacity for Managing Climate Change and the Environment	ADB	Cynthia (Cindy) Malvicini	cmalvicini@adb.org		Nepal	Public sector management
Punjab Irrigated Agriculture Investment Program Tranche 3	ADB	Akhtar Ali	aali@adb.org	http://www.adb.org/projects/search/498	Pakistan	Agriculture
Water Sector Task Force	ADB	Donneth Walton	dwalton@adb.org		Pakistan	Agriculture and natural resources
Water Supply and Sanitation Strategy	ADB	Marko Davila	mdavila@adb.org	http://www.adb.org/projects/search/508	Kyrgyzstan	Multisector
Investment Climate Improvement Program - Subprogram 2	ADB	Ruben Barreto	rbarreto@adb.org		Kyrgyzstan	Multisector
Establishment of Climate-Resilient Rural Livelihoods	ADB	Carey Yeager	cyeager@adb.org	http://www.adb.org/projects/search/502	Mongolia	Multisector
Dzud Disaster Response Project	ADB	Laurence M. Pochard	lpochard@adb.org		Mongolia	Multisector
Rural Renewable Energy Development Project	ADB	Takeshi Shiihara	tshiihara@adb.org	http://www.adb.org/projects/search/520	Bhutan	Energy/ Renewable Energy
Off Grid Pay-As-You-Go Solar Power	ADB	Aniruddha V. Patil	apatil@adb.org	http://www.adb.org/projects/search/513	India	Energy/ Renewable Energy
Climate Adaptation through Sub-Basin Development Investment Program	ADB	Cynthia (Cindy) Malvicini	cmalvicini@adb.org		India	Multisector
Support for the National Action Plan on Climate Change	ADB	Vidhisha Samarasekara	vsamarasekara@adb.org		India	Multisector
Climate protection for developing countries	German Development Cooperation (GTZ)	Christoph Feldkötter	climate@giz.de	http://www.giz.de/Themen/en/3958.htm	Worldwide	

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
Climate adaptation	Swiss Agency for Development (SDC)		gpcc@eda.admin.ch	http://www.sdc.admin.ch/en/Home/Themes/Climate_change/Vulnerability_Adaptation	Worldwide	
NGOS AND RESEARCH INSTITUTIONS						
Opportunities to Reduce Black Carbon Emissions in South Asia	US EPA	Tony Socci	Socci.Anthony@epamail.epa.gov	http://www.epa.gov/international/air/bcsasia.html	Asia	
Natural Hazard Management	Asian Disaster Preparedness Centre (ADPC)			http://www.adpc.net	Asia	
Climate Risk Management, Agriculture	IRI Earth Institute, University of Columbia			http://portal.iri.columbia.edu/portal/server.pt	Asia	
Southeast Asia Disaster Management	SAARC Disaster Management Centre	Santosh Kumar	director@saarc-sdmc.org	http://saarc-sdmc.nic.in/index.asp	Asia	
High Mountain Watershed Management	High Mountain Glacial Watershed Program			http://www.highmountains.org/	Asia	
Himalaya Focus	The Mountain Institute			http://mountain.org/	Himalaya, Andes	
Climate Disaster Management	International Federation of the Red Cross (IFRC)			http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/aggravating-factors/climate-change/	Worldwide	
Adaptation to Climate Change: An integrated science-stakeholder-policy approach to develop an adaptation framework for the water and agriculture sectors in Indian states of Andhra Pradesh and Tamilnadu	International Water Management Institute (IWMI)		iwmi@cgiar.org	http://asia.iwmi.cgiar.org/	Asia	
Climate and Water Advisory Forum in India			iwmi@cgiar.org	http://asia.iwmi.cgiar.org/	Asia	
Impacts of climate change and watershed development on whole-of-basin agricultural water security in the Krishna and Murray-Darling Basins			iwmi@cgiar.org	http://asia.iwmi.cgiar.org/	Asia	
Water availability and demand analysis of the Indus Basin under Climate Change			iwmi@cgiar.org	http://asia.iwmi.cgiar.org/	Asia	
Promote ecosystem-based approaches to climate change adaptation	International Union for the Conservation of Nature (IUCN)	Tanyathon Phetmanee	tanyathon.phetmanee@iucn.org	http://www.iucn.org/about/union/secretariat/offices/asia/elg/rddrp/	Asia	Conservation

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
CGIAR Research Program on Climate Change, Agri-culture and Food Security (CCAFS)	CGIAR	Bruce Campbell	b.campbell@cgiar.org	http://www.cgiar.org/our-research/cgiar-research-programs/cgiar-research-program-on-climate-change-agri-culture-and-food-security-ccafs/	Worldwide	
CGIAR Research Program on Forests, Trees and Agroforestry		Robert Nasi	r.nasi@cgiar.org	http://www.cgiar.org/our-research/cgiar-research-programs/cgiar-research-program-on-forests-trees-and-agro-forestry/	Worldwide	
CGIAR Research Program on Water, Land and Eco-systems		Andrew Noble	a.noble@cgiar.org	http://www.cgiar.org/our-research/cgiar-research-programs/cgiar-research-program-on-water-land-and-ecosystems/	Worldwide	
PAHAR is a non-profit organization dedicated to raising awareness of the fragile Himalayan environ-ment and bringing together scientists, social activists, and common people to save the Himalayas.	People's Association for Himalaya Area Research (PAHAR)		info@pahar.org	http://www.pahar.org/drupal/	Himalaya	
Food security and glacial distribution, landslides	Central-Asian Institute for Applied Geosciences (CAIAG)			http://www.caiag.kg/en/	Asia	
Climate Change and Green Growth	The Asia Foundation		info@asiafound.org	http://asiafoundation.org/	Asia	
BIOM is a public non-profit voluntary organization working since 1993, uni-fying young specialists, scientists and leaders that participates in addressing environmental problems of the Kyrgyz Republic and Central-Asian region	BIOM		biom.kg@google.com	http://www.biom.kg/	Kyrgyzstan	
Resilience to Climate Change, Disaster Risk Reduction	Institute for Social and Environmental Transition (ISET)		info@i-s-e-t.org	http://www.i-s-e-t.org/proj-ects-and-programs/resil-ience-to-climate-change	Asia	
Regional Programme on Adaptation to Change, significant research and adaptation efforts through-out the HMA region	International Center for Integrated Mountain Development (ICIMOD)	Dhrupad Chaudhury	dchoudhury@icimod.org	http://www.icimod.org/	Southern HMA	
Climate change adaptation	International Institute for Environment and Development (IIED)	Ced Hesse - Principle Researcher, Climate Change Group	ced.hesse@iied.org	http://www.iied.org/	Asia	

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
Maintains world glacier inventory, compiles mass balance and terminus measurements	World Glacier Monitoring Service (WGMS)	Michael Zemp, Director	wgms@geo.uzh.ch	http://www.geo.uzh.ch/mi-crosite/wgms/index.html	Worldwide	
The Contribution of Land-Surface Processes to Climate Change on the Tibetan Plateau	Texas A&M University	Oliver Frauenfeld	oliverf@geog.tamu.edu	http://nsidc.org/research/projects/Frauenfeld_Tibet-an_Plateau.html	Asia	
Contribution to High Asia Runoff from Ice and Snow (CHARIS)		Richard Armstrong	rlax@nsidc.org	http://nsidc.org/charis/	Asia	
Global Land Ice Mea-surements from Space (GLIMS)	Univeristy of Arizona	Jeff Kargel	kargel@hwr.arizona.edu	www.glims.org	Worldwide	
Geomorphic-Geodynamic Coupling at the Orogen Scale	Earth Research Institute (ERI)	Doug Burbank	burbank@eri.ucsb.edu	http://projects.crustal.ucsb.edu/nepal/	Asia	
Snow Hydrology Research Group		Jeff Dozier	dozier@bren.ucsb.edu	http://www.snow.ucsb.edu	Worldwide	
Flood Response	International Relief and Development (IRD)		ird@ird-dc.org	http://www.ird.org/our-work/by-region/asia-and-pacific/pakistan	Pakistan	
Atmospheric Radiation, Black Carbon	NASA	Lazaros Oreopoulos		http://atmospheres.gsfc.nasa.gov/climate/index.php?section=130	Worldwide	
International Cooperation on Climate & Energy	World Resources Institute (WRI)	Jennifer Morgan, Director - Climate and Energy Program	jmorgan@wri.org	http://www.wri.org/	Worldwide	
National Adaptive Capacity Framework		Sara-Katherine Coxon	scoxon@wri.org	http://www.wri.org/	Worldwide	
Climate Forcing, Aerosols	NOAA			http://www.esrl.noaa.gov/gmd/	Worldwide	
NATIONAL AGENCIES						
Climate Change Manage-ment	National Environmental Commission, Bhutan			http://www.nec.gov.bt/	Bhutan	
Green technology	Tarayana Foundation		tarayana@druknet.bt	http://www.tarayanafoun-dation.org/	Bhutan	
GLOF, LLOF	Geological Survey of Bhutan	Sonam Tshering, Secretary	sting@druknet.bt	http://www.mti.gov. bt/de-partments.htm	Bhutan	
GLOF management	Ministry of Home Affairs, India			http://www.mha.nic.in/	India	
GLOF, other flooding	National Institute of Disaster Management, India			http://www.nidm.net/	India	

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
Monsoon variability, black carbon studies	The Energy and Resources Institute			http://www.teriin.org/index.php	India	
Meteorological data, glacial observatories	Indian Meteorological Department, India	Dr. Srinivasan	sriniren@gmail.com	www.imd.ernet.in	India	
Glacial retreat, water resources	Ministry of Environment and Forests, India	Dr. JairamRamesh, Minister	envisect@nic.in	http://moef.nic.in/index.php	India	
Earth changes, glacial melt	The WADIA Institute of Himalayan Glaciology, Dehradun, India	Dr. R. K. Mazari, Scientist	mazarirk@wihg.res.in	http://www.wihg.res.in	India	
Glacier Studies	Glaciological Survey, India (GSI)	Dr. Sangewar	gewar@rediffmail.com	www.portal.gsi.gov.in/	India	
Hydrology, water shortages	Institute of Hydrology and Water Problems	Duishen Mamatkanov			Kyrgyzstan	
UNFCCC Focal point	State Agency for the Environment	Arstanbek Davletkeldiev			Kyrgyzstan	
Disaster management	Ministry of Home Affairs, Nepal			http://www.moha.gov.np//en/	Nepal	
Climate, hydrology, weather	Department of Hydrology and Meteorology, Nepal			http://www.dhm.gov.np/	Nepal	
Disaster management	Disaster Preparedness Network, Nepal			http://www.dpnet.org.np/	Nepal	
Disaster management	Department of Water Induced Disaster Prevention, Nepal			http://www.dwidp.gov.np	Nepal	
Water Resources	Water and Energy Commission, Nepal		wecs@mos.com.np	http://www.wec.gov.np/	Nepal	
Government focal point for much of the climate change activity in Nepal related to forests. Coordinating upcoming conference on glacial melt, biodiversity, payment for environmental services (PES) and REDD. Shared focal point for upcoming Alliance of Mountainous Countries Conference.	Ministry of Forests and Soil Conservation (MOFSC),Nepal	Deepak Bohara, Minister of Forests and Soil Conservation	bohara@sca.com.np		Nepal	

PROJECT NAME OR DESCRIPTION	ORGANIZATION DETAILS				GEOGRAPHIC AREA OF FOCUS	SUBJECT AREA OF FOCUS
	Name	*Key Contact*	*Contact Details*	*URL*		
Disaster management	National Disaster Management Authority, Pakistan			http://ndma.gov.pk/	Pakistan	
Climate Change effects on Agriculture	National Agricultural Research Center, Pakistan			http://www.parc.gov.pk/NARC/narc.html	Pakistan	
The main purpose of the Centre is to serve as a think tank in aid of the national planners and decision makers for strategic policy planning in consonance with the changing global environment in areas such as Climate, Water, Energy, Food, Agriculture, Health, Ecology, new technologies etc.	Global Change Impact Studies Center, Pakistan			http://www.gcisc.org.pk/	Pakistan	
GLOF, landslide risk	Geological Survey of Pakistan			http://www.gsp.gov.pk/	Pakistan	
Climate change studies	Ministry of Climate Change, Pakistan			http://www.moenv.gov.pk/	Pakistan	

SCIENTISTS[21]	RESEARCH INSTITUTION	EMAIL	WEBSITE	AREA	RESEARCH AREAS
Bodo Bookhagen	University of California, Santa Barbara	bodo@eri.ucsb.edu	http://www.geog.ucsb.edu/~bodo/	Asia	Himalaya - Quaternary Climate Changes, Erosion, and Landscape Evolution
Tobias Bolch	University of Zurich	tobias.bolch@geo.uzh.ch	http://www.geo.uzh.ch/en/units/physical-geography-3g/about-us/staff/tobias-bolch	Asia	Glaciers and Periglacial Environment of High Mountain Areas, Climate Change in High Mountain Areas and its Impacts, Digital Terrain Analysis, GIS and Remote Sensing
Chiyuki Narama	NIigata University, Japan	narama@env.sc.niigata-u.ac.jp	http://researchers.adm.niigata-u.ac.jp/staff/?userId=100000631&lang=en	Asia	Glaciology, hydrology, climatology.
Richard Armstrong	University of Colorado, Boulder	rlax@nsidc.org	http://cires.colorado.edu/people/armstrong/	Asia	Remote sensing of snow, ice, and frozen ground, snow cover and glacier mass extent as indicators of climate change, properties of avalanche snow, and data set and cryospheric product development.
Vladimir Aizen	University of Idaho	aizen@uidaho.edu		Asia	Glaciology, hydrology, climatology.
Christian Huggel	University of Zurich	christian.huggel@geo.uzh.ch	http://www.geo.uzh.ch/~chuggel/index.html	Asia	Climate impacts, risks and adaptation to climate change, mainly in mountain and high-mountain regions.

21 Due to donor funding cycles, funded projects change frequently, and accurately documenting the scientists active in the region is difficult. Key researchers are identified based on volume of relevant public literature identified in this report.