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Knowledge Sharing for Disaster Risk Reduction: Insights from a Glacier Lake Workshop in the Ladakh Region, Indian Himalayas

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Small glacier lakes are distributed in the Ladakh Range in northwestern India. This area has experienced several glacier lake outburst floods (GLOFs) since the 1970s, damaging settlements along streams. To reduce GLOF risk through a knowledge-based approach focused on nonstructural measures, we held a workshop in May 2012 for residents of Domkhar Village in the northwestern part of the Ladakh Range. More than 100 villagers participated in the workshop, which conveyed useful disaster information to participants while enabling the researchers to understand local knowledge and beliefs about floods. A survey conducted 3 months later confirmed an improvement in residents' knowledge of natural disasters. The researchers also learned useful lessons, such as the need to adjust the program design for diverse participants and the importance of clearly communicating disaster risks and supporting local residents' attempts to incorporate new scientific knowledge into existing local knowledge. Challenges to implementing flood countermeasures in this area included problems relating to land use and emergency communications and the need for coordination of efforts by the government and local residents.

Keywords: *Glacier lake outburst flood; disaster risk reduction; disaster preparedness; indigenous knowledge; local community; Ladakh.*

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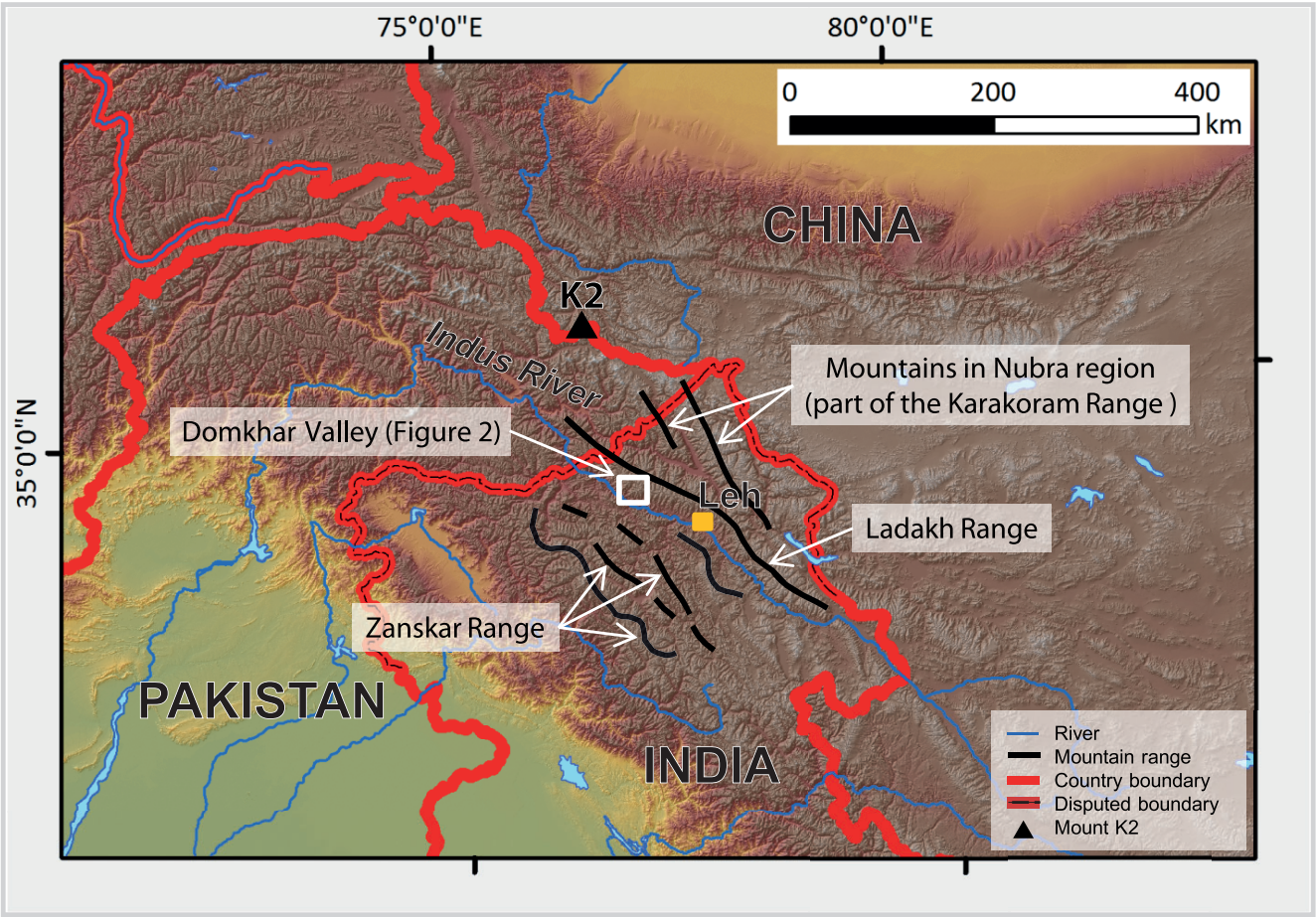
Introduction

Natural disasters in the Ladakh region in northwestern India have included glacier lake outburst floods (GLOFs), which have occurred frequently since the 1970s, as well as flash floods triggered by torrential rains, such as those in August 2010 (Ikeda 2012; Rasmussen and Houze 2012; Thayyen et al 2013). Particularly in recent years, mountain glaciers have been shrinking (Kamp et al 2011; Kääb et al 2012), and numerous lakes have formed in front of glaciers from the accumulation of melted water (Narama et al 2015). The glacier lakes in the Ladakh Range are relatively small compared to the large proglacial lakes in the eastern Himalayas (Mool et al 2001; Ukita et al 2011), but GLOFs have caused severe damage in the Ladakh Range in the past. For instance, in 1971, drainage of a glacier lake 18 km upstream from Nymmo Village, on the southwestern side of the Ladakh Range about 23 km west of Leh (34°10′00″N; 77°35′00″E), the largest city in Ladakh, sent floodwaters crashing into residential areas along the stream, leading to 13–16 deaths according to statements of the villagers. In 2003, a GLOF occurred in Domkhar Village, about 80 km west of Leh, causing damage to bridges, water mills, and farmland (Narama et al 2011). In July 2011, another GLOF hit Talis Village in Pakistan, just north of the Ladakh Range, destroying about 130 houses that stood on the alluvial fan and damaging agricultural fields (OCHA 2011).

Previous analysis of GLOFs in Central Asia and the western Himalayas revealed that the scale of damage (disaster) is not necessarily determined by the size of the glacier lake outburst (hazard). The discharge in the 1998 GLOF in Gissar-Alay in Central Asia, which claimed more than 100 lives, was around 10% of that recorded for the 2008 GLOF in the Tien Shan Mountains, which claimed only 3 lives (UNEP 2007; Narama et al 2010). The scale of damage is significantly affected by the social vulnerability of a community, and knowledge about GLOFs can reduce that vulnerability. There were as many as 266 glacier lakes in the Ladakh Range as of 2014 (Narama et al 2015). Implementing structural disaster-prevention measures (such as stream embankments) for each is unrealistic. Thus, it is important to strengthen nonstructural approaches to disaster preparedness and mitigation (eg Gruntfest 2000; Garcia-Martinez and Lopez 2005) by

FIGURE 1 Location of Ladakh Range and Domkhar Valley in northwestern India. The disputed boundaries are not intended as an accurate reflection of territorial claims. (Map by Chiyuki Narama; image: Shuttle Radar Topography Mission [SRTM] digital elevation model [DEM])



improving community members' disaster awareness, knowledge, and response capacity.

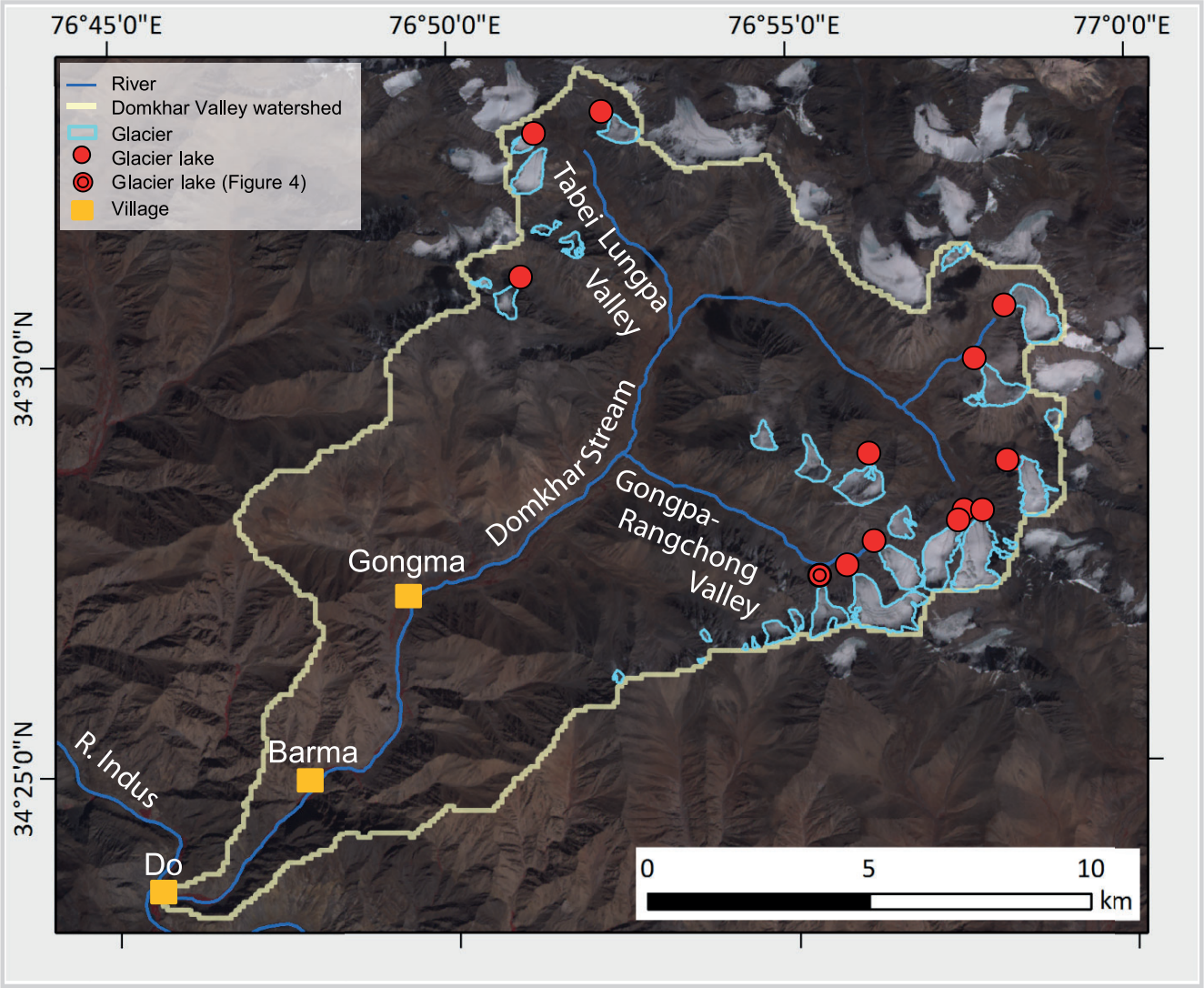
To discuss the problem of GLOFs with local residents, we held a workshop in May 2012 in Domkhar Village, in collaboration with the Ladakh Ecological Development Group, an environmental nongovernmental organization based in Leh. The primary objective of the workshop was to convey results of our research to the local residents based on a 2010 field survey on the status of glacier lakes in the Domkhar Valley, in conjunction with a survey on the appearance and expansion of these glacier lakes from an analysis of satellite images.

Another objective of the workshop was to understand local knowledge about GLOFs in the Ladakh region. A key factor in the success of efforts to promote scientifically based disaster preparedness in remote areas such as Ladakh is the ability to understand and work with local perceptions of the environment and to integrate scientific information and local knowledge (eg Alcántara-Ayala et al 2004; Zimmermann and Issa 2009; Mercer 2012). The importance of this has been recognized in international policy frameworks, namely the Hyogo Framework for Action 2005–2015 and its replacement, the Sendai Framework for Disaster Risk Reduction 2015–2030, adopted at the third World Conference on Disaster Risk Reduction in March 2015 (UNISDR 2007, 2015; Zimmermann and Keiler 2015). Furthermore, the usefulness of indigenous knowledge—including oral traditions, myths, and religious beliefs—has been confirmed in a number of disaster-management studies (eg Cashman and Cronin 2008; Hiwasaki et al 2015), and we believed it could play a similarly important role in our research.

Geographical overview

The alpine region of Ladakh has the Ladakh Range (total length: 380 km) at its center and includes the Zanskar Range as well as mountains with an altitude of 5000–6000 m in the Nubra region on the eastern edge of the Karakoram. Because the moisture carried by the westerlies and the Indian monsoon is blocked by the high peaks, the Ladakh region has an extremely dry climate. Annual precipitation in Leh (elevation 3500 m) is about 100 mm, with relatively high precipitation in the summer monsoon season. Maximum rainfall occurs in

FIGURE 2 Map of Domkhar Valley watershed. The white areas indicate glaciers. Only the boundaries of the glaciers inside the watershed are shown using light blue lines. (Map by Chiyuki Narama; image: Terra/ASTER image taken on 7 October 2006)



August (Yatagai et al 2011), and precipitation is low in autumn.

Domkhar Village is located in the northwestern part of the Ladakh Range in the Domkhar Valley (Figure 1), which has had 13 glacier lakes in its watershed, confirmed using satellite data for the period 2009 to 2011 (Landsat5/TM, ALOS/PRISM, and SPOT4). Most of these glacier lakes were formed in the 1960s or later. GLOFs have occurred at several of these glacier lakes since 2000, including some small-scale ones. Domkhar Village is made up of 3 smaller villages along the Domkhar Stream, which runs through the valley (Figure 2): Gongma has 81 households, Barma has 41, and Do, nearest to the stream's confluence with the Indus River, has 71. As of 2009, 193 households (1269 people) were administratively registered as residents of Domkhar Village (at public health centers in the village), and approximately half of these people were actual residents spending more than half of the year in the village (Yamaguchi et al 2013). Settlements in Domkhar Village are very close to the upstream glacier lakes. They have developed on flat places and gentle slopes such as colluvial footslopes, old alluvial cones, and river terraces formed by the riverbed's fluvial erosion (Figure 3).

The glacier lake workshop

In October 2011, we met with the headman and other residents of Domkhar Village to propose a workshop on glacier lakes and GLOFs in which we would share scientific information (Figure 4), villagers would share their own perceptions and knowledge

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FIGURE 3 Domkhar-Gongma village. Houses and agricultural fields are situated close to the stream on the slopes of old alluvial cones and colluvial footslopes. (Photo by Chiyuki Narama, 7 September 2012)

and respond to the information presented by others, and future flood countermeasures would be discussed.

The villagers agreed, and on 30 May 2012, we held the workshop at the Gongma community hall (Figure 5). About 120 people participated, including more than 100 villagers, the authors, and other scholars and development specialists from the Ladakh Ecological Development Group staff, who worked as group discussion facilitators and interpreters between English and the local language, Ladakhi. Half of the local participants were from Gongma Village, and the other half were from the downstream villages of Barma and Do. Participants represented a wide range of age groups, including school children and the elderly. No significant bias was observed with respect to the male–female ratio.

In session 1 of the workshop, participants divided into 4 groups to discuss the following topics:

- The existence of glacier lakes in the headwater areas of the Domkhar Valley;
- How glacier lakes originate and what causes GLOFs;
- Flood countermeasures adopted up to that point.

One or two participants in each group wrote down the statements made and agreed upon by the group members on a sheet of paper.

In session 2, we presented basic information about glacier lakes and GLOFs and reported on our survey of glacier lakes in the Domkhar Valley, covering the following points:

- The effect of climate change on glaciers;
- What a GLOF is;
- The distribution, size, and recent condition of glacier lakes in Domkhar Valley;
- GLOFs that have occurred in the past in Domkhar Valley;
- A new glacier lake in Tabei Lungpa Valley (a tributary to Domkhar Valley);
- Potential disaster risk reduction measures in relation to GLOFs.

A booklet summarizing the contents of this session in Ladakhi and English was distributed to all participants.

In session 3, participants again gathered in groups and discussed what they had just learned, as well as possible countermeasures against future floods. In session 4, a representative from each of the 4 groups presented the

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BOX 1: Factors shaping local perceptions of glacier lakes

Villagers' knowledge and perceptions of glacier lakes are influenced both by their religious beliefs and their observations of nature.

- *Religious beliefs:* The Gongpa-Rangchong Valley is home to a temple and sacred place visited by pilgrims. Participants of one of the 4 discussion groups mentioned a belief that sacred horses and sheep lived at lakes in the headwater areas of Gongpa-Rangchong Valley, and that floods or other disasters would occur if these animals were offended. This belief was also mentioned by 5 of the 60 people (in their 50s to 80s) interviewed during the survey. Some of them said they shared it. Furthermore, the participants of the same discussion group also noted that they could see Tibetan temples and landscape reflected on the surface of lake. References to scenery reflected on a lake surface occur frequently in the religious culture of the Ladakh region.
- *Observations:* Of the 60 people interviewed during the survey, 12 described the natural environment around the lake areas in detail, mentioning, for example, that there were fish in the lake or birds near it, as well as mosquitoes and bees, but no grass, or that the lake would freeze in the winter. Furthermore, 4 interviewees stated that if a spang-gok (lump of earth covered by vegetation in front of the lake) moves, it means that a GLOF may happen, revealing that some villagers are aware that the phenomenon is a symptom of potential flooding from glacier lakes. Such knowledge is of relevance in designing disaster risk reduction measures.

results of that group's discussion; this was followed by a plenary discussion on GLOF-related disaster risk reduction measures for the village.

Three months later, in September 2012, we revisited Domkhar Village and conducted a survey, asking about villagers' understanding of information provided during the workshop, and additional questions on local knowledge and perceptions about glacier lakes, GLOFs, and flood damage countermeasures. The survey was intended to assess the workshop's effectiveness and to gain additional information about local knowledge and perceptions. Survey interviews were conducted with the assistance of an interpreter. Sixty people, 20 from each village, were randomly selected for interviews while we walked through the villages. The interviewees included 8 people from Gongma and 4 each from Barma and Do who had participated in the workshop; the other 44 interviewees had not attended the workshop. The next section summarizes results from the workshop and survey.

Results

Residents' awareness before the workshop

Most villagers knew of some but not all of the glacier lakes in the valley—primarily those closest to the regular routes used in their daily lives, such as near pasturelands in the headwater areas and along trade routes to the adjacent valleys. Half of the glacier lakes in Domkhar Valley began to emerge in the 1960s. Local herders were the first to visit some of them, mainly in tributaries such as Gongpa-Rangchong Valley within Domkhar Valley, and they told other villagers. (It is unclear which of the 3 glacier lakes in Gongpa-Rangchong Valley identified by our research these herders visited.) Some Domkhar villagers came to think of these lakes as sacred places; this belief is still alive among some villagers, especially older people.

The villagers' perceptions of the glacier lakes also contained items based on their observations of the natural environment in parallel with those based on such religious belief (see Box 1).

Regarding the origin of glacier lakes, many people were aware that they are formed by water from glaciers or snowmelt runoff. Some villagers attributed the lakes' emergence to the rise in air temperatures (global warming) and the consequent increase in snowmelt. These statements attest that some villagers' perceptions of the origin of glacier lakes have a basis in scientific knowledge. However, their perceptions also contained some ambiguity with respect to the distinction between glaciers and snow.

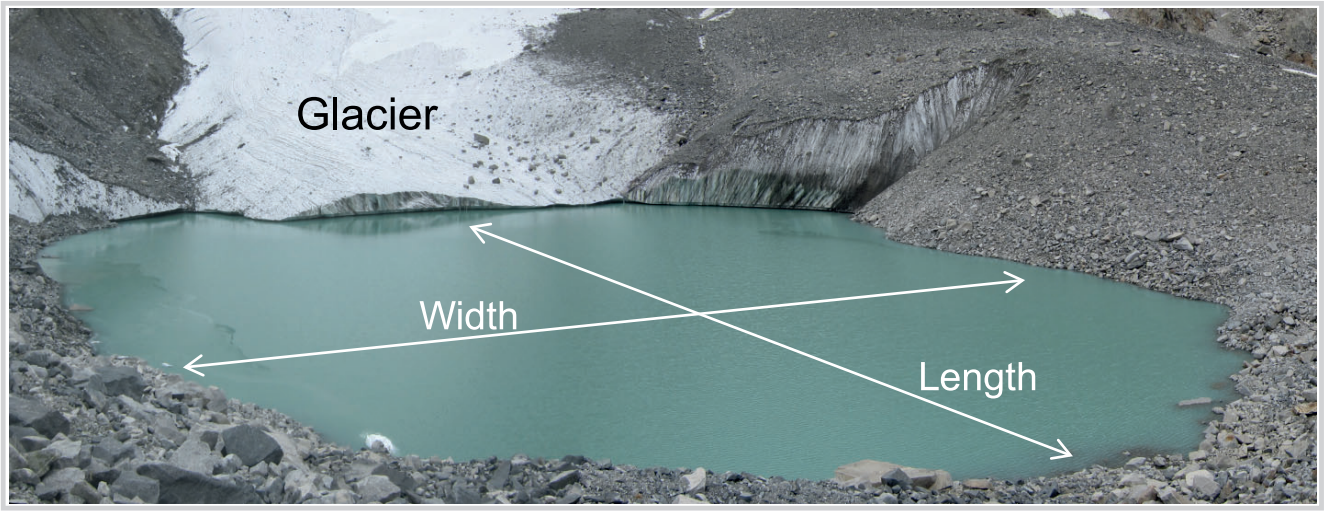
Regarding GLOFs, some villagers comprehended that these were different from floods caused by rain or snowmelt. They identified characteristics such as the suddenness of the discharge, presence of dead fish, and a pungent odor as specific to floods caused by the drainage of lake water. In addition, the results of the survey revealed that some villagers were aware of the danger of GLOFs in Gongpa-Rangchong Valley, and that there has been widespread discussion of the extent of the risk and the magnitude of potential damage, indicating significant fear of this threat among residents of Domkhar Valley.

Regarding potential countermeasures, responses differed in whether they emphasized a religious approach (such as conducting rituals or building pagodas) or focused on practical protective measures such as construction of revetment walls and improvement in land use. Conventional wisdom on flood preparedness in the Ladakh region includes never building houses or planting trees by a stream (because uprooted trees can block the water during a flood). Some villagers proposed building protective walls on the stream banks. However, most of them also stated that protective walls constructed by the government would be easily broken during a flood. Many villagers believed that no effective measures could be undertaken in advance to prevent a flood.

Workshop participants' feedback

On the whole, participants attentively followed the 2 hour presentation. Afterward, they assessed it in group discussions focused on whether they had obtained new

FIGURE 4 One of the glacier lakes located in the Gongpa-Rangchong Valley. This lake is 185 m long, 175 m wide, and 39 m deep. It is the second largest glacier lake in the Domkhar Valley, with a water volume of 410,000 m^3 estimated by bathymetric survey. (Photo by Chiyuki Narama, 10 September 2010)



information, whether there were things about which they wanted to learn more, whether the explanations were reasonably understandable, and what they thought of the booklet summarizing the session 2 (external experts') presentations.

The presence of as many as 13 glacier lakes in Domkhar Valley, and the sudden emergence of a new one in 2011 represented new information for participants. They showed great interest in information about the specific sizes and geographic locations of the glacier lakes in the valley. Some participants commented that they had understood for the first time the underlying process of lake water drainage, and the fact that several of the recent floods they had experienced had been triggered in this way.

Participants expressed the desire to learn more about the emergence of the new glacier lake, the general process from the formation of a glacier lake to the water draining from it, and the risk of flooding from each glacier lake in the valley. Some people indicated that it was difficult to understand one of the figures in the booklet, which showed the transformation processes of glacier lakes. Nevertheless, the booklet was favorably received by participants. This was mostly due to its publication in the local language as well as English and to the abundant use of photographs.

Discussions on GLOF disaster risk reduction measures

During the second half of session 3 and all of session 4, discussions focused on potential flood countermeasures. Group discussions were followed by a session in which each group presented its findings to the workshop as a whole. Next, a general discussion was conducted involving all participants. Participants adopted a set of resolutions, covering actions by villagers to prepare for and prevent disasters and to respond during them. The "Villagers' resolutions" included the following 7 items:

1. A glacier lake monitoring committee, staffed by villagers on a rotating basis, should be established to keep watch on the glacier lakes.
2. Villagers should inform each other whenever they notice a sudden rise in the level of the stream water.
3. People living near the stream should run for safety immediately when a rise in the water level is noticed, without stopping to retrieve valuables from their homes.
4. Villagers should discourage new construction near the banks of streams.
5. Villagers should identify safe spots in or near the village for use as a refuge during floods and should make an evacuation plan.
6. Villagers should frame social and customary rules to refrain from tree planting along streams.
7. Villagers should set up a communication network to inform people downstream and in the hamlets inside each village area of an emergency.

Residents' awareness after the workshop

In the survey conducted 3 months after the workshop, Domkhar villagers were asked what they had learned from the workshop and booklet and what they were currently doing to prepare for floods.

Of the 60 survey respondents, 34 stated that they had acquired new information from the workshop and booklet and described it in detail. Among them, 18 had not participated in the workshop. This showed that information from the workshop and booklet had reached villagers who had not attended the workshop. New knowledge included the following:

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FIGURE 5 Domkhar villagers (A) attending a workshop session; (B) reviewing the booklet provided during the workshop. (Photo by LEDeG, 30 May 2012)

- The existence and characteristics of lakes in the headwater areas of the Domkhar Valley, including the number of lakes and their size and depth (mentioned by 12 workshop participants and 14 nonparticipants);
- The process by which GLOFs occur (2 workshop participants and 2 nonparticipants);
- The need to evacuate swiftly and to inform neighboring villages and those living downstream of a flood (4 workshop participants and 4 nonparticipants);

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- Information on the risk of GLOFs in the Domkhar Valley (4 workshop participants and 8 nonparticipants).

It seems reasonable to say that the workshop and booklets impressed on some of the residents the importance of timely communication and evacuation. In regard to the risk of GLOFs, responses were more mixed. Some interviewees presented accurate perceptions, such as "I understood that a flood can occur even on a clear day" and "I came to know that there is a risk of flooding from a lake." However, some responses indicated inaccurate understanding, such as "The lake is not dangerous"; "I learned that there is no risk of flooding from a lake"; and "There is only one lake that has a risk of flooding." With respect to the correlation between weather and floods, some individuals' responses revealed fragmentary and incomplete recognition, such as, "There is a danger of a lake outburst on bright sunny days," and "One must be careful about a lake outburst when it rains." Almost all the people who made inaccurate comments had not participated in the workshop.

With regard to flood preparedness, 27 of the 60 people interviewed specifically described what they already had been doing. Of these, only 6 people expressed high motivation and positive support for flood countermeasures, saying, for example, that they were prepared for timely communication and/or evacuation in case of a flood, that they were regularly observing stream conditions, or that they were following the advice not to build houses or plant trees on stream banks. On the other hand, quite a few among the 27 people offered rather negative responses about prevention, such as "Nothing else has been done so far apart from building protective walls on the stream bank." Furthermore, 33 people, or more than half of the 60 interviewed, responded that they had not made any particular preparation for flooding. This result confirmed that many residents, despite their awareness of the problem, were not taking the initiative to carry out effective flood countermeasures by themselves, a situation similar to that before the workshop.

Challenges in disaster mitigation

Effective communication of risk and risk reduction measures

Survey responses indicated that some of the workshop's messages were effectively communicated to the participants. They understood the importance of routine monitoring as well as emergency responses like evacuation and communication. They held on to and readily shared the key messages repeatedly conveyed during the workshop, such as "A flood can occur even on a clear day," "One must evacuate if the level of water in the stream rises," and "In the event of a flood, one must alert the people downstream," underscoring the fact that using simple messages like these is important in sharing knowledge on disaster risk reduction. While the participants showed great interest in natural phenomena like glacier lakes and the dynamic process of how hazards like GLOFs emerge, it was still difficult for them to understand these complex processes through a single presentation. This highlights the need to adjust program design for different audiences. Moreover, it is important to follow up with past participants as well as other interested people by offering further opportunities to learn.

Also important are people's views toward the risk of a disaster. Workshop participants were informed that there was a chance of future GLOFs in the Domkhar Valley but that it was difficult to predict when this might occur. However, among people who had not participated in the workshop, some held inaccurate perceptions of the risk of GLOFs, for example, that there was no risk or that there was only one dangerous lake. As the survey results indicated, most residents of Domkhar Valley already feared that a GLOF could occur. Hence, it can be inferred that some residents might have interpreted fragmentary second-hand information received from workshop participants in a simplistic manner to ease their psychological burden. It is important to find ways to effectively convey to every member of the community the concept of a disaster risk that cannot be clearly quantified.

It also became evident through this workshop that Domkhar villagers' knowledge and perceptions of glacier lakes and GLOFs reflected multiple influences: their religious beliefs, their experiences of past floods, their science educational background, and their own observations of nature. This agrees with the analysis by Mercer (2012: 99) that the knowledge inside a community is "dynamic and reactive to global change." Thus, in Ladakh, there seems to be some flexibility in the attitude of local residents toward new knowledge related to disaster mitigation from outside their communities. It is also important to support local residents' attempts to incorporate new information into their existing knowledge base, so that all knowledge is used appropriately and effectively.

Implementation of flood countermeasures

Another challenge is implementing the flood countermeasures proposed during the workshop. Local technological and economic conditions make it difficult for villagers to implement most of these measures on their own. For example, there are no legal restrictions on land use by village residents, and it is difficult for restrictions on building and planting to function effectively based on nonbinding customary laws. Even after the August 2010 flood in Ladakh, some people continued living on flood-prone land (eg along the stream and on the alluvial fan)

because they had customary or legal ownership of the land and could not afford to move. Likewise, it is not easy to regulate the location of new houses in Ladakh because the region is rugged and mountainous, and flat land is limited. Population growth and its increasing concentration in the vicinity of Leh (Goodall 2004; Ikeda 2012) also complicate land-use planning.

An effective disaster communication system requires appropriate facilities and equipment. However, because of the mountainous terrain, many settlements in Ladakh do not have access to stable telephone networks (either landline or mobile) reliable at all times, and existing service was disrupted over a wide area for at least about a half month due to the damage to the telecom facilities caused by the 2010 floods (Anonymous 2010a, 2010b; Ikeda 2012). This demonstrates the local infrastructure's severe vulnerability to disasters (TISS-LAHDC 2010; DCO 2011; Ikeda 2012). In some settlements, satellite phones may be available, but these are few in number (there was only one available in Domkhar Valley as of 2012), and at present they cannot be relied on for rapid communication from upstream to downstream locations within the valley.

As is clear from these cases, it is as important to improve legal and telecommunication systems as it is to promote local residents' disaster preparedness and response abilities. For example, effective long-term land use in Ladakh requires coordination between the disaster management plan for the region and development plans for both urban and rural areas. This requires robust leadership by the government, and that should be accompanied by effective measures to improve socioeconomic conditions of the local residents living on hazard-prone lands (see also Zimmermann and Issa 2009; Le Masson 2015; Zimmermann and Keiler 2015).

Since the 2010 flooding, there has been an increase in support for disaster risk reduction in Ladakh. However, the local government, the Ladakh Autonomous Hill Development Council, has focused primarily on structural countermeasures such as embankments along major streams (Ikeda 2012). More attention needs to be paid to combining structural and nonstructural measures (eg Gruntfest 2000; Zimmermann and Issa 2009), with discussions about the challenges and possible solutions supported by the government, and the multiple initiatives undertaken separately by the government and local residents coordinated for greater effectiveness.

Conclusion

This study documents lessons learned from a disaster mitigation workshop in Domkhar Valley in the Ladakh region of India, during which a large amount of information was conveyed to village residents, including on the location and current status of glacier lakes in Domkhar Valley. Detailed information about disasters was conveyed through lectures, slide shows, and bilingual booklets provided to all participants. The results of a survey conducted 3 months after the workshop indicated that it increased residents' awareness of countermeasures in relation to GLOFs. This suggests that participatory community workshops are an effective way to promote disaster mitigation in this region, and we hope to organize similar workshops that can respond to challenges that we learned about from this study.

It is important to continue exploring improved means of disseminating information to Ladakh residents through workshops and to refining a system through which the deepening and anchoring of disaster mitigation knowledge could be facilitated in the local community. To this end, it is essential to identify and develop local leaders who can promote disaster mitigation activities in their communities with attention both to existing local knowledge and to scientific knowledge from outside the community. It is also important to understand how local cultural and religious values affect perceptions of the natural environment and of natural disasters, so as to ensure that disaster preparedness and mitigation knowledge is presented in a way that is readily acceptable to the community.

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