Impact of climate change on Himalayan glaciers and glacial lakes: Case studies on GLOF and associated hazards in Nepal and Bhutan

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Foreward

The Himalayas have the largest concentration of glaciers outside the polar region. These glaciers are a freshwater reserve; they provide the headwaters for nine major river systems in Asia – a lifeline for almost one-third of humanity. There is clear evidence that Himalayan glaciers have been melting at an unprecedented rate in recent decades; this trend causes major changes in freshwater flow regimes and is likely to have a dramatic impact on drinking water supplies, biodiversity, hydropower, industry, agriculture and others, with far-reaching implications for the people of the region and the earth's environment. One result of glacial retreat has been an increase in the number and size of glacial lakes forming at the new terminal ends behind the exposed end moraines. These in turn give rise to an increase in the potential threat of glacial lake outburst floods occurring. Such disasters often cross boundaries; the water from a lake in one country threatens the lives and properties of people in another. Regional cooperation is needed to formulate a coordinated strategy to deal effectively both with the risk of outburst floods and with water management issues.

The International Centre for Integrated Mountain Development (ICIMOD) in partnership with UNEP and the Asia Pacific Network and in close collaboration with national partner organisations documented baseline information on the Himalayan glaciers, glacial lakes, and GLOFs in an earlier study which identified some 200 potentially dangerous glacial lakes in the Himalayas. The study published here builds upon these past initiatives and investigates the impact of climate change on selected glaciers and glacial lakes.

The publication provides an account of glacier retreat and growth of glacial lakes in two selected river sub-basins, one in Nepal and one in Bhutan. It describes important methodological aspects of assessing the vulnerability for GLOF hazards based on empirical data and evidence. It also investigates the possibility of devising a method for regular temporal monitoring of glacial lakes in remote and inaccessible mountain locations using satellite-based techniques. The results provide a basis for the development of monitoring and early warning systems and planning and prioritisation of disaster mitigation efforts that could save many lives. The report also provides useful information for those concerned with water resources and environmental planning.

Preface

In the face of global warming, most Himalayan glaciers have been retreating at a rate that ranges from a few metres to several tens of metres per year, resulting in an increase in the number and size of glacial lakes and a concomitant increase in the threat of glacial lake outburst floods (GLOFs). Such climate changes have ultimate effects on the life and property of the mountain people living downstream. While the effect of human activity on global climate is still being hotly debated, the retreat of glaciers in the Himalaya is compelling evidence of the need for action on climate change.

Approximately 15,000 glaciers (covering an area of 33,340 sq.km), and 9000 glacial lakes throughout Bhutan, Nepal and Pakistan, as well as selected river basins in China and India were documented in a baseline study conducted earlier by ICIMOD, UNEP, and the Asia Pacific

Network for Global Change Research (APN). Twenty-one GLOF events have adversely affected Nepalese territory in the recent past and to date over 200 potentially dangerous glacial lakes have been documented across the Himalayan region. These facts underline the urgent need to enhance scientific knowledge of glacier environments by continuously monitoring glaciers and glacial lakes, carrying out vulnerability assessments, implementing mitigation and adaptation mechanisms, and developing a glacial lake outburst flood (GLOF) early warning system. Regional co-operation to develop a coordinated strategy to deal with trans-boundary issues related to the impacts which can occur as a result of climate change is also required. This publication focuses on the effects of climate change on glaciers and glacial lakes in two hotspots of glacial activity in the Himalaya: the Dudh Koshi sub-basin of Nepal and the Pho Chu sub-basin of Bhutan. Both these basins have witnessed devastating GLOF events in the recent past. The GLOFs at Dig Tsho in 1985 (Nepal) and Luggye Tso in 1994 (Bhutan) are considered 'textbook' case studies of GLOF events and have drawn the attention of researchers world-wide. A multi-media CD-ROM is being prepared as a companion to this book and will be helpful in raising awareness about the sensitivity of climate change to policyand decision-makers, the concerned scientific community, and the general public. These materials will be helpful in designing mitigation measures to help safeguard human lives and valuable infrastructure in hazardous river valleys.

While this and other activities are helping to raise awareness of the risks posed by GLOFs, it will also be essential to replicate these studies and to continue to extend them systematically to include other high-risk areas in the Himalaya. The scientific modelling approaches and the empirical methods discussed here are both needed first steps that will be valuable in refining and scaling up this type of investigation to other Himalayan hot-spots. What is needed now is urgent action by the international community to help develop even better scientific understanding of the consequences of global climate change and to take the corrective and precautionary measures before it is too late.

This study, prepared in close cooperation with and supported by the United Nations Environment Programme Regional Office for Asia and the Pacific, investigates the impact of climate change on glaciers and glacial lakes in two major glacial hotspots in the Himalayas: the Dudh Koshi sub-basin in the Khumbu-Everest region in Nepal, and the Pho Chu sub-basin in Bhutan. The focus was on changes in the number and size of glacial lakes forming behind exposed end moraines as glaciers retreat, and the resulting potential threat of glacial lake outburst floods (GLOFs). The report aims to demonstrate methodological aspects of monitoring and potential GLOF hazard assessment using a case study approach. A hydrological model was used to calculate discharge and flood arrival times in downstream areas, and classification into terrain units was used to assess vulnerability in the vicinity of a possible Imja Tsho GLOF. Monitoring of glacial lakes in poorly accessible mountain locations using satellite-based techniques is also explored as a basis for monitoring and prioritisation of disaster mitigation efforts. The study recommends refinements and adaptation to the local situation when replicating in other areas. The report will be useful for scientists, planners, and decision makers, as well as for raising the awareness of the public at large to the potential impacts of climate change in the Himalayas.

Executive Summary

The global mean temperature is expected to increase between 1.4 to 5.8ºC over the next hundred years. The consequences of this change in global climate are already being witnessed in the Himalayas where glaciers and glacial lakes are changing at alarming rates. Himalayan glaciers are retreating at rates ranging from 10 to 60m per year and many small glaciers (<0.2 sq.km) have already disappeared. Our study shows that the terminus of most of the high altitude valley glaciers in Bhutan, China, and Nepal are retreating very fast; vertical shifts as great as

100m have been recorded during the last fifty years and retreat rates of 30m per year are common. As glaciers retreat, glacial lakes grow, and many Himalayan basins are reporting very fast growing lakes. A remarkable example is Lake Imja Tsho in the Dudh Koshi sub-basin (Khumbu–Everest region); while this lake was virtually nonexistent in 1960, it now covers nearly 1 sq.km and the Imja glacier which feeds it is retreating at an unprecedented 74m per year (between 2001 and 2006). Similar observations were made in the Pho Chu basin of the Bhutan Himalaya, where the change in size of some glacial lakes has been as high as 800 per cent over the past 40 years. At present, several supraglacial ponds on the Thorthormi glacier are growing quickly and merging. These lakes pose a threat because of their proximity to other large glacial lakes in the Pho Chu sub-basin where, in a worst-case glacial lake outburst flood (GLOF) scenario, they could cascade on to these other lakes with catastrophic consequences.

The study stresses the importance of methodologies used to assess glacier retreat, the expansion of glacial lakes and the impact of GLOFs. The hydrological modelling of glacial lakes, terrain classification, and vulnerability assessment are important scientific means to understand GLOF impacts. They help in devising mitigation measures and early warning systems. A dam-breach model developed by the National Weather Services (NWS-BREACH) was used to simulate the outburst hydrographs of Lakes Imja Tsho in Nepal and Raphstreng Tso in Bhutan. The model provides information on discharge and flood arrival time in downstream areas.

Based on observations of damage caused by the Dig Tsho GLOF of 1985, the vulnerability of various terrain units in the vicinity of a possible Imja Tsho GLOF was assessed. This terrain classification scheme provided valuable information on the possible extent of the damage to be expected in the event of an Imja Tsho GLOF. The vulnerability analysis in the Imja and Dudh Koshi valleys indicated that the upper terrace of the Syomare village as well as lower terraces identified in Ghat, Chutawa, Chermading, Phakding, Benkar, Tawa, and Jorsalle villages could be severely damaged by a GLOF event at Lake Imja Tsho.

GLOF mitigation measures and early warning systems applied in the Nepal and Bhutan Himalayas are also discussed. Such techniques are quite expensive and require much detailed field-work and maintenance, an alternative, which is being considered in a feasibility study, is regular temporal monitoring of glacial lakes by RADAR satellite-based techniques to detect any changes and provide an early warning.

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