Conclusion

Chapter 7

Conclusions

The earth's average surface temperature has been increasing since the end of the Little Ice Age. Over the last one hundred years, the temperature has increased by 0.3 to 0.6ºC. There are predictions that by 2100 the temperature of the Indian sub-continent may increase further by 3.5 to 5.5ºC due to global warming. While the contribution of human activity to global climate change is hotly debated, the retreat of glaciers in the Himalaya is compelling evidence that a change is indeed taking place. Glacial environments are especially sensitive to the impacts of climate change since temperature changes are more pronounced at higher altitudes, and this and other studies show that Himalayan glaciers have been melting at unprecedented rates in recent decades. One phenomenon associated with glacial retreat is the formation of glacial lakes at the terminal moraine. As the size of these lakes increases, so too does the risk of breaching of the unstable moraine dam, with a sudden release of the stored water giving rise to a 'glacial lake outburst flood' or GLOF. Most of the glacial lakes in the Himalaya have appeared within the last five decades, and the region has faced devastating consequences as a result of such floods.

The present study aimed to investigate the impact of climate change on glaciers and glacial lakes in the Himalayas based on empirical evidence and time-series data and information. The Dudh Koshi sub-basin of Nepal and the Pho Chu sub-basin of Bhutan are two known hotspots of glacial activity and have both witnessed devastating GLOFs in the past, thus these two areas were chosen as the focus of the case studies. The studies revealed some interesting insights on retreating glaciers and the growth of glacial lakes. The main findings were as follow.

- It is apparent that the glacier retreat rate has accelerated in recent times as compared to the 1970s. The valley glaciers and small glaciers are retreating fast. The Imja glacier retreated at an average rate of 42m per year in the period from 1962 to 2000. The retreat rate increased to 74m per year during 2001 and 2006, when it became one of the fastest-retreating glaciers in the Himalayas.
- Some of the smaller glaciers in Bhutan have completely disappeared; they could not be found on the satellite images of 2000–2001. In the Bhutan Himalaya the average retreat rate of glaciers was around 30m per year between 1963 and 1993. Some of the glaciers in the Lunana region of the Pho Chu sub-basin were retreating as fast as 57m per year in 2001, with an increase in retreat rate as high as 800% since 1970.
- During a glacier retreat, there is a high probability of formation of new lakes, as well as merging and expansion of existing ones, at the toe of a valley glacier. In the Dudh Koshi sub-basin of Nepal, the total number of lakes has decreased by 37%, but their total area has increased by 21%. Similarly in the Pho Chu sub-basin of Bhutan, the total number of lakes has decreased by 19% but the total area has increased by 8%.
- The Luggye Tso in the Pho Chu sub-basin of Bhutan, from which a GLOF originated in 1994, is once again in the process of enlargement. The Thorthormi glacier in Bhutan had no supraglacial ponds during the 1950s, but now there is a cluster of newly formed

supraglacial lakes which are merging. If this trend continues, they will further merge to form a large lake posing a serious GLOF threat in the near future.

The study also looked at methodologies for carrying out vulnerability and hazard assessment, and discussed possible early warning systems and suitable mitigation measures to reduce the adverse impacts of a GLOF. The main findings of these investigations were as follows.

- Hydrodynamic modelling of a potential GLOF can provide useful information for indicative impacts on life and property downstream. The results of such a model for the Imja and Raphstreng glacial lakes provides important information such as flood height, flood routing and arrival time, and potential discharge from a GLOF, which are all necessary parameters when devising an early warning system.
- The terrain classification of a past GLOF-affected valley can provide valuable information on the anticipated extent of damage in a particular terrain type. It is also useful for assessing the vulnerability of similar terrain in other valleys with potential GLOFs. The hazard assessment of the Imja Tsho indicated that the lower terraces at the Ghat, Chutawa, Chermading, Phakding, Benkar, Tawa, and Jorsalle villages have a possibility of overtopping by a GLOF.
- GLOF mitigation measures and commissioning of early warning systems are daunting and challenging tasks, and also quite expensive. Satellite-based techniques using RADAR imageries may prove a useful approach for monitoring a glacial lake independent of local weather conditions. Monitoring of Lake Imja Tsho using ESA RADAR satellite imagery provided a useful means for detecting growth (change) of the lake over a short time (as quickly as monthly). Such a technique may prove useful for issuing early warnings in a cost effective manner.

Climate change will continue to be a pressing global concern for the foreseeable future. Melting of glaciers warrants a concerted attempt to improve our scientific understanding of the impact of climate change. It is only by investigating much larger areas, that it will really be possible to assess the effects that the change in global climatic patterns is having in the Himalayas. The methodologies presented in this publication provide a basis for further investigations of other hotspots in the region, and can be a model for assessing the impact of climate change on glaciers, glacial lakes, and associated hazards as well as room for refining. Action is needed by the international community to safeguard the precious natural resources of this relatively unexplored, but spectacular, region of the world .