

# Chapter 1

## Introduction to Inventory of Glaciers and Glacial Lakes

### 1.1 INTRODUCTION

Bhutan is a mountainous country, where mountains and hills occupy most of the land. Out of the 2,400 km long Himalayan range, the Bhutan Himalayas extend up to 340 km. The country is vulnerable to various hazards due to fragile geological conditions, great elevation differences, and steep sloping terrain. Apart from landslides and river erosion, the mountainous region is also quite susceptible to disastrous hazards due to glacial lake outburst floods (GLOFs). In general, the area above an elevation of 4,000 masl is mostly covered by snow and ice throughout the year. The glaciers, some of which consist of a huge amount of perpetual snow and ice, create many glacial lakes. These glaciers, as well as the glacial lakes, are the sources of the headwaters of many great rivers in the region. Most of these lakes are located in the down valleys close to the glaciers. They are formed by accumulation of a huge amount of water from the melting of snow and ice cover and by blockage of end moraines. The sudden break of the moraine may generate a discharge of large volumes of water and debris causing flooding.

In the last half-century, several glacial lakes have developed in the Hindu Kush-Himalayas and Tibetan Himalayas. This may be attributed to the effect of recent global warming. The glacial lakes are formed on the glacier terminus due to the recent retreating processes of the glaciers. The majority of these glacial lakes are dammed by unstable moraines, which were formed by the glaciations of the Little Ice Age. Occasionally, the lake happens to burst and suddenly releases an enormous amount of its stored water, which causes serious floods downstream along the river channel. This phenomenon, generally known as glacial lake outburst flood (GLOF), is recognised to be a common problem in Hindu Kush-Himalayan countries such as Nepal, India, Pakistan, Bhutan, and China (Tibet).

In Bhutan, the sources of its major rivers and the bulk of its freshwater resources are locked up in ice and snow. The advance of glaciers during the Little Ice Age has built up prominent end moraines in the Higher Himalaya of Bhutan in the headwaters of Mo Chu, Pho Chu, Mangde Chu, Chamkhar Chu, Kuri Chu, and Pa Chu. During the last few decades there has been a rapid retreat of glaciers creating many dangerous moraine-dammed lakes. In some glaciers (e.g. Thorthormi Glacier) small isolated lakes/ponds have formed. They are increasing in size at a very fast rate. It has been observed that some of the glaciers in Bhutan are retreating by about 20–30m in a year.

The first study on glacial lakes of Bhutan was done in the 1960s. However, until the GLOF of 7 October 1994 in Punakha–Wangdue Valley, the general public had little or no knowledge about the potential dangers of GLOFs. After an investigation into the causes of the 1994 GLOF, it was found that the moraine dam of the large Raphstreng Tsho was damaged due to a breach of Lugi Tsho Glacial Lake. As a result, the study of glaciers and glacial lakes in the Lunana region had to be taken up immediately. A number of teams were fielded to the area to find ways to mitigate the GLOF hazard. Subsequently, mitigation measures on Raphstreng Tsho were taken up to reduce the hydrostatic pressure on the weakened barrier. The work commenced in 1996 and was completed in 1998. In 1998 a Japan–Bhutan joint research team carried out an assessment of GLOFs in Bhutan. In 1999 an Austria–Bhutan expedition carried out integrated geophysical, hydrological, and geological investigations in the Lunana area with special emphasis on Raphstreng Tsho and Thorthormi Tsho.

One should be fully aware of the dangerous nature of large glacial lakes, especially if they happen to exist at the headwaters of rivers that flow through inhabited valleys or are harnessed for the generation of hydropower and/or for other purposes. It is an utter necessity to identify such lakes initially from the study of satellite images (and aerial photographs if available) and to assess their field conditions without delay. Some of these lakes may need only regular monitoring whereas a few may really need structural counter measures to reduce the inherent hazards they pose. As the Department of Geology and Mines of Bhutan (DGM) neither has the expertise nor the facility, DGM and the International Centre for Integrated Mountain Development (ICIMOD) held discussions and decided to update the publication of the Geological Survey of Bhutan (GSB) entitled ‘Glaciers and Glacial Lakes in Bhutan 1999’ using remote sensing (RS) and geographic information systems (GIS).

For the mapping and inventory of the glaciers and glacial lakes, the methodology used in this study is based on the research study of the Temporary Technical Secretary for the World Glacier Inventory of the Swiss Federal Institute of Technology (ETH), Zurich (Muller et al. 1977; World Glacier Monitoring Service (WGMS) 1989).

## **1.2 OBJECTIVES**

- To understand the GLOF phenomenon by creating an inventory of existing glacial lakes and monitoring the GLOF events on a regular basis
- To establish an effective early warning mechanism to monitor GLOF hazards using RS and GIS in the Hindu Kush-Himalayan region
- To develop the capacity building of national institutions to assess and monitor the GLOF phenomenon
- To disseminate the results and outputs to the relevant organisations in the region that could make use of this information for GLOF hazard prevention and mitigation planning

## **1.3 OUTPUTS**

- An inventory of glaciers and glacial lakes of Nepal and Bhutan
- Identification of potential risk lakes
- Recommendations for the establishment of a system for monitoring potential risk lakes using RS and GIS
- Strengthening of capabilities of the national institutions to implement an early warning system for GLOF hazard monitoring
- Dissemination of the results and outputs to relevant institutions

## **1.4 ACTIVITIES**

### **a) Glacier and glacial lake inventory**

- Acquisition of Land Observation Satellite (LANDSAT) Thematic Mapper (TM) images for 1999 covering the northern part of Bhutan

- Collection of GIS data layers including digital elevation models (DEM), geology, soils, hydrology (rivers), land use, infrastructure (roads), settlements, forest, administrative boundaries (districts and villages), urban areas, and tourist spots on a scale of 1:50,000
- Data analysis and report writing

**b) Monitoring potential risk lakes**

- Acquisition of LANDSAT TM/ Système Probatoire Pour l'Observation de la Terre (SPOT)/RS images of 1990 and 1995 for four glacial lakes
- Acquisition of time series satellite images for 1990 and 1995
- Field checking and validation of results.
- Report writing

**c) Establishment of an early warning system**

- Developing the methodology using RS and GIS techniques for the inventory of glaciers and glacial lakes and for the GLOF monitoring and early warning system
- Training two participants each from Nepal and Bhutan

**d) Results dissemination/publication**

- Publication of a comprehensive report including (1) to (3) above
- Dissemination of results and outputs in the form of reports, on CD, and through the Internet
- Organisation of a workshop to release the results and outputs

## 1.5 FLOW CHART

