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ORIGINAL ARTICLE

Improving adaptive capacity and resilience in Bhutan

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Abstract Bhutan, a small least developed country in the Himalayan Mountains, faces five current climate change related vulnerabilities: landslides and flooding, deteriorating agricultural production, impoverished forests, worsening health security, and impaired hydroelectricity generation. The country is attempting to adapt to these challenges through two globally sponsored adaptation efforts. One is the "Reducing Climate Change-induced Risks and Vulnerabilities from Glacial Lake Outburst Floods in the Punakha-Wangdue and Chamkhar Valleys" project, or GLOF, a $7.7 million project being funded by the Global Environment Facility, United Nations Development Program, and the government of Bhutan. Another is the GLOF Risk Reduction Project in the Himalayas, or GRRP, a $730,000 program funded by the United Nations Development Program (UNDP). These projects offer great potential for improving infrastructural, institutional, and community resilience within Bhutan, but must also overcome a series of pernicious social, political, and economic challenges if they are to succeed.

Keywords Bhutan · Adaptive capacity · Climate change adaptation · Resilience

1 Introduction

The Himalayan range of mountains is greatly affected by climate change, the most noticeable consequence the accelerated melting of glaciers. As glaciers recede, supra-glacial lakes form which can contribute to the severe risk of uncontrollable flooding. With a geographic area smaller than Switzerland, Bhutan is home to 983 of these glaciers and 2,794 glacial lakes (Nayar 2009). This article therefore focuses intently on the climate-related vulnerabilities Bhutan is facing and will face. Its objective is to investigate the benefits from investing in adaptation activities in Bhutan and identify the challenges planners must overcome in implementing adaptation projects. More specifically, it explores

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two ongoing adaptation efforts: the "Reducing Climate Change-induced Risks and Vulnerabilities from Glacial Lake Outburst Floods in the Punakha-Wangdue and Chamkhar Valleys" project, or GLOF, a $7.7 million effort being funded by the Global Environment Facility, United Nations Development Program (UNDP), and the government of Bhutan. It also investigates the GLOF Risk Reduction Project in the Himalayas, or GRRP, a $730,000 program funded by the UNDP.

The article begins by describing its methods of data collection, consisting of research interviews, site visits, and a literature review. It then classifies the climate change vulnerabilities of Bhutan into five broad categories relating to landslides and flooding, agriculture, forestry, health security, and hydroelectricity generation. This is followed by a detailed description of both ongoing adaptation projects—GLOF and GRRP—including their components, participating agencies, benefits, and challenges to implementation. The study concludes by offering implications for climate policy more generally.

Such an analysis is extremely important for planners in Bhutan and around the globe. For policymakers in Bhutan, the population of the country is very small (about 600,000) and one-tenth of the population is at risk to catastrophic flooding to say nothing of the indirect effects of glacial melting and changing surface temperatures on agricultural production, energy supply, and community livelihood.

For planners elsewhere, Biermann and Boas (2008) estimate that hundreds of millions of people depend on water supply from glaciers and glacial melting, meaning that glacial flood control could become a pressing policy concern well beyond the Himalaya-Hindu-Kush mountain range. There have been numerous instances of Glacial Lake Outburst Floods (GLOFs) causing severe damage in Pakistan, Peru, Nepal, and Tibet (National Environment Commission 2008; Bajracharya et al. 2007; Ives et al. 2010). For instance, in 1929 the Chong Khumdan Glacier outburst in Pakistan released 3.5 million cubic meters of water causing widespread floods in the entire Upper Indus River as far as 1,300 km downstream. In 1941, a single GLOF destroyed the entire city of Huaraz in Peru. In 1985, the Dig Tsho glacier in Nepal unexpectedly melted and induced a flood that destroyed the site for the $1.5 million Namche Small Hydroelectric Project, drowned hundreds of villagers, and swept away 14 bridges. In August 2000, one of the barley producing areas of the Tibetan Plateau was destroyed by a GLOF when more than 10,000 homes, 98 bridges, and dozens of dykes were destroyed at an estimated cost of $75 million. Alaska, Canada, Iceland, and Switzerland have also seen sub-glacial outbursts in the past creating massive Tsunami-like floods carrying voluminous amounts of debris, destroying highways and bridges, and decimating cultivated land.

2 Methods

The authors selected Bhutan for analysis because of (1) its unique susceptibility to glacial flooding; (2) its status as a least developed country; and (3) its role as the first recipient of aid from the Least Developed Countries Fund (LDCF), a global fund managed by the United Nations Framework Convention on Climate Change (UNFCCC) and Global Environment Facility (GEF).

First, Bhutan is at grave risk to climate change, as one respondent put it "possibly the single country most at risk." Life in Bhutan's hilly mountainous topography is highly dependent on the natural environment. As Fig. 1 shows, the country is part of the Himalaya-Hindu-Kush region with altitudes ranging from 100 m in the south up to more than 7,500 m in the north (causing one interview respondent to remark that the country was

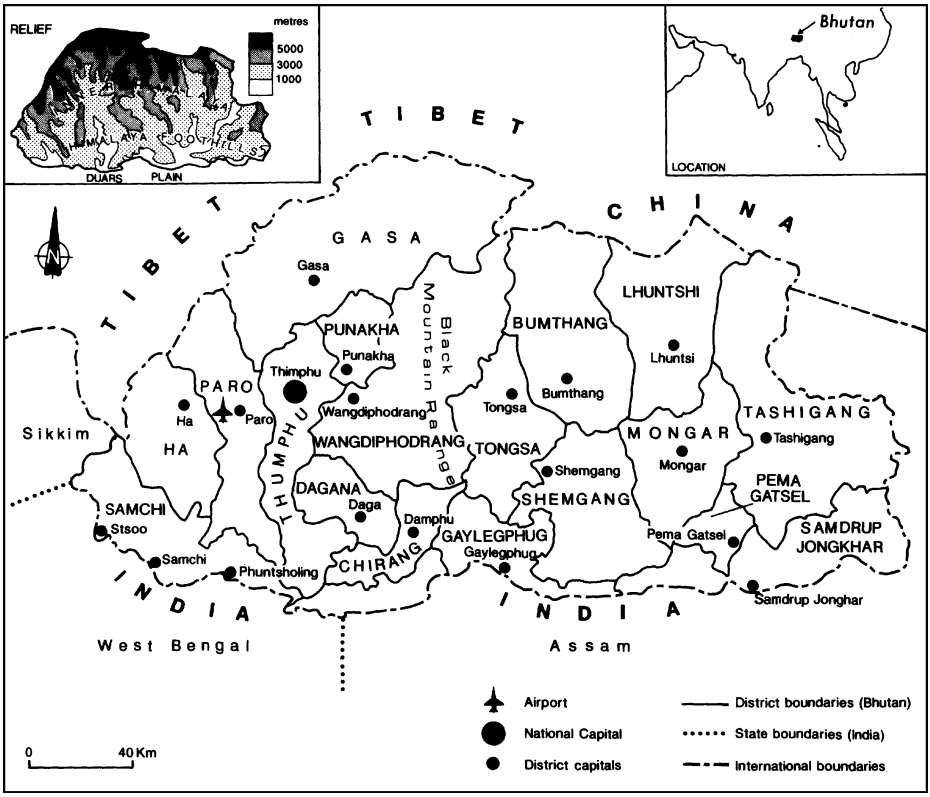

Fig. 1 Topographic and political map of Bhutan. Source: Young 1991

like "a giant staircase"). Because it is difficult to build human settlements and pump water into the highlands, most farms and housing complexes are situated close to rivers, giving them better access to drinking water and water-based transport but also placing them at severe risk to glacial floods. Yet the National Environment Commission (2009: 4) reports that, using disaggregated Intergovernmental Panel on Climate Change (IPCC) data, a median temperature increase of 3.3° by 2100 will likely occur, with the largest warming in higher altitudes that will also see decreasing surface albedo associated with the melting of snow and ice. Given that Bhutan derives its rich culture and religious practices from Drukpa Buddhist traditions, major sectors of the economy involve agriculture, livestock, forestry, extractive industries and tourism. These sectors are highly climate sensitive, and place Bhutan at risk to climate-related disruptions to economic activity. Tourism forms a large part of the country's income and is also adversely affected by unpredictable weather events. The World Bank (2010) reports a decline of $7 million in annual tourism revenues from 2008 levels, and an estimated loss of $67 million in 2009 due to earthquake and cyclone damage.

Second, Bhutan is a least developed country. Bhutan adopted the Gross National Happiness (GNH) philosophy of social and economic development during the reign of the 4th King HM Jigme Singye Wangchuk in 1972. It refers to a set of social and economic interventions that evaluate societal change in terms of the collective happiness of people and the quality of the natural environment. The philosophy attempts to harmonize economic progress with spiritual and emotional wellbeing. Per capita gross domestic product,

however, remains low at less than $5,300 and places the country at 132nd in terms of its Human Development Index ranking. Moreover, the country's population density is the lowest in South Asia at less than 12 persons per square kilometer yet it has one of the highest growth rates in the world at more than 3%. About one-third of rural communities also live below the national poverty line. The confluence of these factors—low incomes, low density, high population growth—promises to create significant stress on existing social and political systems. And even though the government started alleviating poverty through investments in education, health care, nutrition, and infrastructure, gains that reduced child mortality by 50% and improved life expectancy by 20 years, such achievements could be completely undone by climate change (National Environment Commission 2008).

Third, Bhutan was the first country to receive adaptation money from the LDCF (Nayar 2009). Established in 2001, the LCDF was created exclusively to help least developed countries prepare and implement national adaptation programs of action (NAPAs) aimed at improving resilience and adaptive capacity related to climate change. Currently the world's largest fund for climate adaptation, the GEF has so far leveraged $180 million in voluntary contributions to support 45 adaptation projects in 33 countries, projects implemented in tandem with partner agencies including the World Bank, United Nations Development Program, and Food and Agriculture Organization. Focusing on Bhutan offers insight into the dynamics of the LDCF, including challenges to implementation the fund must overcome.

To collect data related to climate change adaptation, glacial flooding, and Bhutan, the authors depended primarily on in-country field research and research interviews. The authors conducted 20 semi-structured interviews over the course of June and July 2010. The authors relied on a purposive sampling strategy to ensure a representative mix of institutions participated, including:

- National government agencies such as the National Environment Commission, Gross National Happiness Commission, Ministry of Home and Cultural Affairs, Department of Energy, Department of Agriculture, and Department of Geology and Mines;
- State and local government agencies such as Punakha Valley Township, Wangdue Valley Township, Chamkhar Valley Township, Punakha Dzongkhag Administration, and the Bumthang Dzongkhag Administration;
- Civil society and intergovernmental organizations such as the GEF, UNDP, and World Wildlife Fund.

The interviews were transcribed for accuracy and consisted of open-ended questions related to the impacts of climate change on Bhutan and the various challenges faced by the agencies in preparation and implementation of adaptation efforts. The authors also asked respondents to recommend relevant literature confirming their points, seamlessly connecting our interviews to the literature review described below. To respect confidentiality, all comments from the interview respondents are presented here anonymously. Nonetheless, Table 1 provides an overview of the institutions visited for the research interviews.

We relied primarily on research interviews and field research, qualitative methods of collecting data, for multiple reasons. The use of semi-structured questions, sometimes referred to as "intensive interviewing" or "responsive interviewing," asks participants a set of standard inquiries but then allows the conversation to build and deviate to explore new directions and areas (O'Sullivan et al. 2010). We depended on this method because it enabled us to collect information difficult or impossible to represent in numerical or statistical form. Many of the variables of interest to us, such as the ongoing climate change challenges facing Bhutan, or the benefits of adaptation efforts, are difficult to measure, and

Table 1 Institutions for research interviews and site visits

Date	Institution	Location	Number of Interviews/visits
June 2010	UNDP	Thimpu	3
June 2010	National Environment Commission	Thimpu	1
June 2010	Disaster Management Division, Ministry of Home and Cultural Affairs	Thimpu	2
June 2010	Gross National Happiness Commission	Thimpu	1
June 2010	World Wildlife Fund	Thimpu	1
June 2010	Department of Geology and Mines	Thimpu	2
June 2010	Punakha Dzongkhag Administration	Punakha	1
June 2010	Bumthang Dzongkhag Administration	Chamkhar, Bumthang	1
June 2010	Department of Energy	Thimpu	1
June 2010	Department of Agriculture	Thimpu	1
June 2010	Punakha Dzong	Punakha	1
June 2010	Punakha Valley Township	Punakha	2
June 2010	Wangdue Valley	Wangdue Phodrang	2
July 2010	Chamkhar Valley	Bumthang	1

to describe them with quantitative methods would amount to what George and Bennett (2004: 19) call "conceptual stretching." We also believed semi-structured interviews were appropriate since they enabled us to use face-to-face interaction, or spoken words and images, rather than text to solicit information. Many farmers and rural community leaders in Bhutan, for example, are illiterate, making textual collection of data difficult.

That said, our method does have some notable shortcomings. One is the relatively small sample (twenty) of our respondents, when hundreds of people are involved in climate change work in Bhutan. One is strategic bias, a term that refers to a situation where respondents can deliberately give answers that will sway the outcome of the study in their favor. A final one is coding: the data collected from interviews is "thick" or "rich" and thus full of detail and context, making it challenging to code.

Nevertheless, we endeavored to overcome these limitations by triangulating responses (i.e., looking for common responses to questions), undertaking a review of the academic literature, and supplementing the interviews with site visits. Our literature review consisted of peer reviewed academic articles related to the vulnerability of Bhutan to climate change published within the past 10 years. The authors also conducted four site visits to settlements that would be directly affected by glacial flooding in Punakha Dzong, the Punakha Valley settlement, the Wangdue Valley, and the Chamkhar Valley in Bumthang. In each of these locations the authors spoke with local residents and district administrators, and two of these settlements are in close proximity to the flood-vulnerable rivers presented in Figs. 2 and 3.

Lastly, some readers may wonder about the value of our study given the preponderance of reports and data produced by the GEF on the LDCF as well as the Bhutan government on climate change adaptation. Our study has four unique advantages to these sources of data. The first is our method: our study is the first we know of to utilize a "mixed method" approach that combines interviews, site visits, and a literature review together instead of relying on such tools in isolation. We also ensured that a broad mix of stakeholders were included in our sample of respondents. The second is focus. Most of the literature on

Fig. 2 Human settlements in the Punakha Valley

climate change in Bhutan remains centered on climate change vulnerabilities, or on the details of LDCF-related projects. None, however, has yet looked at vulnerabilities and the mechanics of programs *as well as* the expected benefits to those programs, challenges to implementation, and lessons for other policymakers. The third is recency. Bhutan's NAPA

Fig. 3 Human settlements in the Wangdue Valley

is already almost 3 years old and the GEF has released little updated information about ongoing activities in the country. The fourth, and perhaps most important, is neutrality. Both the GEF and Bhutanese government have a direct stake in the LDCF, they thus have a potential incentive to bias their evaluation of it. The authors, by contrast, have no stake at all in adaptation efforts and can approach our study dispassionately and neutrally.

3 Results and discussion

This section presents and discusses the results of our study. It divides the data we gleaned from our interviews, site visits, and the literature into four subsections: one investigating Bhutanese climate change vulnerabilities, one articulating ongoing adaptation efforts, one iterating the benefits to adaptation, and one elucidating challenges to implementation.

3.1 Vulnerability to climate change

Interview respondents and the academic literature identified five current climate change related vulnerabilities: landslides and flooding, agricultural productivity, forestry, health security, and hydroelectricity.

3.1.1 Landslides and flooding

Due to its topography, elevation, and location, Bhutan sits on the "roof of the world" in the Hindu Kush-Himalayan region, home to the largest areal extent and volume of permanent ice and permafrost outside of the Polar Regions (Ives et al. 2010). Yet much of this ice is melting unexpectedly. Based on satellite images, maps, and archived photographs, Ageta et al. (2000, 2001) estimate that Bhutanese glaciers are retreating at an average of 30 to 35 m per year. Karma et al. (2003) looked at 66 glaciers and compared 1963 topographic maps with 1993 satellite images and concluded that glaciers had retreated a mean of 8%. Bajracharya et al. (2007) specifically assessed glacial lakes in the Pho Chub sub-basin of Bhutan and found that glacial lakes were growing as glaciers shrank. They counted 82 new lakes that have formed over the past 40 years, and estimated that some of the existing glacial lakes have grown by 250 to 750%. They also, worryingly, observed accelerated melting of ice, increases in the gradients of glacial snouts, and the erosion of moraine ridges. Using satellite imagery and depicted in Fig. 4, Komori (2008) identified more than 50 moraine dammed ice contact or ice proximal lakes in Bhutan, of which 14 were growing by about 70 m per year, and expanding in area by about 0.04 km^2 per year. Nayar (2009) noted that glaciers are melting so quickly in Bhutan they can actually be heard as "deafening" cracks and booms every few minutes as blocks of ice rip off, crash into lakes, and stir up trails of dust and snow.

In confluence, these events have begun to alter the hydrological cycle in ways that make Bhutan more vulnerable to landslides and flooding. As one respondent put it:

> Changes have been observed in the volume, timing, and consistency of rainfall and snowfall patterns since the last few years. Several areas have reported cases of intermittent, untimely and heavy rainfall. This has led to drying up of perennial sources affecting irrigation channels. Sudden rains have led to increase in the incidence of landslides and floods causing damages to rural water supply schemes and the water needed for agriculture.

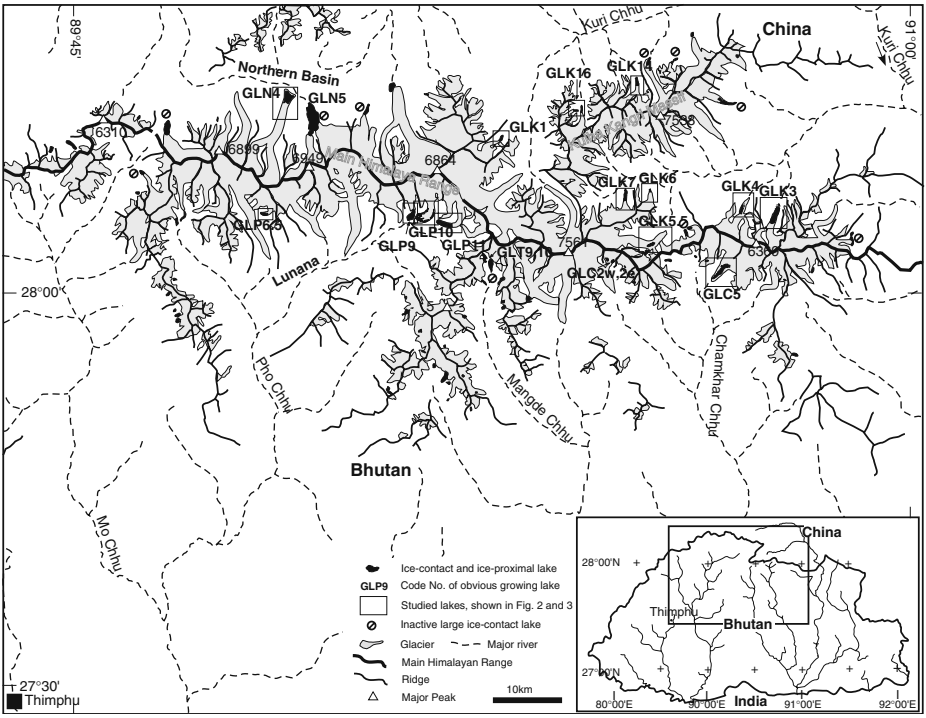

Fig. 4 Inventory of glaciers and glacial lakes in Bhutan. Source: Komori 2008: 178

The National Environment Commission (2008) has already recorded two extreme events this past decade, with severe landslides and floods occurring in 2000 when the southern regions of Bhutan received the maximum rainfall ever recorded, inducing flash floods that eroded valleys, closing the highway to the capital city of Thimphu for a month, and causing the Toorsa and Dhotikhola rivers to change their course. Flashfloods occurred again in 2004 when severe rainfall destroyed hundreds of homes, wetlands, highways, and crops of maize, rice paddies, and orange trees along with 39 irrigation channels and 22 bridges.

One grave aspect of changes in the hydrological cycle is that of a Glacial Lake Outburst Flood, or GLOF. As glaciers thin and retreat, glacial lakes form between the frontal moraine and the receding glacier; or they can form on the surface of lower glacial sections. These kinds of lakes are held back, or dammed, by unstable moraine complexes. When these dams breach—through ice avalanches, the melting of the moraine dam, erosion, changes in water pressure, earthquakes, or croseisms—a GLOF occurs, releasing all of the water in the lake at once (Ives et al. 2010; Nayar 2009). Glacial lakes may hold millions of cubic liters of water and can release high volumes in minutes, devastating valleys and communities downstream.

GLOFs pose an imminent threat to lives, livelihoods and the pace of development in Bhutan. The Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods conducted by the United Nations Environment Program (UNEP) and the International Center for Integrated Mountain Development (ICIMOD) in 2001 listed the 24 high-risk glacial lakes depicted in Fig. 5 (Dorji et al. 2001; Ives et al. 2010). Nine of these high-risk glaciers are located in the Pho Chu Sub Basin and three are located in the Chamkhar Chu Sub Basin, within close proximity to hundreds of human settlements (Tshiteem 2009).

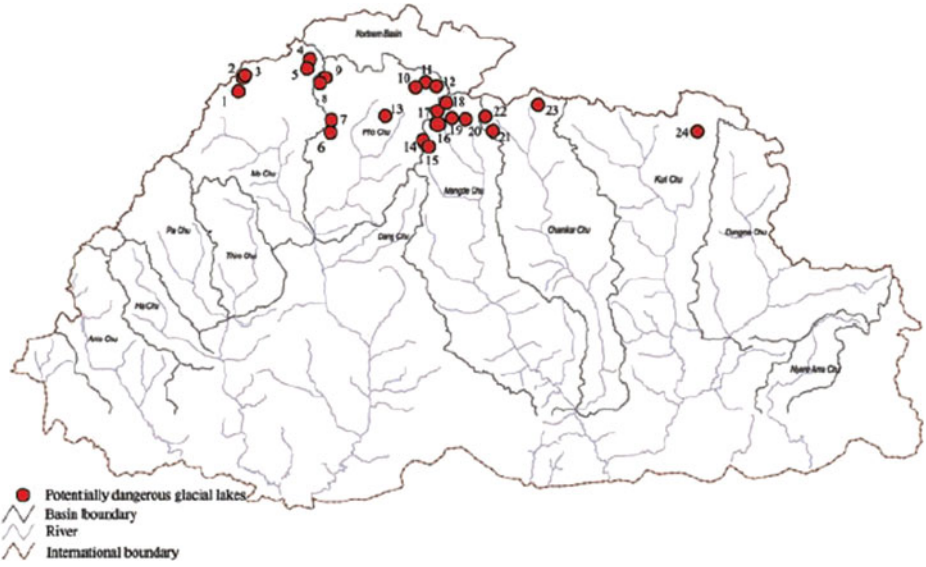

Fig. 5 Twenty-four "dangerous" glacial lakes identified by ICIMOD. Source Ives et al. 2010: 9

Multiple participants cautioned that a GLOF originating in Thorthormi Lake represents a dire threat due to sudden increases in glacier melting, depicted in Fig. 6. Another lake, Rapstreng, is already completely formed due to glacier melting, depicted in Fig. 7. As one respondent noted:

> New floods in the Pho Chu Sub Basin or Chamkhar Chu Sub Basin quite literally could be devastating. Past incidents of GLOFs in 1957 and 1960 and more recently in 1994 devastated the Punakha-Wangdue valley, but then thankfully few were living in the area. The particular GLOF in 1994 damaged more than 1,700 acres of agriculture and pasture land, washed away five mills and 16 yaks, destroyed six tons of food grains, obliterated houses, caused critical infrastructure damage and killed 22 people. My worry is that new flooding, if it were to occur now, could be much worse.

Fig. 6 A potential GLOF forming in Thorthormi Lake

Fig. 7 A potential GLOF forming in Raphstreng Lake

Respondents noted that if the barrier between either of the two lakes breaks the resultant GLOF will be of magnitudes of order stronger than the one in 1994. Other participants mentioned that unexpected events like cyclone Aila, which had severe adverse effects of landslides and flash floods with strong winds and sudden rainfall, could intensify as climate change occurs.

Compounding these risks is the tendency for developers to continue to build homes and commercial buildings close to rivers, placing them in the direct path of GLOF. As one respondent explained, "developers and investors continue to build new hotels on vulnerable river banks despite it being well known that those banks could be vulnerable to flooding." Hospitals, schools, hotels, and houses have also popped up closer to the river banks in the past few years, along with a partially completed $760 million hydroelectric power station (Nayar 2009). Figure 8 shows a series of these hotels and guest

Fig. 8 Newly constructed hotels and guest houses on exposed river banks near Wangdue Phodrang

houses being built near Lunana. Several new settlements have also sprung up very close to the rivers in all three valleys of Punakha, Wangdue and Chamkhar. As one respondent noted, even an airstrip has been proposed for construction in close proximity to the flood plain of Chamkhar Chu.

3.1.2 Agriculture

Respondents described a second category of climate risks related to farming, water, and agriculture. Farming is difficult in Bhutan due to a prevalence of deep, impassable gorges and the Indian and South Asian summer monsoons. Yet despite this difficulty, and the fact that less than 3% of the total land surface of Bhutan is cultivatable, the agricultural sector is a major source of GDP and responsible for 79% of national livelihood, income, and employment. Most farmers participate in a rural economy based on barter with small holdings ranging from one to five hectares, making the sector small-scale and traditionally subsistence oriented. Cereals such as rice are grown wherever water is available in addition to maize in the south and east, and buckwheat, wheat, and barley in the Himalayan valleys. Yet the small land holdings, monsoon rains, and fragile and steep mountain ecosystem make it all but impossible for farmers to shift to new sources of land in the face of erosion, landslides, and floods. Making matters worse, the primary cash crops of rice, potatoes, chilies, apples and oranges are highly sensitive to water and temperature (Young 1991; Saxena et al. 2005; National Environment Commission 2008; Meyer et al. 2009).

In the past decade, farmers have already reported instabilities in crop yields, losses in production, declining crop quality, and decreased water available for farming and irrigation. Moreover, they have documented loss of soil fertility from erosion and runoff, delayed sowing of crops due to premature frost, and outbreaks of new pests and diseases (National Environment Commission 2008). Additional sources of water need to be identified to avoid water scarcity and ensure food security. One respondent claimed that "the sector most affected by climate change impacts is the agricultural sector, heavily influenced because small and marginal farmers don't have resources to cope with changes. The amount of arable land is shrinking and at risk to landslides, erosion, lack of water and irrigation facilities, making it very difficult for farmers to earn their livelihoods." The inconsistency in rainfall has led to shifts in paddy cultivation and changes to the general cropping calendar and cropping patterns. Farmers have had to delay their paddy transplantation to July–August, which is otherwise a harvesting period. The result has been "increasing pest problems and crop diseases including 'citrus greening' and pests like common cutworm and bollworm." Another respondent complained that:

> Early rains completely destroy chili crops, a primary source of produce. Farmers are being forced to change their traditional practices. Bumthang has seen drastic reduction in potatoes due to unexpected frostings. Orange plantations have succumbed to pests and unanticipated colder temperatures. Farmers are now forced to grow other fruits and crops: oranges have now been replaced with mangoes, farmers in Bumthang now grow paddy and maize which they never did in the past, decreasing the production of traditionally grown buckwheat.

Since most farmers practice terrace farming, there is greater difficulty irrigating fields as streams dry up and landslides erode topsoil and render terraces infertile. With poor management of watersheds, another respondent commented that "farmers are at greater risk to droughts and drying of water sources." Also, landslides and weather events that close roads also interrupt cash flows to farmers selling crops as their primary source of income.

Many of these sentiments were confirmed by Chettri (2003), who warned that climate change could undermine both pillars of agricultural production in Bhutan. In the higher Alpine zone, where yak rearing is a main source of livelihood, crop production is limited to barley, wheat, and vegetables and farmers barter for other products. But those land plots are under increasing threat to erosion and landslides. In lower elevations, with more moderate microclimatic temperature zones, farmers rely on irrigated rice, barley, and potatoes as well as apples, pears, and peaches. But these lowlands are becoming more prone to flooding and the destruction of irrigation channels. Between the two climatic zones, moreover, damage from flooding can destroy footbridges connecting villages, irrigation diversions, and the land itself. Due to these factors, Chettri (2003: 23) projects a reduction in crop yields and agricultural productivity by up to 30% by 2100. Also, farmers will likely shift cultivating zones to higher elevations, but such land is unstable, steeper, less productive, and more dangerous. The study warned that the most vulnerable to climate change will be poor farmers that depend on their crops to meet subsistence needs, share croppers that have no land of their own, and landless low wage workers.

3.1.3 Forestry and forest products

Respondents suggested that the impacts of climate change would also adversely affect forests and forestry products. One explained that "climate change is contributing to increased infestations of undesired invasive species, which are replacing the natural flora. Some species like *Aesendra Butyracae* have been wiped out and conifers along Thimpu-Paro-Wangdue Phodrang are dying, along with small bamboos along the Thimpu-Bumthang highway." Another reported that "increased droughts and shortages of water have contributed to an increase in forest fires, which cause a lot of destruction to forests each year." Others noted that droughts cause an increase in forest fires triggered by lightning, and have also changed the migration patterns of some wildlife. One respondent noted that the Samdingkha community has observed a decrease in the number of crows and eagles leading to an increase in frogs and rats that destroy vegetables and paddy, demonstrating the interconnection between the agricultural and forestry sectors. Another community leader in Bumthang reported "mass deaths of wild boar."

3.1.4 Health security

Floods and landslides not only affect agriculture and forestry, but human health as well. Higher morbidity and mortality will result from more extreme weather as riverine floods, flash floods, GLOFs, and breached landslide-dam floods expand vector born diseases and make distribution of food and medical services difficult. Moreover, changes in temperature, rainfall, and vegetation all increase the likelihood of outbreaks of cholera and diarrhoeal diseases, dengue, malaria, and encephalitis as well as the spread of such diseases into higher elevations (National Environment Commission 2008; Tschering and Sithey 2009).

3.1.5 Hydroelectricity generation

A major source of income for Bhutan's economy is hydroelectric power. Four major river systems with a total length of 7,000 km—the Ammochu, Wangchu, Sankosh, and the Mansa—drain into Bhutan (Uddin et al. 2007). The country therefore has the potential to develop nearly 23,000 MW of hydroelectric capacity, of which only 5% is tapped currently. The Tenth Five Year Plan for Bhutan proposes to develop this capacity to 1,602 MW by

2013 with intentions to harness 10,000 MW by 2020. Most of the electricity currently produced is exported to India and both countries have agreed to develop 10 hydropower projects in the future, and nearly 4,000 MW of hydropower is under construction.

Yet as one respondent explained, "with faster glacier melting, hydropower becomes a less attractive investment. It is already facing the adverse effects of flashfloods and landslides because of sediments that flow into the dams. A GLOF or a major flood can wash away an entire hydroelectric project." Other respondents were "very concerned" with the "future of hydropower" and stressed the need to make "hydropower plants more resilient to flooding and landslides." Their concerns center on the fact that climate change can affect both the "fuel" and the structural integrity of hydroelectric plants themselves. Seasonal changes in water levels and runoff can cause shortages of "fuel" to ensure reliable operation, and floods and landslides can destroy dams and infrastructure. Though hydropower installed capacity, and electricity generated, may seem small, it already contributes to 12% of national GDP, with electricity exported to India to then finance development in other areas. The National Environment Commission (2008: 2) reports that earnings from hydropower constitute 45% of national government revenue, meaning disruptions can spillover into agriculture, health care, and the provision of government services.

3.2 Adaptation projects in Bhutan

Perhaps because of these five vulnerabilities, two major adaptation projects are ongoing in Bhutan. The first, entitled GLOF, focuses on reducing glacial floods, the second, GRRP, centers on overall climate risk reduction. The Royal government of Bhutan in collaboration with the GEF and UNDP launched the GLOF project in 2008 to tackle disaster risks. This project, formally called "Reducing Climate Change-induced Risks and Vulnerabilities from Glacial Lake Outburst Floods in the Punakha-Wangdi and Chamkhar Valleys," has three primary components; Table 2 offers an overview of participating agencies (Global Environment Facility 2008a, b; United Nations Development Program 2010).

Table 2 Participating agencies of the GLOF project

Agency/Name	Role
Department of Geology and Mines (DGM)	Executes all technical aspects regarding design of the project, in close collaboration with the Disaster Management Division and other stakeholders
Disaster Management Division (DMD)	Provides coordination and guidance during implementation, particularly to facilitate logistics. It will collaborate closely with DGM to incorporate climate change issues into the disaster risk management framework
National Environment Commission (NEC)	Provides input on vulnerabilities related to climate change and disasters, particularly in promoting awareness and training for local staff and communities
Planning Commission	Creates hazard zoning maps and integrates these into development plans for the Punakha-Wangdi Valley and Chamkhar Valley
The *Dzongkhag* Administrations	Assists the DGM and DMD with implementation in local communities
National Committee on Disaster Management	Provides policy direction for which climate-resilient disaster risk management schemes will be incorporated
UNDP Country Office	Acts as overall coordinator and monitor project funds. It will help mobilize and coordinate support from other partners through a global network

A *lowering of lake water levels* component is being undertaken by the Department of Geology and Mines (DGM) to reduce the risk of GLOFs. So far mitigation work by DGM has focused only on one lake, Thorthormi, where it is aiming to reducing the lower lake's water level by 5 m, enough to eliminate hydrostatic pressure on its unstable moraine dam. Techniques to reduce the risk of a GLOF, to drain water from the lake in order to reduce its volume, are termed "structural mitigation" and consist of:

- Controlling the breaching of the moraine dam;
- Constructing artificial outlets and channels;
- Pumping or siphoning water from the glacial lake;
- Tunneling through the moraine or under an ice dam to allow a measured release of water;
- Replacing moraines with sluice gates or human-made dams;
- Widening and deepening river channels along the GLOF pathway

Work started in 2009 and 67 cm has been drained in 1 year's time. Because the lake is at a very high altitude, only 3 to 4 months are workable onsite. The process so far has included removing boulders and debris from the lake and increasing depth by digging. This is combined with diverting the water entering the lake and the deepening of river channels downstream.

An *early warning* component is being led by the Department of Energy (DOE). Previously, the DOE managed only a single station in Thanza, which housed two people with a wireless radio set and a single satellite phone that monitored glacial lake water levels (and drank copious amounts of hot coffee). The problem is that the two people have not always reported for work, have fallen asleep, and can be killed by the GLOF itself. Under the project, the DOE will replace the manual system with an automatic one composed of gauges monitoring glacial lake bathymetry (depth) as well as sensors along rivers connected to automated sirens. The project will also expand the automated warning system to cover more glacial lakes. The DOE and DMD have so far identified 21 vulnerable communities and given one person in each a mobile phone, simcard and voucher for each year to alert authorities in the case of a flood. Three vulnerable areas of Punakha, Wangdi and lower part of Hamozingha have been taken as pilot project areas for the installation of automated early warning systems.

A *community awareness and capacity building* component is being undertaken by the DMD, aimed at raising awareness in three pilot districts: Punakha, Wangdi and Bumthang. District disaster management committees have been formed and training has been given for an integrated disaster management plan which will enable communities to identify hazards and vulnerabilities. Community leaders will then ostensibly prioritize their own ranking of hazards along with recommended solutions. The DGM is also creating a zoning map to mark several safe evacuation areas and extremely unsafe zones. The final stage of the project will set up emergency operation centers at district administration offices to enable them to better handle crises.

Another UNDP Project, the GLOF risk reduction project, or GRRP, is working simultaneously on creating a regional GLOF database. The overall objective of the project is to develop and implement comprehensive risk management strategies in the Himalayan region to reduce the risks faced by mountain communities and to mitigate impacts of hydro-meteorological and climatic hazards. This project, also, has many components:

- Regional hazard assessment, which includes scanning for historical data on disasters since 1960 and assessing their scale, level, and impact;
- Creating an inventory of glacial lakes and glaciers, which are or could be impacted by climate change;

- Conducting workshops on risk and management of risk where people can undertake hazard ranking and disaster profiling as well as learn about best practices for early warning systems, search and rescue training, shelter information, evacuation in case of emergency and first aid training;
- Establishing a policy framework to strengthen emergency operations centers at district, nodal and local levels;
- Creating a database of information on glacial lakes and GLOFs that can be shared with other Himalayan countries such as Nepal and Tibet.

In essence the GRRP is sensitizing the departments, media, legislators through workshops and orientations for ministry secretaries.

3.3 The benefits of adaptation

The biggest benefits from the GLOF and GRRP projects center on vulnerable communities. Early warning systems at lakes and river junctions and siren towers at glacial lakes and other locations will increase the preparedness of community leaders and reduce risk and unwanted consequences. The Gross National Happiness Commission (GNHC) and the National Environment Commission (NEC) are trying to link adaptation activities with other issues such as poverty and gender streamlining for the developing country.

Participants suggested that both projects will improve *community resilience* by "giving communities a better understanding of the risks and hazards surrounding GLOF occurrences." Another noted that "a better understanding of disaster risk reduction and community plans in case of disasters is essential to community wellbeing. The GLOF project is helping sensitize not only community leaders and adults but the elderly and school children about hazards such as floods, landslides and earthquakes." This information enables communities to better plan for where to locate infrastructure, homes, and farmland. Communities are trained how to respond to calamities and emergency situations using mobile phones and radio broadcasts in addition to traditional sounding gongs and bells from monasteries. As Fig. 9 shows, the DMD and UNDP have produced a set of six posters to communicate these issues to the local population in both English and the local language of Dzongkha. There are plans to train community members to understand and operate automatic early warning systems, when these are installed in the community areas.

Respondents noted that the projects will improve *institutional resilience* by "educating the major political stakeholders of the risks faced by the country in case of a GLOF, especially policymakers." One respondent noted that there has been an increase in awareness in national institutions and streamlining between agencies. As they noted, "the aim has been to get interest for the project and related activities, for instance, building capacity for geologists and employment for civil engineering work." The Department of Agriculture is also working on generating regional capacity on agriculture related issues through four research institutes. The other main institutional work is of the community based disaster management (CBDM) committees. Their job is to highlight hazards and form district disaster management teams at the block and *cheo* (village) level.

Respondents lastly discussed how the projects would promote *infrastructural resilience*. The first infrastructural benefit is the lowering of glacial lake water levels. At Thorthormi Lake, a channel is being widened to accelerate draining and an automatic warning system, with electronic sensors and backup systems, is being constructed. The warning systems are also being integrated with television, mobile phones, and radio broadcasts so that information can be disseminated to all channels. As one of the respondents noted, "The

Fig. 9 A GLOF Educational Poster near Punakha Dzong

early warning system is the technological part of the project. Important instruments have been bought for surveys and to be used in mapping and other essential office equipment has been procured.

3.4 The challenges to adaptation

Building Bhutanese resilience and implementing both adaptation projects is not without challenges, however. First is the sheer complexity of draining glacial lakes, made all the more difficult due to their remote location, their extreme altitude, the boulder strewn terrain, unpredictable weather, lack of data, and poverty. Thorthormi Lake, for example, is so remote that the nearest potential helicopter landing site is more than 90 min away by foot. The unstable terrain makes the use of excavators impossible, and transporting equipment and scientific instruments to the site often damages them. Boulders and silt make it difficult to measure how quickly ice is retreating, and create a safety hazard as drifting icebergs and strong winds make bathymetric surveys dangerous and have capsized boats in the past. Unpredictable weather plays a part as well, with snow blocking the path to the site 8 months of the year and storms, such as Cyclone Aila, preventing necessary equipment from reaching Bhutan as scheduled. Heavy rainfall in 2009 also washed away several key bridges to the site, delaying work by days. Lack of data and poverty exacerbate these issues, with high resolution satellite imagery expensive, meaning the country can only purchase it infrequently, and Bhutan unable to afford even its own helicopter (Nayar 2009). Thus, under these conditions, project managers could only afford to pay a few hundred local horseman to use shovels, spades, and a few jackhammers and chisels to drain the Lake; no automated or heavy machinery at all. These laborers could only work part time. More than half a month was spent just reaching and returning to the site from Lunana. And work has progressed "at a snail's pace, much slower than we had hoped."

At a deeper level, nearly all respondents suggested that Bhutan "lacks the institutional capacity to implement all their responsibilities" and that "better institutional capacity is needed." Respondents cautioned that actors involved with adaptation have several

commitments and conflicting priorities for resource allocation. The most obvious are meeting developmental and energy security needs. For example, Bhutan is trying to implement several development projects for education, development of the private sector, access to health care and agricultural water supply. These are all contenders for funding and personnel from the central and local governments. As one respondent put it, "even if adaptation efforts in Bhutan were fully funded, that is, money was given for every possible area of vulnerability, district administrations would still lack people that could implement those projects."

Other challenges include lack of coordination between institutions and the absence of mainstreaming of goals and activities of different departments. As one respondent stated, "sometimes, departments are not aware of each other's work and there have been cases of repetition or conflict in agendas. There is lack of convergence and communication between departments." Another respondent stated that "implementation of programs is a difficult task due to lack of capacity in participating institutions. There is a paucity of data in most regions. Though there is political support and procedures are less bureaucratic, most projects are dependent on lengthy processes for development assistance and tenders for technology projects." One of the respondents who had participated in the initial process of framing the NAPA felt that it already needed updated.

Some respondents noted that "awareness among people has been low". During the community discussions and workshops conducted by the authors, men were still open to discussions but women were introvert and rarely participated. Some of the participating members were illiterate making communication tedious. The respondents also stated that there have been problems in selecting suppliers of early warning system technology and recruiting laborers for lowering the water level at Thorthormi Lake. Bhutan's small population has always faced a shortage of labor and the difficult working conditions of this project have made it nearly impossible to recruit staff, since the glacial lakes often rise above 4,000 m and are far away from human settlements. There is a "lack of professionals" and a need for "multidisciplinary experts who have knowledge of water level measurement, ICT usage, communication systems, and their integration into an early warning system." "Most of the professionals already here in Bhutan are being recruited from other countries and unlikely to stay," another respondent lamented.

4 Conclusion

We offer three conclusions for those concerned with adaptation in general and global climate policy. First is that the impacts of climate change are not always off far away in the future. Bhutan reminds us that a pernicious assortment of climate change related consequences can affect countries in the very near-term. Untimely and heavy rainfall and altering precipitation patterns are already causing more landslides and flooding. Arable land is shrinking and the inconsistency of rainfall has already forced a shift in rice paddy cultivation and disruptions to the cropping cycle. Diseases and invasive species are spreading and destabilizing forest ecosystems. Flooding and sedimentation is affecting the performance and viability of hydroelectric power stations. To those that think we can wait to act on climate change until 2050 or 2100, or that we only have to worry about events on the distant horizon, Bhutan is a pertinent example of countries and communities already at risk to a changing global climate.

Second is that adaptation projects seem to work best when they blend forms of resilience. The GLOF and GRRP projects in Bhutan, for example, strengthen not only

infrastructural resilience but also community and institutional resilience. These projects are simultaneously enhancing awareness among vulnerable communities, establishing early warning systems, training citizens in emergency response and search and rescue, educating stakeholders, and building the institutional capacity of local and national government. The projects are also investing in infrastructure such as channels and drainage systems that are lowering the levels of glacial lakes and changing zoning and building standards so homes and human settlements are no longer built in vulnerable areas. They remind us that hardware and technology are only one part of the adaptation puzzle; strengthening community assets and promoting good governance are also key pieces.

Third, though, is that while these adaptation projects have the potential to bring immense benefits, properly implementing them is a challenge. Put another way, the benefits of adaptation do not occur automatically. Like many other least developed countries, better institutional capacity is needed and adaptation efforts must compete for the resources and attention of policymakers. Lack of coordination between institutions and different departments has led to competing goals and priorities, and high quality data on specific climate risks and vulnerabilities is costly and time intensive to gather and hard to come by. Community awareness, despite being a key area targeted by both adaptation projects, is still low, with many Bhutanese skeptical about climate change and a paucity of women participating in climate-related discussions. These barriers remind us that no matter how great the benefits of adaptation may be in specific communities, accomplishing those benefits in practice will take time, effort, and targeted public policy intervention.

References

Ageta Y, Iwata S, Yabuki H, Naito N, Sakai A, Narama C, Karma T (2000) Expansion of glacier lakes in recent decades in the Bhutan Himalayas. In: Debris-covered glaciers, Proceedings of a workshop held in Seattle, Washington, USA, September 2000, International Association of Hydrological Sciences (IAHS) Publ. No. 264. IAHS, Wallingford, pp 165–175

Ageta Y, Naito N, Nakawo M, Fujita K, Shakar K, Pokhrel AP, Wangda D (2001) Study Project on the Recent Rapid Shrinkage of Summer Accumulation Type Glaciers in the Himalayas, 1997–1999. Bull Glacial Res 18:45–49

Bajracharya S, Mool PK, Shresthna BR (2007) Impact of Climte Change on Himalayan Glaciers and Glacial Lakes: Case Studies on GLOF and Assocaited Hazards in Nepal and Bhutan. International Center for Integrated Mountain Development and United Nations Environment Program, Kathmandu

Biermann F, Boas I (2008) Protecting climate refugees: the case for a global protocol. Environment 50(6):8–16

Chettri GB (2003) Climate change adaptation technology needs assessment: agriculture sector. Background paper for technology needs assessment for Bhutan prepared for NEC: National Greenhouse Gas Project Phase II. Ministry of Agriculture, Thimphu

Dorji W, Bajracharya SR, Kunzang K, Gurung DR, Joshi SR, Mool PK (2001) Inventory of glaciers and glacial lakes and glacial lake outburst floods monitoring and early warning systems in the Hindu Kush-Himalayan Region Bhutan. ICIMOD and UNEP, Kathmandu

George AL, Bennett A (2004) Case studies and theory development in the social sciences. Harvard University Press, Cambridge

Global Environment Facility (2008a) Project identification form: reducing climate change-induced risks and vulnerabilities from glacial lake outburst floods in the Punakha-Wangdi and Chamkhar Valleys. GEF, Washington, DC, February 6, GEF Agency Project ID 3722

Global Environment Facility (2008b) Request for CEO endorsement/approval: reducing climate change-induced risks and vulnerabilities from glacial lake outburst floods in the Punakha-Wangdi and Chamkhar Valleys. GEF, Washington, DC, February 6, GEF Agency Project ID 3722

Ives JD, Shrestha RB, Mool PK (2010) Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment. International Center for Integrated Mountain Development, Kathmandu

Karma T, Ageta Y, Naito N, Iwata S, Yabuki H (2003) Glacier distribution in the Himalayas and glacier shrinkage from 1963 to 1993 in the Bhutan Himalayas. Bull Glaciol Res 20:29–40

Komori J (2008) Recent expansions of glacial lakes in the Bhutan Himalayas. Quatern Int 184:177–186
Meyer MC, Hoffmann CC, Gemmell A, Haslinger E, Hausler H, Wangda D (2009) Holocene glacier fluctuations and migration of neolithic yak pastoralists into the high valleys of Northwest Bhutan. Quatern Sci Rev 28:1217–1237
National Environment Commission (2008) Bhutan National Adaptation Program of Action. Royal Government of Bhutan, Thimphu
National Environment Commission (2009) Strategizing climate change for Bhutan. National Environment Commission, Royal Government of Bhutan, Thimphu
Nayar A (2009) When the ice melts. Nature 461:1042–1046
O'Sullivan E, Rassel GR, Berner M (2010) Research methods for public administrators. Pearson Longman, New York
Saxena KG, Maikhuri RK, Rao KS (2005) Changes in Agricultural Diversity: Implications for Sustainable Livelihood in the Himalaya. JMS 2(1):23–31
Tschering D, Sithey G (2009) Climate and health in Bhutan. Tiempo 71:24–26
Tshiteem K (2009) Climate change adaptation experience of Bhutan. Gross National Happiness Commission, Royal Government of Bhutan, Thimphu
Uddin SK, Taplin R, Xiaojiang Yu (2007) Energy, Environment, and Development in Bhutan. Renewable Sustainable Energy Rev 11:2083–2103
United Nations Development Program (2010) Understanding sectoral impacts of climate change: an attempt to understand the changing Bhutanese communities. UNDP Bhutan, Regional Climate Risk Reduction Project, Thimpu
World Bank (2010) Bhutan economic update 2010. World Bank Group, Washington, DC
Young LJ (1991) Agricultural changes in Bhutan: some environmental questions. Geog J 157(2):172–178