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FOR MOUNTAINS AND PEOPLE

Glacial Lakes and Associated Floods in the Hindu Kush-Himalayas

INFORMATION SHEET #2/10

It is now generally accepted that climate warming is having a significant impact on the Himalayas. One of its effects is that glaciers are thinning and retreating throughout much of the region. This is accompanied by formation of melt-water lakes, both on the glacier surface and in front of them. Already several, like Imja Lake and Tsho Rolpa, are more than two kilometres long and about 100 metres deep. Glacial lakes are usually dammed by end moraines; these are mounds of rubble carried down the valley by glaciers and deposited as ridges when the glaciers were much larger than today. Because the moraines are not well consolidated and frequently contain an ice core that is also melting they are often unstable. This means that glacial lakes are in danger of bursting their moraine dams to cause a catastrophic flood (GLOF) in the valley below. Several outbursts have already occurred with attendant loss of life and property, although it should be noted that the actual threat is often exaggerated.

Following identification of lakes that pose a threat, measures can be taken to reduce the danger and install early warning systems. Glacial lakes can also be beneficial, both as new sources of water and hydro-electricity. Their identification and management requires good cooperation with the local people.

The Hindu Kush-Himalayan (HKH) region embraces the greatest agglomeration of high mountains and plateaus in the world. It consists of many distinct but inter-connected mountain ranges and plateaus extending for about 3,500 km from the Hindu Kush of Afghanistan and Pakistan in the northwest, through the Himalayas of India, Nepal, and Bhutan in the central part, to the Hengduan Mountains in southwest China in the east. It contains the world's highest mountains, many above 8,000 metres, together with the world's greatest areal extent and volume of permanent ice and permafrost outside the polar regions. Without doubt, it is central for any understanding of the effects of the current climate warming. One special element of the process of climate warming is its impact on the glaciers, and especially on the development of potentially dangerous glacial lakes within the Hindu Kush-Himalaya region.

Glacial lakes and glacial lake outburst floods

With the onset of climate warming about 1850-1905 (generally considered as the end of the Little Ice Age), many glaciers throughout the world, including in the HKH region, began to thin and their termini to retreat. This has led to the creation of many glacial lakes. The lakes of interest at present are those that form on the surface of the terminus end of a

Potentially dangerous glacial lakes: Tsho Rolpa, eastern Nepal, in 2009 (above); Raphstreng Tso, Bhutan in 1999 (below).
(Right) Remains of past glacial lake outburst event: landslides, bank erosion, and damaged trails from the Nare GLOF (1977) as seen in 2009

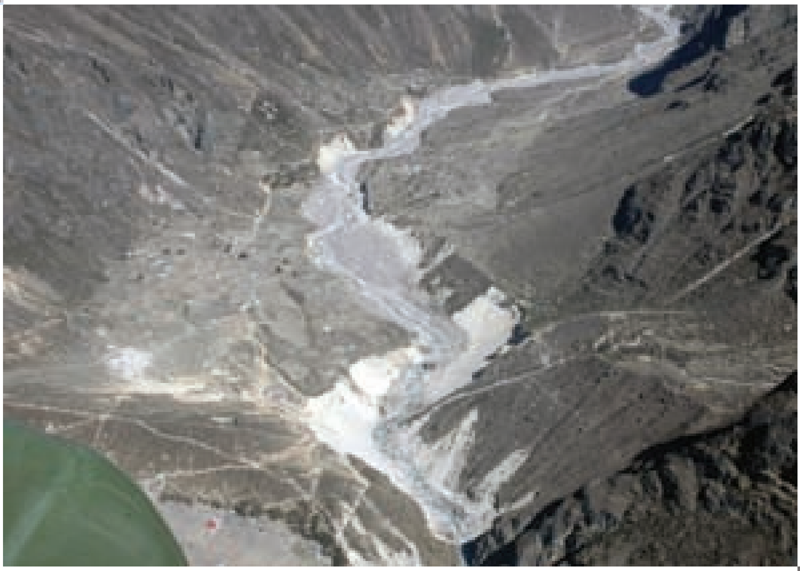
glacier or in the depression exposed between the retreating glacier front and its end moraine (formed when glaciers advanced during the Little Ice Age and deposited debris carried down within the glaciers or on their surface).

Glacial lakes are potentially unstable because their end moraines are composed of unsorted and unconsolidated boulders, gravels, sands, and clays. Furthermore, they are frequently reinforced by frozen cores (permafrost) that, like the glaciers themselves, are now beginning to melt. As the volume of a lake that is accumulating behind an end moraine increases, hydrostatic pressure builds up to put additional stress on the moraine dam causing it to become more unstable. Eventually it may fail and release much, or all, of the lake water. Depending on the manner in which the dam fails, the ensuing outbreak of water can be sudden and highly dangerous to people and infrastructure located downstream. The surging flood water will often have the energy to entrain large masses of loose material (boulders, gravel, sand, and clay, as well as any broken masonry or torn out trees) as it is propelled down-valley. The resulting cataract is known as a glacial lake outburst flood (GLOF).

The degree of destruction caused by a GLOF will depend on many factors, especially the original volume of water in the lake and the rapidity and completeness of the drainage. The latter will be influenced by the level of instability of the moraine dam and, therefore, its rate of collapse. Some lakes may drain quite slowly and so prove comparatively harmless; others may empty within a very short time (hours) and be catastrophic.

The actual failure of the moraine dam may be influenced by many factors (triggers). Ice or snow avalanches, or rockfalls (landslides) may cascade into the lake from adjacent precipitous mountain walls to cause a surge wave in the lake that overtops the dam. Seepage of water though the dam, especially where the ice core is melting, may undermine the unconsolidated materials and cause a total or partial collapse – the resulting discharge of large volumes of water will then accelerate failure of the dam. The lake level may rise due to the inflow of an increasing amount of meltwater until it overflows the dam at its lowest point and thereafter erodes a channel through it. Several of these processes may act together.

Catastrophic glacial lake outbursts have occurred in many mountain ranges throughout the world and, in some instances, have caused extensive damage and loss of life



further downstream. The HKH region is no exception. If climate warming continues, as is predicted, accelerated glacier thinning and retreat is likely. Thus the danger posed by GLOFs will increase. The HKH region is also one of extreme seismic instability. Earthquakes could act as major triggers for glacial lake outbursts. Earthquake prediction is in its infancy and not likely to assist in GLOF risk assessment in the near future. Nevertheless, the earthquake hazard makes the identification of potentially unstable glacial lakes that much more critical. GLOF risk assessment has become an issue of great urgency.

Glacial lake outburst floods in the HKH

Awareness of glacial lake outburst floods in the HKH region is derived from the memories of local people and from incidentally documented evidence. However, the precise location, frequency, and actual scale of their effects are not adequately known. Scientific investigation has revealed that a glacial lake outburst flood occurred along the Seti Khola about 450 years ago. It produced a debris deposit, up to 50 metres deep, that mantled an extensive area of the Pokhara valley in western Nepal. It appears that glacial lake outbursts have occurred more frequently during the last fifty years, for example, the following.

On 11 July 1981, the diversion weir at the Sun Koshi Hydro-electricity Project, Nepal, was struck by a large flood and incurred significant damage. The flood also destroyed two bridges and extensive sections of the Arniko Highway, resulting in some U.S. $3 million in damages. It was later realised that the flood resulted from the outbreak of the Zhangzangbo (Boqu) glacial lake in Tibet, China. On 4 August 1985, an outburst flood from Dig Tsho glacial lake in the Khumbu Himal, Nepal, destroyed the nearly completed Namche Small Hydel Project and caused additional extensive damage farther downstream. On 7 October 1994, a glacial lake outburst flood occurred from Lugge Tsho 90 kilometres upstream of Punakha Dzong in Bhutan; the resulting deluge along the Pho Chhu river caused extensive material damage and some loss of life. GLOF events can propagate for considerable distances downstream and are thus liable to cross international boundaries. This has implications both for warning and for assessing responsibility (if any) for loss of life and damage to property.

Despite the scale of the risk associated with a GLOF, mitigation is possible, for example through artificial lowering of the water level (draining) and installation of early warning systems. Furthermore, given adequate mitigation measures, the glacial lakes can be regarded as a form of water storage and valuable potential source of water and hydroelectric power.

ICIMOD and the study of GLOFs

ICIMOD embarked on studies of glaciers and glacial lakes in 1985, with an assessment of the Dig Tsho outburst. In 1999, ICIMOD started preparation of an inventory of glaciers and glacial lakes, and identification of potentially dangerous lakes, using a combination of remote sensing images and published maps. The survey of Nepal and Bhutan was completed in 2001 and later extended to selected watersheds in China (Tibet AR), India, and Pakistan, working in collaboration with the national institutions of the countries concerned. Potentially dangerous lakes were identified using criteria such as large and rapidly expanding lake size, rise in lake water level, activity of supra-glacial lakes, position of lakes in relation to moraines and associated glaciers, dam stability, glacier condition, and surrounding physical conditions. Altogether 8790 glacial lakes were mapped, of which more than 200 were identified as potentially dangerous. The inventory is now being updated and extended to the entire HKH region.

More recently, methods for assessing and mapping the vulnerability of downstream communities have been developed and are being used to prioritise lakes of most concern. A 2009 study using remote sensing data and other information identified 1466 glacial lakes in Nepal of which

six were classified as potentially dangerous and requiring detailed field investigation. Detailed field investigations were made of three lakes (Imja, Thulagi and Tsho Rolpa). In all three, the immediate risk of dam break was found to be lower than previously reported, although they should be monitored regularly. The socioeconomic assessment showed a high risk of damage if an outbreak were to occur. Comparable investigations should be extended to other areas of the HKH region in collaboration with member countries.

ICIMOD team and partners investigating Imja lake (left); Taal village, Marshyangdi in the flood path downstream of Thulagi lake (above)

Future outlook

As new glacial lakes are being created and existing ones continue to grow, the issues of risk assessment, early warning systems, and mitigation measures to reduce impact are becoming ever more important. It is vital to identify potentially dangerous glacial lakes and the risks they pose, and highlight the critical ones. Planners, policy makers, development workers, and scientists need to develop and implement appropriate mitigation measures including the implementation of early warning systems. Collaboration with local people is essential.

Given the enormous extent and poor accessibility of the HKH region, use of remote sensing is essential for identification of those lakes that require detailed investigation. A repeat monitoring system using time series satellite images is necessary to identify changes over time. Detailed glaciological and geotechnical field investigations of priority lakes are needed to determine the real degree of glacial lake instability, and socioeconomic assessment with modelling of the downstream flood path to discover the likely risk. Only then can effective preparedness and mitigation measures be implemented.

Dig Tsho glacial lake in 2009 after the GLOF event of 1985 (right); satellite image of the Bhutan Himalayas (below) (Source: NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team)

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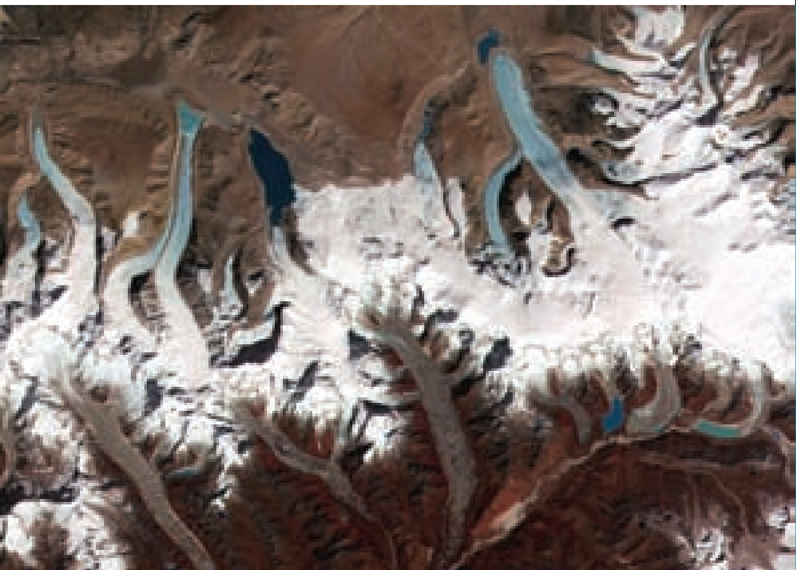

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Front photo: Lumding Tsho, Dudh Koshi valley, Nepal 2009
Photos: Sharad P Joshi
except p2 Bhutan ICIMOD archive, p4 satellite image NASA

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