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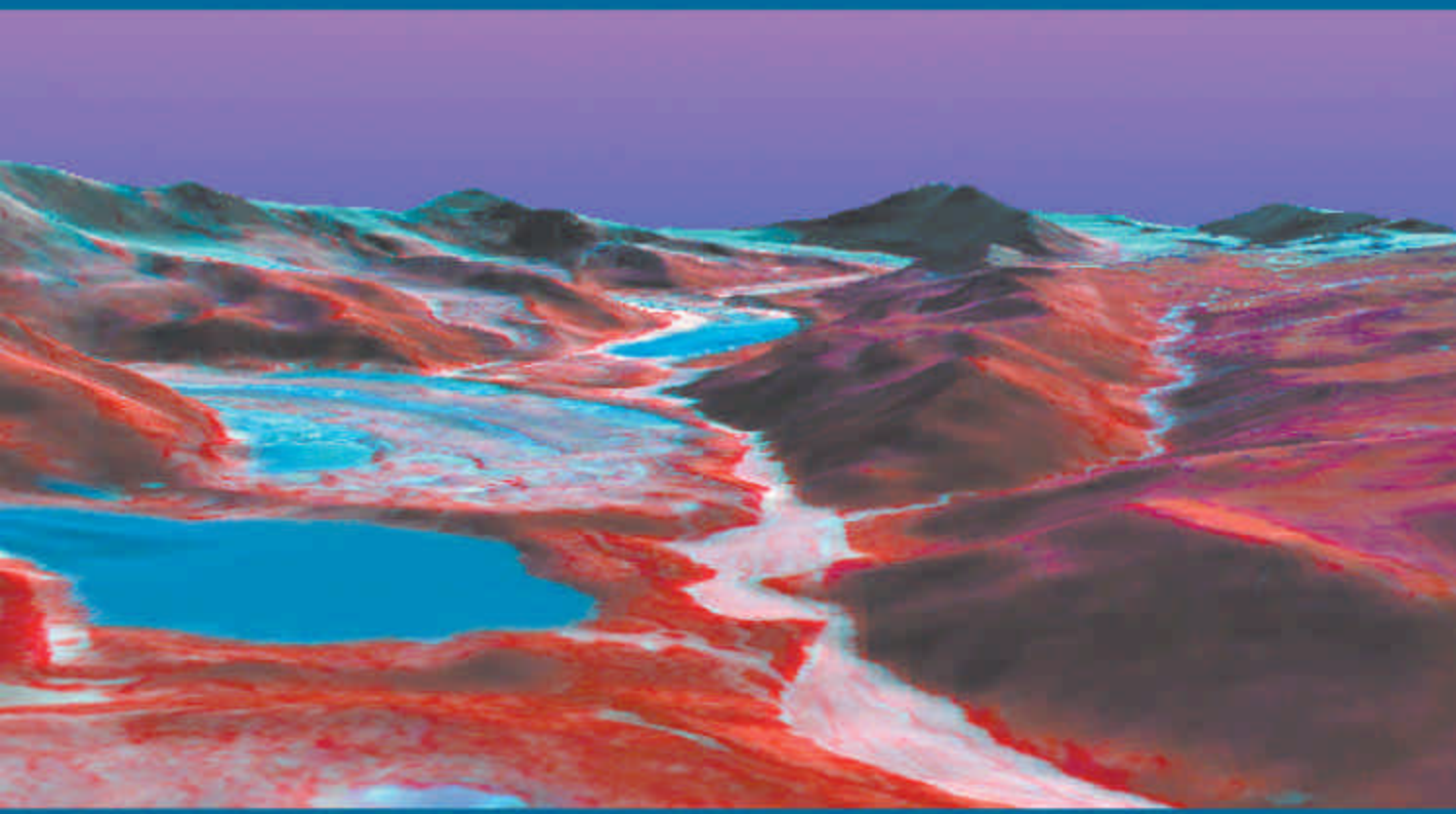
Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods

Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region

Bhutan



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In cooperation with
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Cover plate:

Front: Three-dimensional perspective computer-generated view of Raphstreng Tsho showing the Thorthomi glacier and Lugge Tsho area, and the effect of the Lugge Tsho GLOF in the Pho Chu area (1999 IRS1D LISS3 and PAN data)

Back plates:

The Pho Chu basin area in Bhutan which includes the Lugge Tsho, Raphstreng Tsho, and their associated glaciers

Top: *Lugge Tsho Glacial Lake two weeks after the GLOF of 7 October 1994 — Yeshi Dorji*

Bottom clockwise:

Satellite image (IRS1C PAN) of 3 January 1999 draped on a digital elevation model (DEM) derived from topographic maps showing the breached area of Lugge Tsho Lake

Field photo of Thorthormi Glacier and Lugge Tsho showing the breach point of Lugge Tsho — *Phuntso Norbu*

Satellite image (IRS1D PAN) of 3 December 2000 showing Punakha Dzong, the impact area of the GLOF

Field photo of Punakha Dzong three days after the disaster of 1994 — *Phuntso Norbu*

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Foreword

The glaciers of the Hindu Kush-Himalayas (HKH) are nature's renewable storehouse of fresh water from which hundreds of millions of people downstream benefit just when it is most needed – in the dry hot season before the monsoons. While the total number of glaciers in the region is still unknown, this study has for the first time documented that there are 677 glaciers in Bhutan alone. Covering an area of 1,317 square kilometres, these high frozen reservoirs release their water at the top of their watersheds. They serve as the perennial sources of rivers that wind their way through grazing, agricultural, and forest lands and are used as renewable sources of irrigation, drinking water, energy, and industry.

However, these glaciers are retreating in the face of accelerating global warming. They are particularly vulnerable to climate change, and the resultant long-term loss of natural fresh water storage will have as yet uncalculated effects on communities downstream. More immediately, as glaciers retreat, glacial lakes form behind some of the now exposed terminal moraines. Rapid accumulation of water in glacial lakes, particularly in those adjacent to receding glaciers, can lead to a sudden breaching of the unstable 'dam' behind which they have formed. The resultant discharges of huge amounts of water and debris – a **glacial lake outburst flood** or **GLOF** – often have catastrophic effects downstream.

Many glacial lakes are known to have formed in the HKH in the last half century and a number of GLOFs have been reported in the region, including in Bhutan, in the last few decades. These GLOFs have resulted in many deaths, as well as the destruction of houses, bridges, fields, forests and roads. The lakes at risk, however, are situated in remote and inaccessible areas. When they burst, the local communities may have been devastated, while those in far away cities were largely unaware of the event.

In Bhutan, the catastrophic Lugge Tsho glacial lake flood in 1994, which followed a similar event in nearby Nepal in 1985, raised awareness of the problem considerably. As described in this publication, a partial burst from this lake caused loss of life and property along the Punakha-Wangdue valley, damaged part of the Dzongchung of Punakha Dzong, and washed away or covered nearly 1,000 acres of pastureland.

Despite numerous studies of individual cases, there is still no detailed inventory of glaciers and glacial lakes, of GLOF events or of potential GLOF sites, in the HKH region – let alone of their impact on downstream populations and investments. This publication, along with the sister publication on the glaciers and glacial lakes of Nepal, is designed to begin filling this pressing need. The research upon which it is based started in 1999, when the United Nations Environment Programme Regional Resource Centre for Asia and the Pacific (UNEP/RRC-AP) provided ICIMOD with the opportunity of using its expertise in the area of geographic information systems (GIS) to create a comprehensive inventory and GIS database of glaciers and glacial lakes in Nepal and Bhutan using available maps, satellite images, aerial photographs, reports, and field data on different scales. It built on ICIMOD's experience and long-standing concern with collecting and distributing material on the means to identify and mitigate mountain disasters and safeguard the livelihoods of vulnerable mountain people and their downstream neighbours.

One of the study's major objectives was to identify areas where GLOF events had occurred and lakes that could pose a potential threat of a GLOF in the near future. Out of a surprisingly large total of 2,674 glacial lakes, the researchers found 24 lakes that are potentially dangerous. These results thus provide the basis for development of a monitoring and early warning system and for the planning and prioritisation of disaster mitigation efforts that could save many lives and properties situated

downstream, as well as guide infrastructure planning. In addition, it is anticipated that this study will provide useful information for many of those concerned with water resources and land-use planning.

As a presentation of the first results of the UNEP/RRC-AP supported study, this publication also includes a description of the methods used to identify glaciers, glacial lakes, and glacial lakes that may pose a threat; as well as an inventory (and maps) of the glaciers and glacial lakes in Bhutan. It includes a summary of the results of studies of various glacial lakes, and a brief review of the causes and effects of known GLOF events in Bhutan. The database and analysis are the first to cover the whole of the country on a large scale.
We are thus confident that this comprehensive report and digital database will be of service to scientists, planners, and decision-makers in many areas. Through their informed actions, we hope it will contribute to improving the lives of those living in the mountains, and help safeguard future investments for the benefit of many people in the region.

ICIMOD is grateful to UNEP/RRC-AP for its support to this work and the strong support and advice given while carrying out the project. We are also pleased that this project has enabled us to continue to strengthen our collaboration with the Department of Geology and Mines of the Royal Government of Bhutan and to continue to assist in developing regional capacity and co-operation.

J Gabriel Campbell
Director General
ICIMOD

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Editor's note

The terms glacier lake and glacial lake are often used interchangeably to refer to any lake associated with a glacier, regardless of the means of formation, although some investigators restrict their definitions to particular types of lake. For the purposes of this document, all lakes in contact with or near a glacier, or formed by recent glacial morphology, are referred to as 'glacial lakes'. In practice, most are of the type produced on a glacier's perimeter by meltwater from the glacier, by many termed a 'proglacial lake'.

The terms 'Himalaya' and 'Himalayas' are use to refer to the geological formation and the geographical region, respectively.

Abbreviations and Acronyms

CD	compact disk
DEM	digital elevation model
DGM	Department of Geology and Mines
DOR	Department of Roads
EAP-AP	Environment Assessment Programme – Asia Pacific
EMS	electromagnetic spectrum
ERTS	Earth Resources Technology Satellite
ESCAP	Economic and Social Commission for Asia and Pacific
ETH	Swiss Federal Institute of Technology
FCC	false colour composite
GDP	gross domestic product
Gl	glacial lake
GIS	geographic information system
GLOF	glacial lake outburst flood
Gr	glacier
GSB	Geological Survey of Bhutan
GSI	Geological Survey of India
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation)
HKH	Hindu Kush-Himalayas
HRV	High Resolution Visible sensor (SPOT)
ICIMOD	International Centre for Integrated Mountain Development
ILWIS	Integrated Land and Water Information Systems
IR	Infrared
IRS1C	Indian Remote Sensing Satellite series 1C
IRS1D	Indian Remote Sensing Satellite series 1D
Landsat	Land Resources Satellite
LIGG	Lanzhou Institute of Glaciology and Geocryology
LISS	Linear Imaging and Self Scanning sensor
masl	metres above sea level
MBT	Main Boundary Thrust
MCC	Meteor Communication Corporation
MCT	Main Central Thrust
MENRIS	Mountain Environment and Natural Resources' Information System
MOS	Marine Observation Satellite
MSS	Multi Spectral Scanner (Landsat)
NEA	Nepal Electricity Authority
NRSA	National Remote Sensing Agency
PAN	Panchromatic Mode sensor system (SPOT)

RRC	Regional Resource Centre
RBA	Royal Bhutan Army
RGB	red green blue
RGOB	Royal Government of Bhutan
RS	remote sensing
SPOT	Système Probatoire Pour l'Observation de la Terre / Satellite Pour l'Observation de la Terre
SWIR	Short Wave Infra Red sensor
TM	Thematic Mapper (Landsat)
TTS	Temporary Technical Secretary
UNDP	United Nations Development Project
UNEP	United Nations Environment Programme
VNIR	Visible and Near Infra Red (AVNIR)
WAPCOS	Water and Power Consultancy Services (India) Limited
WECS	Water and Energy Commission Secretariat
WGI	World Glacier Inventory
WGMS	World Glacier Monitoring Service
WWW	World Wide Web
XS	Multispectral Mode sensor system (SPOT)

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