Chapter 1
Introduction

Global climate change occurs naturally and periodically and is often attributed to continental drift, variations in the earth's axis and orbit, variations in solar energy output and the frequency of volcanic activity. The average surface temperature of the earth has been increasing since the end of the Little Ice Age (15th–18th centuries). Over the past few decades, human activities have significantly altered the atmospheric composition, causing a climate change not previously experienced. The average surface temperature of the earth has increased between 0.3ºC and 0.6ºC over the past hundred years and the increase in global temperature is predicted to continue rising during the 21st century. On the Indian sub-continent, temperatures are predicted to increase between 3.5 and 5.5ºC by 2100 (IPCC 2001a) and an even greater increase is predicted for the Tibetan Plateau (Lal 2002). It is estimated that a 1ºC rise in temperature will cause alpine glaciers worldwide to shrink as much as 40 per cent in area and more than 50 per cent in volume as compared to 1850 (IPCC 2001b; CSE 2002).

The Himalayas are an extraordinarily high mountain chain, spanning 2500 km east to west across five countries and encompassing many varied cultures and an extensive diversity of flora and fauna. The glaciers of the Hindu Kush–Himalayan (HKH) region are one of nature's greatest renewable storehouses of fresh water; properly utilised, they benefit hundreds of millions of people downstream. A study carried out jointly by ICIMOD, UNEP, and Asia-Pacific Network for Global Change Research (APN) between 1999 and 2003 documented about 15,000 glaciers and 9000 glacial lakes in Bhutan, Nepal, Pakistan and selected basins of China and India (Mool et al. 2005b; Figure 1.1). Such a high concentration of captive water and ice has aptly earned the Himalayan region the designation 'Third Pole' (Dyhrenfurth 1955). This mountain range feeds most of the major perennial river systems in the region and is considered the lifeline for approximately 10 per cent of the world's population.

Today, glaciers in the region are retreating, this is compelling evidence of global climate change; if the trend continues, a long-term loss of natural fresh water storage is predicted to be dramatic. As glaciers retreat, lakes commonly form behind the newly exposed terminal moraine. The rapid accumulation of water in these lakes can lead to a sudden breach of the moraine dam. The resultant rapid discharge of huge amounts of water and debris is known as a glacial lake outburst flood (GLOF) — and the results can be catastrophic to the downstream riparian area (Richardson and Reynolds 2000). Every country within the Himalayan region has at some time or other suffered a glacial lake outburst flood event. Records show 15 GLOF events recorded in Nepal, 6 in the Tibet Autonomous Region of China (with consequences for Nepal) and 5 in Bhutan. According to Yamada (1998), WECS (1987) and Mool (2001a,b), the following GLOFs have occurred in Nepal since 1970: Nare (1977), Nagma Pokhari (1980), Dig Tsho (1985), Chhubung (1991), and Tam Pokhari (1998). The Zhangzhangbo (1981) and Jinco (1982) GLOFs occurred in the Tibet Autonomous Region of China; and the Luggye Tso GLOF (1994) occurred in Bhutan (Watanabe and Rothacher 1996; Geological Survey of Bhutan 1999; Gansser 1970).

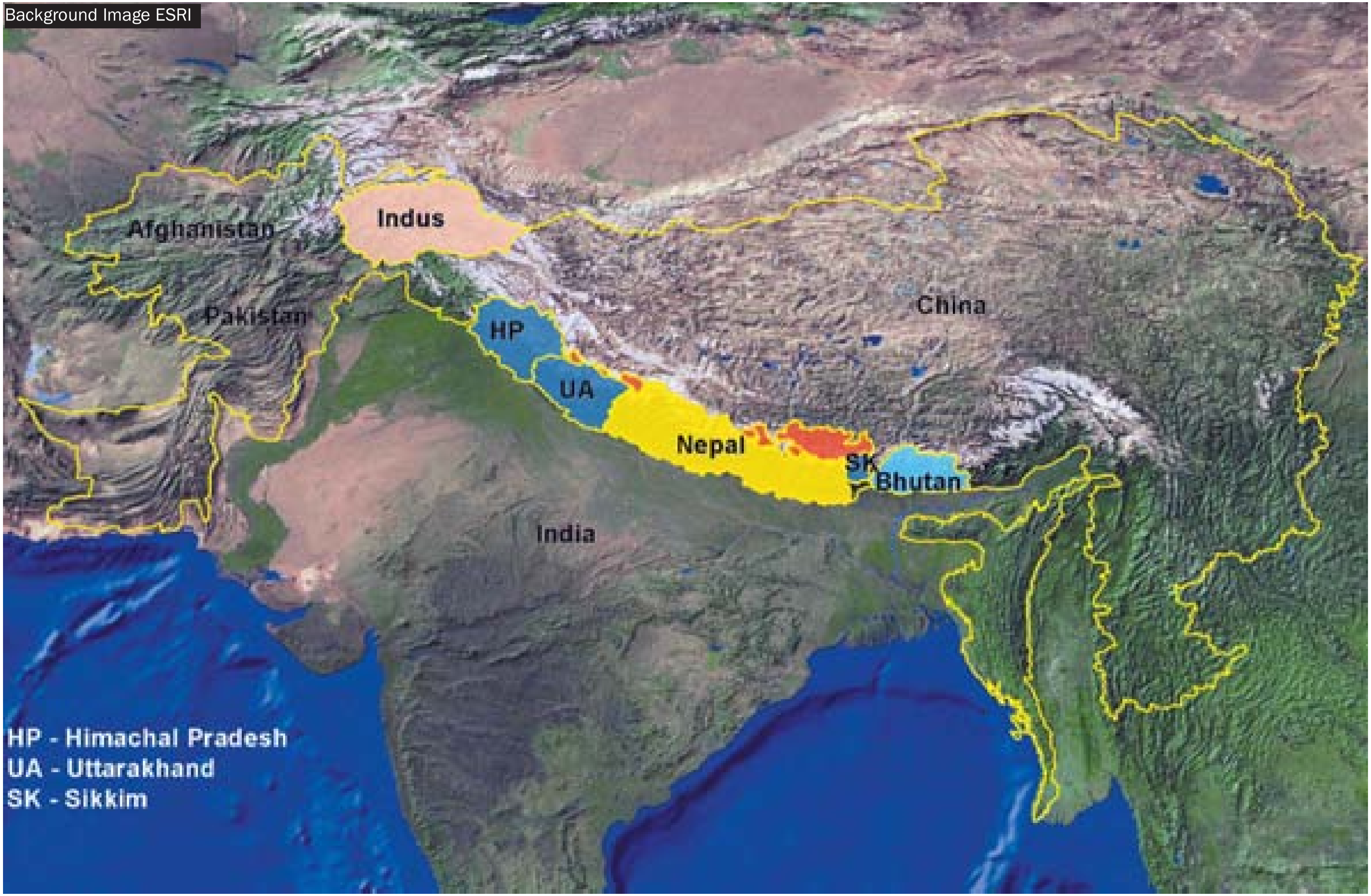

Figure 1.1: Location map of glaciers and glacial lakes studied in Bhutan, Nepal, India, Pakistan, and China during the ICIMOD, UNEP, and APN Project of 1999-2003

The Zhangzhangbo GLOF of 1981 caused damage in the Zhangzangbo and Sun Koshi valleys. It destroyed the Sun Koshi Power Station and the Friendship Bridge at the Nepal-China border, as well as two other bridges and devastated extensive sections of the Arniko Highway; losses totalled more than US $3 million (XuDaoming 1985; Mool et al. 2001a). Four years later, the Dig Tsho GLOF occurred and destroyed the nearly completed Namche Hydropower Plant (with an estimated loss of US $1.5 million), 14 bridges, trails, and cultivated land, and cost many lives. This unprecedented degree of damage and property loss attracted the attention of different government and non-government organisations. The systematic study of glacial lakes in Nepal began at the Water and Energy Commission Secretariat (WECS) in 1985, (WECS 1987, Yamada 1998). Similarly, the 1994 Luggye Tso GLOF in Bhutan, which damaged the sacred Punakha Dzong, ravaged much cultivated land, and killed over 20 people, prompted the Royal Government of Bhutan to take action. Bhutan's Department of Geology and Mines (DGM) subsequently undertook a study of the glacial lakes.

Glaciers and glacial lakes abound in the Himalayas; Chapter 2 reviews the status of Himalayan glaciers in China, India, Bhutan, and Nepal. Recent studies by ICIMOD show that glaciers in the Dhud-Koshi sub-basin of Nepal are retreating at unpredicted rates; glacier retreat rates of 10 to 60m per year and, in exceptional cases, as fast as 74m per year, have been recorded.

Regular monitoring of potentially dangerous glacial lakes at high risk for GLOF events is essential. Mool et al. (2001a,b) documented 24 potentially dangerous glacial lakes in Bhutan and 20 in Nepal. Out of these, eight lakes are located in the Pho Chu basin of Bhutan and twelve in the Dudh Koshi sub-basin of Nepal. These two basins have the highest concentration of glacial lakes in their respective countries. Chapter 3 focuses on glacial lakes in these two sub-basins; with the highest concentration of glacial lakes they are also 'hot spots' for potential GLOF activity. Lake Imja Tsho in Nepal and Lake Raphstreng Tso in Bhutan are discussed in detail.

Hazard assessment, especially in those river valleys that are known to be potentially at risk for GLOF events, is essential in developing the most appropriate responses and mitigation measures. Hydrodynamic dam breach modelling can help in understanding flood height, flood routing, and potential discharge from a likely GLOF event. Lakes Imja Tsho and Luggye Tso were selected for modelling analysis and the results are discussed in Chapter 4.

While GLOF modelling can give some useful insights it is helpful to supplement these both with data gathered from previous GLOF events and with field data. The study of past GLOF affected areas allows classification of various terrain units. This type of classification assesses the extent of damage sustained by a particular terrain unit after a GLOF event and uses that information to predict what damage subsequent GLOFs might cause, information that can then be incorporated into hazard maps. Chapter 5 discusses the terrain classification of the Langmoche valley where the Dig Tsho GLOF occurred in 1985 and shows that a similar classification scheme can be applied in the Imja valley.

Mitigation measures may help to prevent a GLOF event and/or reduce the severity of its impact. Early warning systems, including satellite-based and other techniques, are helpful in reducing the threat that GLOFs pose to people in the downstream areas. Chapter 6 discusses examples of both the mitigation measures and early warning systems that are already in place in Bhutan and Nepal. In addition, preliminary data from a new regular temporal monitoring system using RADAR datasets to onitor the growth of glacial lakes in Nepal is discussed.