ICIMOD

FOR MOUNTAINS AND PEOPLE

Case Studies on Flash Flood Risk Management in the Himalayas

In support of specific flash flood policies

USAID
FROM THE AMERICAN PEOPLE

About ICIMOD

The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalization and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

ICIMOD gratefully acknowledges the support of its core donors:
The Governments of Afghanistan, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Switzerland, and the United Kingdom.

Case Studies on Flash Flood Risk Management in the Himalayas

In support of specific flash flood policies

Editors
Arun B Shrestha
Sagar R Bajracharya

International Centre for Integrated Mountain Development, Kathmandu, 2013

Published by
International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Nepal

ISBN 978 92 9115 269 8 (printed)
978 92 9115 270 4 (electronic)
LCCN 2013-310100

Photos: Cover, pp 49, 51 – Prof. Yougshu Han
pp 20, 21 – Wali Mohammad Khan
pp 27, 28 – Partha J Das
pp 52, 53 – Sagar Ratna Bajracharya

Printed and bound in Nepal by
Hill Side Press (P) Ltd., Kathmandu, Nepal

Production team
Andrea Perlis (Senior editor)
Susan Sellars Shrestha (Consultant editor)
Amy Sellmyer (Proofreader)
Dharma R Maharjan (Layout and design)
Punam Pradhan (Layout and design)
Asha Kaji Thaku (Editorial assistant)

This publication is available in electronic form at www.icimod.org/publications

Citation: Shrestha, AB; Bajracharya, SR (eds) (2013) *Case studies on flash flood risk management in the Himalayas: In support of specific flash flood policies.* Kathmandu: ICIMOD

Contents

Foreword

A growing body of evidence indicates that the frequency and intensity of flash floods are increasing in the countries of the Hindu Kush Himalayan region. On 5 May 2012, a flash flood in Kaski, Nepal, killed at least 31 people, with many more unaccounted for. In Uttarakhand, India, 10 people lost their lives and 53 people went missing after a flash flood on 4 August 2012, and little more than a month later 33 people died and 35 people went missing from another flash flood on 15 September 2012. In Pakistan, 78 people were killed in a flash flood on 10 September 2012. These events call for the urgent attention of policy makers. This publication provides detailed evidence to help practitioners present the case for specific policies and action to manage flash flood risks.

Flash floods are severe flood events that occur with little or no warning. They can be triggered by intense rainfall, the outburst of a landslide dam lake, the failure of a natural or artificial dam, or a glacial lake outburst. The frequent occurrence of flash floods in the Hindu Kush Himalayan region poses a severe threat to lives, livelihoods, and infrastructure, both in the mountains and downstream. Vulnerable groups such as the poor, women, children, the elderly, and people with disabilities are often hardest hit. Flash floods tend to carry with them much higher amounts of debris than normal floods and as a result cause more damage to hydropower stations, roads, bridges, buildings, and other infrastructure.

Since its establishment in 1983, ICIMOD has explored different ways to reduce the risk posed by natural disasters and the physical and social vulnerability of the people in the region. Approaches have included training courses, hazard mapping, and vulnerability assessments, as well as fostering dialogue among stakeholders and developing materials for capacity building.

ICIMOD, in collaboration with various partners, has compiled and published resource materials on flash flood risk management to support capacity development and especially the training of planners and practitioners. As part of these efforts, ICIMOD published a set of resource manuals on flash flood risk management through community-based management covering structural and non-structural measures. Based on these materials, ICIMOD has also recently published a training of trainers manual.

The case studies in this publication provide evidence to help practitioners influence policy and decision makers in ICIMOD's regional member countries. The studies provide evidence in support of a number of recommendations – above all that the countries of the region should develop policies and strategies specific to flash flood risk management, integrate flash flood management in watershed and water resource management, improve preparedness at all levels, and promote effective early warning systems. They should also empower communities to play a central role in flash flood management and collaborate with other countries for transboundary management of flash floods. The studies also demonstrate the need for institutional strengthening, flash flood modelling and hazard mapping, and the development and implementation of land use guidelines and building codes. Furthermore, countries should strengthen national networks of hydrological and meteorological observation and document flash flood events in a systematic way to enhance understanding.

This publication has been produced as part of the project 'Flash Flood Risk Reduction – Strengthening Capacity in the Hindu Kush Himalayas', supported by the United States Agency for International Development, Office for Foreign Disaster Assistance (USAID/OFDA). We hope that it will contribute towards developing effective strategies and policies and ultimately to reducing disaster risk and providing greater security for the people of this vulnerable region.

David Molden
Director General, ICIMOD

Acknowledgements

This publication is an output of the project 'Flash Flood Risk Reduction – Strengthening Capacity in the Hindu Kush Himalayas', which was supported by the United States Agency for International Development, Office for Foreign Disaster Assistance (USAID/OFDA). Special thanks go to Sezin Tokar and Liza Mantilla of USAID/OFDA for their support to the project.

We would like to express our heartfelt thanks to the authors of the chapters for their hard work and keeping to deadlines. We are grateful to the many ICIMOD colleagues who reviewed the manuscript and provided constructive comments. We are grateful to Professor Hua Ouyang, then Programme Manager for Integrated Water and Hazard Management, for seeing the work through to completion, and to all the staff in this programme who supported its preparation.

Comments and suggestions from two external reviewers, Dr Juerg Merz, HELVETAS Swiss Intercooperation Nepal, and Dr KJ Anandha Kumar, National Institute of Disaster Management, Ministry of Home Affairs, Government of India, greatly helped to improve the document.

Warm thanks go to Susan Sellars-Shrestha (consultant editor) for bringing the manuscript to its present form. Thanks also to the editorial team of Andrea Perlis, senior editor, and Amy Sellmyer, proofreader, for their helpful insights. Heartfelt thanks to Dharma Ratna Maharjan and Punam Pradhan for their hard work in laying out the manuscript in a very short time and to Asha Kaji Thaku for his editorial assistance.

Acronyms and Abbreviations

CERT	Community Emergency Response Team
DEM	digital elevation model
FOCUS	Focus Humanitarian Assistance
GIS	geographic information system
GLOF	glacial lake outburst flood
HEC-RAS	Hydrologic Engineering Center-River Analysis System
HKH	Hindu Kush Himalayas
LDOF	landslide dam outburst flood
NAPA	National Adaptation Programme of Action
NGO	non-governmental organization
RS	remote sensing
VDC	village development committee

Part 1

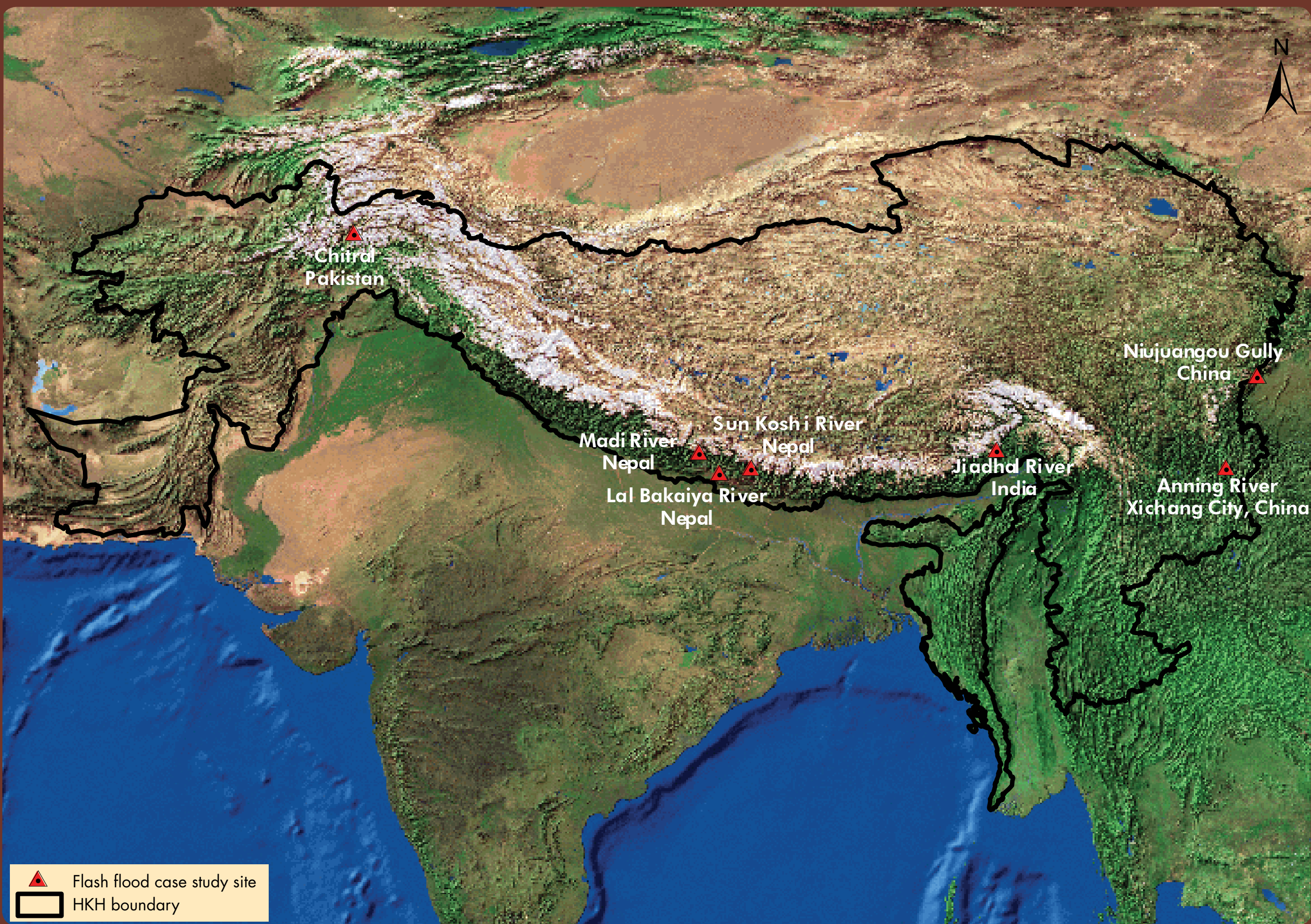
Overview

About This Study

Since 2006, ICIMOD has commissioned various case studies as part of a study on flash flood risk reduction in the Hindu Kush Himalayan region. The purpose of these studies was to create a knowledge base on flash flood processes in different parts of the region with diverse climatic and socioeconomic conditions in order to understand existing flash flood risk management mechanisms, including policies and institutional mechanisms, and increase awareness about flash floods. Altogether, eight case studies were conducted in Xichang and Niujuangou in Sichuan, China; Dhemaji District in Assam, India; the Bhote Koshi/Sun Koshi basin (two case studies), Lal Bakaiya, and Madi in Nepal; and Chitral District in Pakistan (Figure 1).

This publication contains a summary of each case study (Part 2), as well as an overview of the status of flash flood risk management in the region and a list of regional recommendations to be brought to the attention of policy makers (Part 1).

Figure 1: **Case study sites**



Flash Flood Risk Management in the Hindu Kush Himalayan Region

Arun Bhakta Shrestha and Sagar Ratna Bajracharya, ICIMOD

Countries in the Hindu Kush Himalayan region generally lack policies, strategies, and plans dealing specifically with flash floods. Most of the existing policies relate to riverine floods or to disasters in general.

Introduction

The Hindu Kush Himalayas (HKH) is a mountain system of extremes with great influence over the Asian continent. The system stretches 3,500 km over eight countries, from Afghanistan in the west to Myanmar in the east. It is the world's largest and highest mountain system, with more than 30 peaks measuring over 7,600 m. It is also the youngest mountain system on Earth and still tectonically active. The HKH region is characterized by fragile bedrock, steep slopes, and a high rate of surface erosion. Its superlative dimensions give it enormous influence over the climate of Asia. The HKH mountains block the monsoon from the south as well as extremely cold air blowing from the north. Consequently, the southern slopes and valleys host some of the wettest, greenest mountain ecosystems in the world, particularly in the east, for example the subtropical uplands of Myanmar. In contrast, the northern mountains and Tibetan plateau are generally snowy, much colder, and in some areas dry and nearly devoid of vegetation.

The world's most populous mountain system, the Hindu Kush Himalayas are home to over 140 million people and affect the lives of hundreds of millions beyond. The inhabitants of the HKH are, by and large, poor and depend heavily on the land and natural resources for their livelihoods and wellbeing.

The HKH system is one of the Earth's great water reservoirs, providing freshwater for fields, industry, and drinking. Himalayan rivers generate electricity for countless homes, with many more hydroelectric dams planned. While the water flowing from this region sustains the lives and livelihoods of the millions of people residing in the HKH, it is also a source of considerable hazard. In addition to the geological conditions, intense seasonal precipitation in the central and eastern Himalayas during the summer monsoon (June–September) and in the western Himalayas during winter triggers a variety of natural hazards. Floods are one of the most common forms of natural disaster in this region, and flash floods are particularly devastating. The mortality rate from flash floods is much higher than from other water-induced disasters.

Despite their destructive nature and their immense impact on the socioeconomy of the region, flash floods have not received adequate attention from policy and decision makers. This is mainly because of poor understanding of the processes involved and measures needed to manage the problem. The current understanding of flash floods remains at the level of general concepts; most policy makers have yet to recognize that flash floods are distinctly different from normal riverine floods in term of causes, propagation, intensity, impacts, predictability, and management. Flash floods are generally not investigated as a separate class of event but are rather reported as part of the overall seasonal flood situation. As a result, the countries of the HKH region generally lack policies, strategies, and plans relating specifically to flash floods. Most of the existing policies relate to riverine floods or to disasters in general, and flash floods are dealt with using the same strategies as riverine floods.

Causes of Flash Floods in the HKH Region

High intensity rainfall events in the HKH are often localized and have important implications for flash floods. These intense rainfall events, sometimes called cloudbursts, can occur in remote areas as a result of topographic variations and are generally unreported because of inaccessibility and isolation. An intense rainfall event may occur in the high reaches of a mountain stream in an unpopulated area yet may produce a flash flood affecting downstream communities. Prolonged monsoon rainfall can also cause flash floods, as occurred in central Nepal in 1993 and in Niujuangou gully, China in May 2010. Monsoon depressions are another climatic factor that causes flash flood, particularly in Pakistan. In the western Himalayas, accumulated snow can melt rapidly during spring, leading to flash floods.

The glaciers in the Hindu Kush Himalayas, particularly in the eastern Himalayas, are in a general state of retreat, probably because of climatic warming (Ageta and Kadota 1992; Kadota and Ageta 1992; Kadota et al. 1997). Himalayan glaciers in the Dudh Koshi are retreating at rates ranging from 10 to 60 m per annum, and many glaciers smaller than 0.2 km^2 have already disappeared (Bajracharya et al. 2007).

Retreating glaciers often leave behind voids filled by meltwater called glacial lakes. Glacial lakes tend to burst because of internal instabilities in the natural moraine dams retaining the lakes (e.g., as a result of hydrostatic pressure, erosion from overtopping, or internal structural failure) or as a result of an external trigger such as a rock or ice avalanche, or even earthquake. Glacial lake outburst floods (GLOFs) can be catastrophic and are common in the HKH region. Floodwaters from this phenomenon contain a huge amount of sediment from glacial moraines, which can cause morphological changes in the river channel and devastating loss of life and property at great distances from the outburst source. The GLOF of Dig Tsho glacier lake on 4 August 1985 and the Zhangzanbo GLOF event of 1981, both in Nepal, caused great damage. The Zhangzanbo GLOF hampered trade between China and Nepal for a number of years.

Because of the young geology of the Himalayas and the instability of their slopes, the HKH region is prone to recurrent and often devastating landslides and debris flows. Such landslides and debris flows, released by torrential rain or seismic activity, may cause temporary dams across river courses impounding immense volumes of water. Subsequent overtopping or breaking through of the earth dam can result in a landslide dam outburst flood (LDOF), which, similar to a GLOF, is difficult to predict and may cause serious loss of life and damage to property. One remarkable LDOF event was the Larcha LDOF of 22 July 1996 in Nepal, which wiped out Larcha village killing 54 people.

The failure of artificial structures, such as embankments and hydropower dams, can also cause flash floods. Occasionally, the uncoordinated operation of hydraulic structures causes flash floods and loss of life and property. The major flood in the Jiadhal River basin in 2007, which devastated about 30 villages on the right bank in Dhemaji District, Assam, India, and the Koshi flood of 2008, which affected Nepal and India, are examples of flash floods caused by structural failure.

Socioeconomic Factors Contributing to Vulnerability

The Hindu Kush Himalayan region is one of the poorest regions in the world, containing about 40 per cent of the world's poor. Five of the eight counties in the region are categorized as least developed countries with 30 to 50 percent of the population living under the poverty line (Table 1). The region is the most densely populated in the world, with population density as high as 180 persons per square kilometre in some places. The population growth rate is also quite high. High population density results in scarcity of natural resources such as land and water, forcing people to live in areas vulnerable to natural disasters. On top of the physical and environmental factors, these social and economic conditions exacerbate the vulnerability of people in the region to different types of disaster including flash floods.

Policies, Strategies, and Institutional Framework

The countries of the Hindu Kush Himalayan region generally lack policies, strategies, and plans specifically dealing with flash floods. Most of the existing policies relate to riverine floods or to disasters in general. China has a somewhat better policy framework for flash floods; however, all of the countries in the region are yet to recognize and address mountain hazards as a separate issue from both upstream and downstream disaster risk perspectives, particularly in relation to flash flood risk reduction. This section gives a brief overview of the policy and institutional frameworks in place in each of the countries of the Hindu Kush Himalayan region.

Table 1: **Socioeconomic status of the countries in the Hindu Kush Himalayan region (2011)**

Country	Area within HKH region (km^2)	Population[a] (million)	GDP (current USD, billion)	Annual population growth rate (%)	Annual GDP growth rate (%)	Infant mortality rate (per 1,000 live births)	Access to improved water source (% of population)	Literacy rate (% of population)	Population below national poverty line (%)
Afghanistan	390,475	22	17.2	2.7	8.2	149	50	37.8	53
Bangladesh	13,295	1	100.0	1.2	6.1	48	81	47.9	50
Bhutan	38,400	0.74	1.7	1.7	8.4	56	96	52.8	23
China	2,420,266	32	7,298.1	0.5	9.1	18	91	95.9	13.4
India	461,139	46	1,848.0	1.4	6.9	63	92	74	29
Myanmar	317,629	11	–	0.8	13.7	66	83	92	32.7
Nepal	147,181	30.49	18.9	1.7	3.9	50	89	68.2	25.2
Pakistan	489,988	38	211.1	1.8	2.4	87	92	86.2	33

[a] Calculated based on 1997 data using average growth rate.
Source: World Bank 2011

Afghanistan

Afghanistan is just beginning to build its capacity for disaster management and is establishing institutions to deal with this issue. Among the existing institutions, the Ministry of Energy and Water is responsible for the development and management of water resources and could potentially take the lead in flash flood management. Community-based organizations and non-governmental organizations (NGOs) are not as prominent in Afghanistan as they are in some of the other countries in the region. The Afghanistan National Disaster Management Authority is the focal point for disaster management and has a coordinating role during emergency operations.

Policy on natural resource management in Afghanistan is indirectly related to flash flood management as it favours preservation of the environment which helps ensure flash flood hazard reduction. River basin and watershed management are included in the policy framework of the water sector, and the Environment Act is in the process of being finalized. The Department of Disaster Preparedness has prepared a draft National Disaster Management Strategy focused on the structure of the Department of Disaster Preparedness; type of disasters that might happen in Afghanistan; various stakeholders available to work jointly; the need for an early warning system and awareness programme; emergency response operations; reporting; planning/programming; capacity building; the identification of problems; and the establishment of a revolving fund to cope with issues related to emergencies caused by flash floods, earthquakes, and other natural disasters.

Bangladesh

Bangladesh has a long history of managing floods, with plans for flood control measures dating back to the 1950s. A master plan for water development was drawn up in 1964. Severe floods of 1987 and 1988 prompted the Flood Action Plan and introduced the concept of ‘controlled flood’, instead of full flood control. The Government of Bangladesh formulated the National Water Policy in 1995 and the National Water Management Plan in 2003. Within this policy framework, there are some set policies related to flash floods. Flash flood prone areas have been delineated in the national strategy, and programmes for mitigation measures are being implemented. In 1997, the Government issued a Standing Order on Disasters documenting instructions and orders for disaster activities and management. It initially only covered cyclones but was revised in 1999 to cover all types of disasters, including flash floods. This is an important policy document encompassing many aspects of disaster management such as arrangements for local focal points, supervision, rescue, and evacuation. Bangladesh’s strategy focuses on collaboration with upstream countries in the exchange of data and joint assessments.

Bhutan

In Bhutan, the Department of Disaster Management under the Ministry of Home and Cultural Affairs is responsible for disaster management activities. Considering the susceptibility of the country to various types of flash floods, the Department of Disaster Management, in collaboration with the Department of Geology and Mines and the Department of Hydro-Met Services, is raising awareness among downstream communities about flash floods. The Department of Energy is the lead organization for addressing GLOF hazards and is working on an early warning system, while mitigation aspects are led by the Department of Geology and Mines. The National Disaster Bill for Bhutan, which is coordinated by the Department of Disaster Management, is in the process of finalization.

In addition, Bhutan is in the process of setting up disaster management committees in all of its Dzongkhags (districts). All Dzongkhags will be mandated to have emergency, prevention, and mitigation plans included in their annual and five year plans. The emergency plan will specify who will do what during a disaster and how. The prevention and mitigation plans will focus on what is to be done to prevent and mitigate disasters. The Department of Local Governance is in the process of formulating a disaster management strategy for the whole country.

China

China is the only country in the HKH region that deals with flash floods separately from other floods and disasters. China has an institutional set up and policies specifically targeted at flash flood risk management. The flash flood hazard prevention team is led by the State Flood Control and Drought Relief Headquarters. Representatives from the Ministry of Water Resources, Ministry of Land and Resources, China Weather Bureau, Ministry of Construction, and the State Environmental Protection Administration of China are members of the team.

China has a number of policies indirectly related to flash flood management and is preparing policies with a particular focus on flash floods. Existing policy ensures the consideration of flash flood hazards during construction planning. China also has a mechanism to allocate funds for flash flood prevention. China's flash flood prevention strategies are based on three principles: the principle of "harmonious coexistence between people and nature"; the principle of "reliance on prevention and a combination of prevention and control" and "reliance on non-structural measures and a combination of structural and non-structural measures"; and the principle of "making full use of existing resources and avoiding repetitive construction". China has short-term (by 2010) and long-term (by 2020) plans for flash flood management. The short-term plan, which focuses on non-structural measures such as monitoring, telecommunication, forecasting, and warning and combines them with structural ones, is being set up as a preliminarily measure in key regions. The long-term plan is a comprehensive flash flood hazard prevention and reduction system combining non-structural and structural measures and will be implemented in all flash flood prone areas.

India

In India, flood management is organized at the central, state, and local levels. The central level provides guidance to the states, which implement flood management at the field level. The main central-level agencies are the Ministry of Home Affairs and the Ministry of Water Resources. In addition to the relevant ministries, commissions, and technical support agencies, the central government has created river boards for the major rivers such as the Ganges and Brahmaputra. A National Committee on Disaster Management was recently established under the Prime Minister to review disaster situations in the country.

The first flood policy of India was prepared in 1954. Since then, India's flood policy has been modified repeatedly. The most comprehensive flood policy was completed in 1980. The National Water Policy was released in 1987 and revised in 2002, and a draft revised policy of 2012 is under discussion after being posted on a website for public opinion. These policy documents stress the importance of non-structural measures in mitigating flood risk. The National Water Policy emphasizes an integrated basin approach to flood management and public participation in flood management. The traditional strategy of flood management in India was through structural measures. This trend is changing, and the following four strategies have been adopted for flood management: modification of floods; modification of susceptibilities to flood damage; modification of loss burden; and bearing the loss. India plans to implement these strategies through various activities. Emphasis will be placed on flood plain management, i.e., on regulating land use in flood plains to minimize the damage caused by floods while deriving maximum benefits from them. Floodproofing measures will also be implemented to mitigate distress and provide immediate relief to populations in flood prone areas. Floodproofing is essentially a combination of structural changes and emergency action that does not involve evacuation. India plans to set up flood forecasting and early warning systems as part of its non-structural measures to manage flash floods. India also plans to take action towards disaster preparedness and response planning, flood relief and rehabilitation, and flood insurance.

Myanmar

Myanmar organizes flood management mainly at the central level with the involvement of the Department of Meteorology and Hydrology, Irrigation Department, Relief and Resettlement Department, and the Myanmar Red Cross Society. These institutions are responsible for flood forecasting and warning, constructing structural mitigation measures, conducting disaster management training courses, and erecting signs for hazard control. A National Disaster Preparedness Central Committee has been formed under the chair of the Prime Minister as the apex body for disaster management.

Myanmar has not prepared a policy framework for flood, or flash flood, management. Land use policies and various national and local policies indirectly address flash flood issues. Myanmar's strategies related to flash flood management are gradually evolving towards reducing losses in the event of a hazard. The primary aim is to reduce the risk of death and injury to the population, and the secondary aim is to reduce damage to public infrastructure and consequent economic loss.

Nepal

In Nepal, water-induced disasters are accorded high priority. Flash flood management is led by the Central Natural Disaster Relief Committee, which is chaired by the Minister for Home Affairs; members include two other ministers, the secretaries of most ministries, various director generals, and representatives from the armed forces, police, scouts, and Nepal Red Cross Society. At the local level, there are regional, district, and local natural disaster relief committees. The Department of Water Induced Disaster Prevention is responsible for implementing flood mitigation programmes. The Department of Hydrology and Meteorology is responsible for monitoring glacial lakes and issuing weather forecasts and flood forecasts. A number of NGOs are actively involved in flood risk management including community-based flood risk management.

The promulgation of the Natural Calamity (Relief) Act in 1982 was a milestone in systematic disaster management in Nepal. This act provides a framework for disaster mitigation in the country and has been amended twice. However, it only describes the duties and responsibilities of the Ministry of Home Affairs. It is now accepted that the duties and responsibilities of other disaster management agencies should be more defined. The Tenth Plan (2002–2007) underlines the need to develop means for improved prevention, mitigation, and reduction of natural disasters. In terms of water, the National Water Plan is currently under finalization and will operationalize the Water Resource Strategy adopted in 2002.

Recently, Nepal prepared the Water-Induced Disaster Management Policy, which covers five areas: emergency protection; information dissemination for effective relief, rescue, and protection; awareness raising; warehouses for rescue and relief supplies; and a rehabilitation fund. In 1996, Nepal prepared a National Report and Action Plan for Disaster Management. The Action Plan contains a Disaster Preparedness Plan and Risk Assessment for Disaster Management. The National Water Plan sets out detailed activities to be carried out to implement the Water Resource Strategy and envisions the establishment of disaster prevention, warning/ preparedness, and mitigation measures in at least 20 priority districts by 2010 and across the whole country by 2027. In the meantime, documents related to disaster mitigation are gradually being developed.

No separate policy has been formulated for managing GLOF risk. However, some national policies contain strategies and programmes to reduce the risk of GLOF. These include the Sustainable Agenda for Nepal, 2003; Water Resource Strategy, 2002 and National Water Plan, 2005; Disaster Risk Reduction Strategy, 2009; and Climate Change Policy, 2011. Many of these policies have adopted integrated water resource management and river basin management approaches with emphasis on community-based risk management. The National Adaptation Programme of Action (NAPA) to Climate Change 2010 and the Climate Change Policy, 2011 specifically mention GLOF. Monitoring of potential GLOF lakes, implementation of structural measures, establishment of early warning systems, forecasting and preparedness in downstream communities, and support for vulnerable communities are some of the recommended programme activities contained in the NAPA and Climate Change Policy, 2011.

Pakistan

In Pakistan, the National Crisis Management Cell under the Ministry of Interior is responsible for monitoring natural hazards and coordinating emergency response services with the Provincial Management Cells. The Emergency Management Cell under the Cabinet Division is responsible for relief operations during emergencies. The Civil Defence Department and Pakistan Army play an important role in relief operations. The other federal agencies that deal with flash floods are the Pakistan Meteorological Department, Federal Flood Commission, and Dam Safety Council. Besides government institutions, there are a few NGOs involved in flash flood management. One prominent NGO in this regard is Focus Humanitarian Assistance (FOCUS), Pakistan.

Pakistan lacks policies directly related to flash floods. The National Calamities (Prevention and Relief) Act 1958, Emergency Services Ordinance 2002, and Local Government Ordinance 2001 are some of the policy documents indirectly related to floods and flash floods. The Federal Flood Commission makes polices in light of the decisions made at pre- and post-flood meetings at the national and regional levels. These policies are reviewed according to the shortcomings identified during the flood season and are implemented at the grassroots level as strategies and action plans to reduce vulnerability to flash floods. Strategies related to flash flood management are gradually evolving in Pakistan. The main strategies are to strengthen flood forecasting, to strengthen the technical capacity of institutions involved in flood forecasting, and to improve rescue and relief activities. Emphasis is placed on improving the communication system for the proper dissemination of forecasts.

Flash Flood Mitigation Measures

Major emphasis has been placed on structural and non-structural measures for flash flood hazard mitigation in the HKH region. Like China, India has relied heavily on structural measures for flood control in the past. China, however, is gradually accepting that absolute immunity from flood damage is unattainable. An integrated approach encompassing flood plain zoning and flood plain management is gaining ground. Bangladesh also has an extensive network of structures aimed at reducing inundation-related hazards from floods. A combination of hard and soft measures to reduce the damage caused by floods is postulated. Similarly, Bhutan is trying to protect its forests as a way of protecting downstream areas from floods.

Afghanistan and Bhutan have no operational flood forecasting system. Nepal is currently conducting a test of flood forecasting models and intends to provide flood forecasting in the near future. China operates a forecasting system which includes weather, stream, debris flow, and landslide forecasting. The accuracy of forecasts is improving in China, although flash flood forecasting in small drainage areas is still difficult. India and Bangladesh have an extensive flood-forecasting network, but forecasting is mostly for riverine floods, not flash floods. Pakistan has a network of weather radar used for flood forecasting and has been successful in flood forecasting and minimizing human casualties in recent years.

Mitigation efforts in the HKH rely mainly on the development of detection and response warning systems, which have undergone tremendous transformations in recent times as a result of technological innovations. Real time observations combined with hydrometeorological models allow for increasingly accurate and timely forecasts and warning, increasing the lead time for evacuation. ICIMOD is undertaking a few initiatives in this field, such as the HKH Hydrological Cycle Observing System (HYCOS) and Satellite Rainfall Estimation (SRE). In addition, ICIMOD has developed a Resource Manual on Flash Flood Risk Management, which contains materials needed to help people working in risk prone areas to understand the problem and manage the risks associated with flash floods. The first and second modules (Shrestha et al. 2008; Shrestha 2008) focus on community-based management and non-structural measures for managing flash flood risk. The third module (Shrestha et al. 2012) focuses on structural measures for flash flood risk management. The main objective of this resource manual is to build the capacity of people working in district-level government and non-governmental organizations for flash flood risk management; it is also expected to be of use to district-level disaster mitigation and relief workers as well as professionals from community-based and non-governmental organizations including hydrologists, meteorologists, and civil engineers.

The countries of the HKH region differ in the extent of their flash flood early warning infrastructure. Many of the countries in the region have no early warning system in place. It is increasingly acknowledged that the management of flash floods, including early warning systems, is best handled by local communities, as outlined in the case studies on the Jiadhal River basin in Assam, India and Chitral in Pakistan in Part 2 of this publication. China, India, Myanmar, and Bangladesh have flash flood early warning systems in operation in some watersheds. Nepal has a GLOF early warning system based on a meteor burst communication system downstream from Tsho Rolpa glacial lake.

Conclusions

- The current understanding of flash floods in the HKH remains at the level of general concepts and processes, but systematic learning and reflection from past events are lacking.
- The capacity to manage flash floods in terms of prevention, preparedness, response, and recovery is lacking in most countries of the HKH.
- With the exception of China, none of the countries in the HKH give particular focus to flash floods; instead these events are dealt with as part of overall disaster management or riverine flood management.
- The countries in the HKH differ greatly with respect to flash flood management mechanisms, policies, and implementation. For instance, some countries follow a top-down and centralized approach to flash flood management, while others enlist local community participation in the design and implementation of flash flood management systems. This diversity poses difficulties in the development of cross-border and integrated flash flood management; however, it offers great opportunities for regional learning and exchange. For example, China has an advanced setup for total flash flood disaster management, which other countries could learn from.

Recommendations for Strengthening Flash Flood Risk Management in the Hindu Kush Himalayan Region

- Develop policies specific to flash flood risk management in the countries of the HKH region.
- Raise awareness and knowledge about flash floods at all levels among communities, practitioners, and policy makers to enhance preparedness.
- Improve the institutional setup for flash flood risk management and ensure that it deals with flash floods as separate from other types of floods and disasters, but still addresses the need for an integrated disaster management approach. This also requires the strengthening of other bodies responsible for disaster management, including those responsible for flash floods.
- Empower communities to play a central role in flash flood management including preparedness, adaptation, and mitigation. Promote the concept of community-based disaster management and the use of indigenous and local knowledge.
- Adopt a watershed management approach with community involvement and integrated water resource management.
- Develop a standard methodology and format for documenting flash flood events and for subsequent reflection on the causes, effects, and lessons that can be derived from such events.
- Strengthen the national network of hydrological and meteorological observation, weather radar, and the processing of modern satellite-derived products for the acquisition of real-time data to forecast flash floods and provide warning.
- Promote effective early warning systems with the involvement of upstream and downstream communities to save lives and reduce the risk of flash floods in vulnerable areas of the HKH region.
- Strengthen communication and coordination among relevant institutions and as part of national disaster risk management strategies. National stakeholders should be encouraged to establish formal and informal platforms to facilitate cross-sectoral dialogue to improve flash flood management.
- Conduct flash flood modelling and hazard mapping to identify hazard prone areas and develop land use guidelines and building codes, and implement these with the strong involvement of local stakeholders.
- Develop transboundary collaboration, both international and national, for the management of flash floods including information exchange, joint implementation of mitigation projects, and establishment of flash flood early warning systems.

Part 2

Case Studies for Regional Learning and Exchange

Bhote Koshi/Sun Koshi River, Nepal

Potential GLOF risk assessment and management

Narendra Raj Khanal, Tribhuvan University; **Kamal Banskota, Arun Bhakta Shrestha, Pradeep Mool**, ICIMOD and **Chitra Prasad Acharya**, Consultant

Based on two different flood scenarios, the value of property at risk of potential GLOF in the Bhote Koshi/Sun Koshi basin – a trade route with well-developed infrastructure – is estimated to range from USD 153 million to USD 189 million. Infrastructure development planning is necessary to prevent such high loss of property.

Introduction

The Bhote Koshi is a transboundary river originating on the southern slopes of the Himalayas in the Tibet Autonomous Region of China (Figure 2). This river is called the Poiqu (Boqu) in Tibet, the Bhote Koshi in Nepal from the Nepal-China border (Friendship Bridge) down to the confluence with the Sun Koshi at Barhabise, and the Sun Koshi downstream from this confluence. Twenty-four GLOF events have been reported in Nepal, ten of which occurred in the Tibetan catchments of rivers flowing into Nepal (ICIMOD 2011). The Bhote Koshi/Sun Koshi River experienced three such GLOF events: in 1935, 1964, and 1981. The 1981 GLOF caused heavy loss of life, property, and infrastructure. The maximum discharge was estimated at 15,920 m^3 per second 23 minutes after bursting and the bursting flood lasted for an hour. Approximately 19 million cubic metres of burst water was discharged, 16 times more than the average annual flood in this river. Nearly 4 million cubic metres of debris was carried in the floodwaters as sediment in a moving layer ranging from 4 to 10 m thick (Xu 1985). The 1981 GLOF event swept away five people, 41 houses, two highway bridges, and many water mills. About 27 km of road were severely damaged. The total loss was estimated at NPR 11 million (about USD 750,000 at the 1981 conversion rate). Trade and traffic flow between Lamosangu (the start of the Lamosangu-Jiri road) and the market centre of Barhabise was blocked for 36 days and transport services between Barhabise and Kodari were disrupted for three years.

In the Bhote Koshi/Sun Koshi basin, 139 glacial lakes and nine lakes have been identified as potentially dangerous (Figure 3). Time series analysis shows that the number, area, and ice reserves of glaciers in this basin are declining, but that the number of glacial lakes and their area are increasing (Mool et al. 2005). One study warns that GLOFs with surges double the magnitude experienced in 1981 are likely to occur in the future in the Bhote Koshi/Sun Koshi River (WECS 1987). As the risk of GLOF in this basin is likely to increase in the future, this study was carried out to:

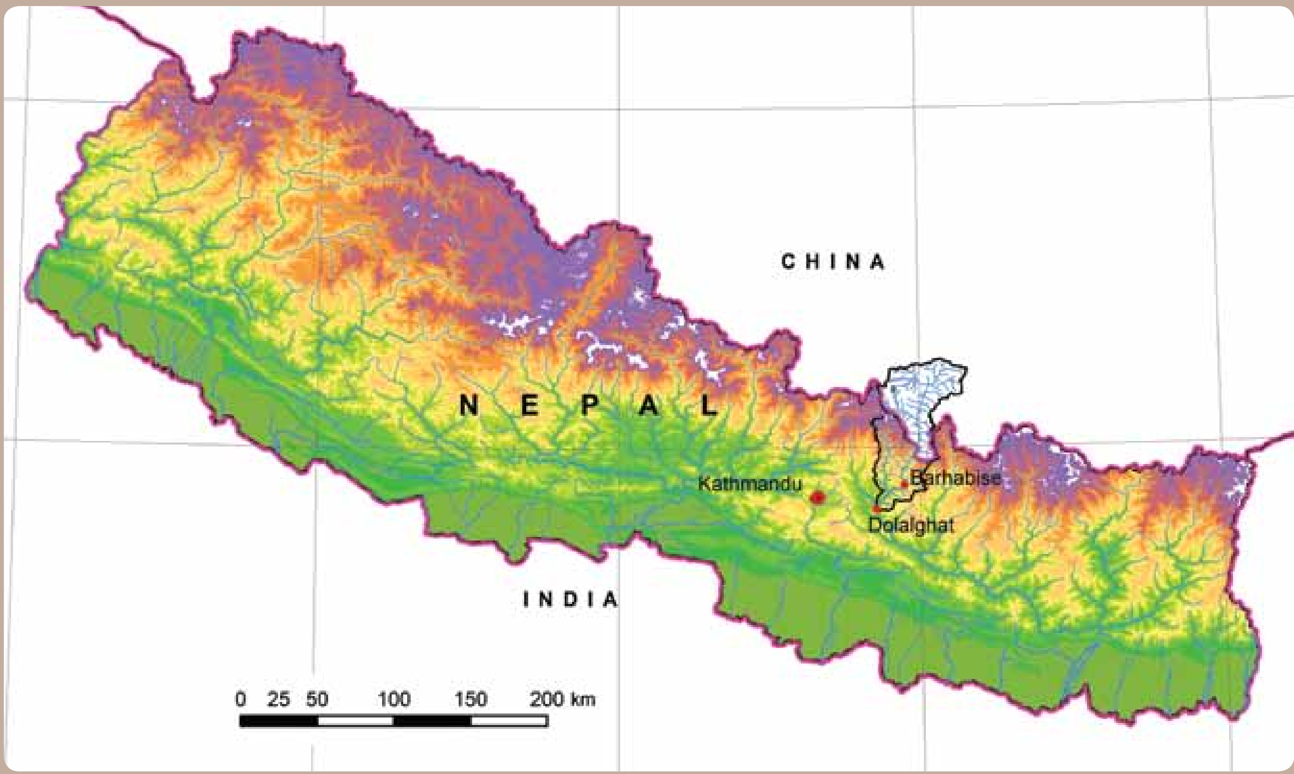
- review past GLOF events in terms of magnitude, loss, and damages and the rescue and relief activities conducted;
- identify and quantify (including in monetary terms) the elements exposed to GLOFs; and
- assess the perceptions and capacity of local people and identify their needs for capacity enhancement.

Methodology

The 1981 GLOF event was taken as a baseline event for the purposes of the study. The study area is along the Bhote Koshi/Sun Koshi valley from the Nepal-China Friendship Bridge on the border between Nepal and China in the north to Dolalghat in the South.The Bhote Koshi/Sun Koshi River was divided into ten blocks, each incorporating at least one major settlement.

Two flood scenarios were used to assess the potential GLOF risk. The first was the flood level experienced during the 1981 GLOF. Local people were asked to mark the 1981 flood level in different places and

Figure 2: **Map of Nepal with the Bhote Koshi/Sun Koshi basin**



those areas were delineated in topographical maps. The second scenario was subjectively fixed at 10 m higher than the 1981 level and those areas that would be affected by a flood of this magnitude were also delineated in topographical maps.

At least one meeting was held with key informants in each block to gather information. Discussions with wholesale agents, personnel of the Tatopani Customs Office, and local traders were also conducted to collect information on trade and traffic flow and their impact on employment and livelihoods.

Per unit cost was used to estimate the monetary value of potential loss. The value of individual property was calculated and added together to give a figure for total potential loss. Local prevailing purchase values were used for household assets (land, crops, and livestock) and replacement costs were used for infrastructure.

After preparation of a draft report, a one-day risk communication workshop was organized at the township of Barhabise. Local people from each block were invited to attend the workshop and share their perceptions and experiences.

Figure 3: **Major glacial lakes and potentially dangerous lakes in the Bhote Koshi/Sun Koshi basin**

Findings

Nearly 900 households with a corresponding population of 5,800 will be directly affected if a GLOF of the same magnitude as the 1981 GLOF occurs in the Bhote Koshi/Sun Koshi River as they are living within the GLOF hazard zone or their properties are within the hazard zone. This figure will increase to 2,519 households with a corresponding population of 16,313 people if GLOF is 10 m higher than the 1981 GLOF (Table 2).

The major ethnic/caste groups exposed to flash flood risk in the area are Sherpa, Tamang, Thami, Newar, Majhi, Chhetri, Bahun, and Dalit. Of these groups, Majhi and Thami are defined by the National Committee for Development of Nationalities as highly marginalized, Tamangs are categorized as marginalized, and Sherpas as a disadvantaged indigenous ethnic group. Nearly 50 per cent of families exposed to risk are poor and up to 30 per cent ultra poor. Poor, marginalized, and disadvantaged groups generally have less access to resources and decision-making processes, making them highly vulnerable to disasters including flash floods.

A GLOF in the area would affect the flow of vehicles, goods, and people along the Lamosangu-Jiri road, spreading the indirect impact to many village development committees (VDCs) in Dolakha, Ramechhap, and Solukhumbu districts (Figure 2). As per the population census of 2001, a total of 639,000 people are likely to be indirectly affected by damage to the Arnico Highway and Lamosangu-Jiri road (Central Bureau of Statistics 2001). Many more people involved in international trade with China and tourism activities to Tatopani and the Khumbu region are also likely to be affected.

The livelihood support system of more than 3,800 families living inside and outside the GLOF hazard areas is likely to be severely affected including wholesale and retail traders, hotels, industry, transport services, government services, and tourism. The Sun Koshi River is one of the world's top ten rafting rivers, with about six rafting spots along a 28 km reach of the river. A GLOF would affect seven hotels and numerous rafting operators, river guides, and tourism operators that serve the rafting tourism industry along this river.

The transport sector is also likely to be affected. More than 60 jeeps, 50 buses and minibuses, and 60 trucks shuttle daily along the Arnico Highway. This flow will be disturbed. Tatopani, which is located near the Nepal-China Friendship Bridge, is an international trade hub with China. The volume of international trade, including the amount of revenue collected by the government, will be affected by GLOF damage to bridges and roads and the consequent disruption in the flow of goods and services.

The estimated total value of property at risk of GLOF is USD 153 million under scenario 1 (a GLOF level the same as 1981) and USD 189 million under scenario 2 (a GLOF level 10 m higher than 1981). There will be a drastic increase in the share of private property (buildings, land, crops) and roads affected

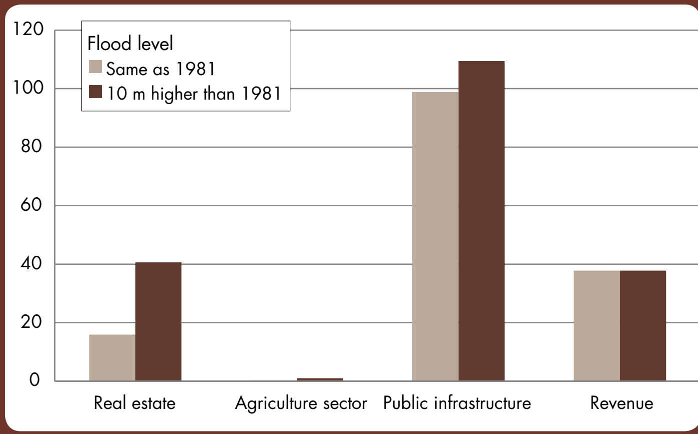
Table 2: **Elements exposed to potential GLOF event on the Bhote Koshi/Sun Koshi River**

Element exposed	GLOF level	
	Same as 1981 GLOF	10 m higher than 1981 GLOF
Households (number)	866	2,519
People (number)	5,782	16,313
Irrigated land (ha)	28.3	102.1
Unirrigated land (ha)	7.9	64.4
Housing plots (ha)	5.1	21
Paddy (tonnes)	122.5	384.5
Wheat (tonnes)	23.8	94.5
Maize (tonnes)	72.9	258.5
Millet (tonnes)	13.8	82.4
Potatoes (tonnes)	1.5	53.2
Fruit (tonnes)	27.3	81.7
Vegetables (tonnes)	166.3	586.8
Livestock (number)	1,005	2,620
Concrete houses (number)	248	586
Non-concrete houses (number)	483	1,527
School buildings (number)	6	13
Office buildings (number)	15	17
Temples (number)	7	10
Roads (km)	24	36.5
Trails (km)	1.4	20.5
Embankments (km)	5	5
Highway bridges (number)	2	7
Suspension bridges (number)	15	23
Hydropower plants (number)	3	3
Water mills (number)	4	11
Transmission lines (number)	14	24.5
Drinking water supply pipeline (km)	3.5	7.5
Fibre cable line (km)	5.5	8.5

under scenario 2 (Figure 4). The estimated total value of property at potential risk under scenario 1 is more than 153 times higher than the estimated loss experienced during the 1981 GLOF. This difference is partly due to the fact that there is now a lot more infrastructure in the area, including the Bhote Koshi Hydroelectricity Project, Power House of Sanima Hydroelectricity Project, and a fibre cable line along the road, and partly due to the fact that the total estimated value lost during 1981 was based on actual loss, which is far less than the potential loss.

Nearly 50 per cent of the property (in terms of monetary value) likely to be damaged is located in the Hindi area followed by Khandichaur (21 per cent), Lipin (17 per cent), and Barhabise (7 per cent), where major infrastructure development and economic activities are concentrated (Figure 5).

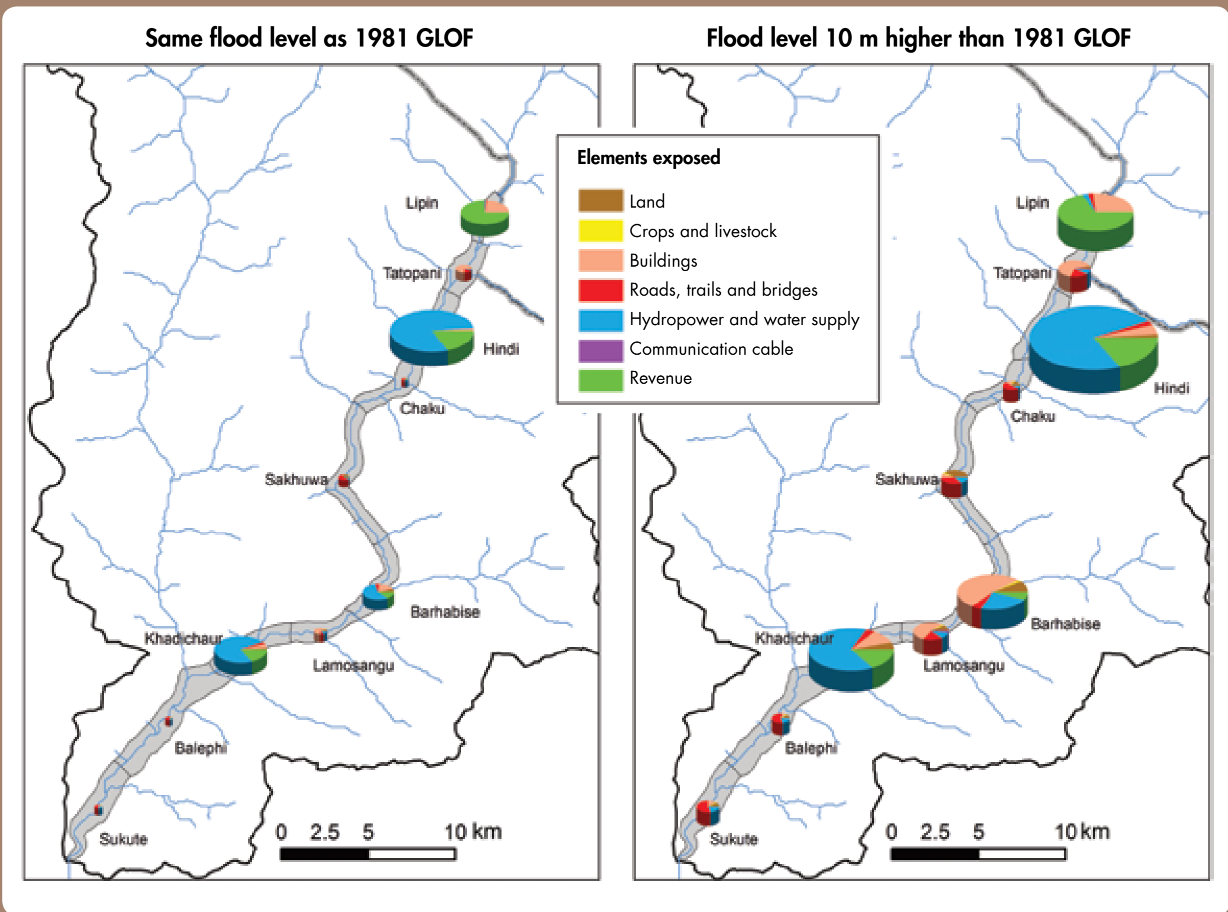
Figure 4: **Property at risk of GLOF in the Bhote Koshi/Sun Koshi basin, Nepal (million USD)**



Lessons for Risk Management

Local people are aware of the risk of GLOF and flash flood as they have experienced two major floods in the recent past: the GLOF event of 1981, which caused massive damage from the China-Nepal Friendship Bridge to Khandichaur downstream, and the cloudburst flood of 1987, which also caused heavy damage between Barhabise and Sukute. Many are also aware of the different mitigation measures necessary to reduce losses, such as early warning systems; rescue and relief operations; the establishment of shelters with food, water, clothing, sanitation, and health services; the construction and

Figure 5: **GLOF risk map of the Bhote Koshi/Sun Koshi basin, Nepal**



Note: The size of the pies are representative of the relative population size.

maintenance of embankments; and the formulation and enforcement of land use guidelines and building codes. But the implementation of such measures is limited because of poor technical and managerial knowledge about such measures combined with a lack of financial resources, institutional arrangements, and legal provisions.

An early warning system has been installed on the Bhote Koshi/Sun Koshi River by the Bhote Koshi Hydroelectricity Project. Five sensors are placed near the Nepal-China Friendship Bridge and automatic sirens have been placed in four different locations. The system is tested every three months and is fully functional. People living in those localities have been trained by the project, and signboards about the siren system have been erected in various localities. However, there is no warning system downstream for the powerhouse site at Hindi and there are no sensors in the upper reaches of the river in Tibet, China. For there to be enough lead time for evacuation, transboundary cooperation is necessary to monitor glacial lakes and develop an effective early warning system as all of the glacial lakes at risk of potential GLOF in this basin are located on the Chinese side of the border. A real-time data sharing mechanism is also essential.

After the 1981 GLOF, several mitigation measures were introduced. The road alignment was changed in several places from the flood plain/fan area to higher up the mountain slopes, and bridges were reconstructed and their design changed from truss to arch. Emphasis was placed on bioengineering and hill slope runoff management for the stability of toe slopes. River embankments were also constructed in several places to protect roads and settlements from flash floods including GLOFs.

Although different government and non-governmental institutions are involved in disaster risk reduction, their activities are limited and mainly focus on structural measures. There is no local-level institution focusing on disaster management in a holistic way to link upstream and downstream communities. There is also no institution responsible for the planning and safe development of human settlements along the road/riverbank, and land use guidelines and building codes are not enforced. In the absence of such control mechanisms, more and more settlements and infrastructure are being built in areas exposed to GLOFs.

There is no separate policy for managing GLOF risk in Nepal. However, some national policies do contain strategies and programmes to reduce the risk of GLOF. Many of these policies have adopted an integrated water resource management and river basin management approach with emphasis on community-based risk management. All these policies have programmes for the mapping and assessment of risk and vulnerability; establishment of early warning systems; development of non-structural measures such as flood forecasting and warning, floodproofing, and disaster preparedness; implementation of preventive measures; community sensitization and capacity development for risk management; development and strengthening of bilateral and multilateral cooperation in transboundary areas; land use and settlement planning; community-based disaster risk management planning; emergency response; and analysis of disasters to draw lessons to allow faster and effective deployment in case of disasters. The monitoring of potential GLOF lakes, implementation of structural measures, establishment of early warning systems, forecasting and preparedness in downstream communities, and support to vulnerable communities are some of the recommended programme activities in the NAPA and the Climate Change Policy, 2011.

Recommendations

- Extend the existing early warning system to the downstream reaches of the river (as far as Dolalghat) and adjoining areas to cover the entire area at risk of GLOF.
- Raise awareness among local people of the probability and magnitude of GLOF risk in the area and provide them with skill development training for preparedness planning and rescue and relief operations.
- Formulate a preparedness plan for GLOF risk reduction together with local communities.
- Strengthen regional, national, and local capacities for GLOF risk reduction through awareness creation and skill development activities.
- Establish an emergency fund and community shelter with provisions for food, clothing, drinking water, and health services.
- Develop and implement land use guidelines and building codes together with the local community.
- Integrate and coordinate road network development, land use planning, and settlement and market centre development with disaster risk reduction activities.
- Form a transboundary (Nepal-China) team to conduct field investigations on glacial lakes and the river channel to determine the probability and potential magnitude of a GLOF in the Bhote Koshi/Sun Koshi basin towards developing a flood forecasting model and an early warning system with enough lead time to enable evacuation.
- Establish a network of institutions dealing with disaster risk reduction at the regional/transboundary, national, and local levels to share information on GLOF risk.
- Establish institutions that focus on flash flood management with dense community networks.

Chitral, Pakistan

Flash flood risk assessment, capacity building, and awareness raising

Wali Mohammad Khan and Salman Uddin, Focus Humanitarian Assistance (FOCUS) Pakistan

FOCUS Pakistan partnered with communities in Chitral District to develop a flash flood early warning system consisting of announcements in mosques and other gathering places and via mobile phones, and to build community response skills through a dedicated team of volunteers. This approach could be scaled up to greatly minimize vulnerability across the whole district.

Introduction

Chitral District is located in the Koh Hindu Kush range in Khyber-Pakhtunkhawa Province of Pakistan. It shares a border with Afghanistan to the west and north and with Gilgit-Baltistan, the northernmost part of Pakistan. Geographically, it is one of the largest districts in Khyber-Pakhtunkhawa Province, covering an area of around 14,800 km^2 with a population of over 450,000 people.

Administratively, Chitral District has two tehsils (Chitral and Mastuj), 24 union councils, and 523 villages. Around 4.8 per cent of the land is covered by forest and 76 per cent is mountains and glaciers; barely 4 per cent of the total land area is viable for cropping. The literacy rate is 59 per cent (men 77 per cent; women 40 per cent) and the population growth rate has been estimated at 2.5 per cent per annum. The people of Chitral belong to over a dozen different cultures and speak more than 14 languages. As a result of its unique location and historical links with Central Asia, the culture of Chitral bears traces of Greek, Iranian, Mongolian, Tatar, and Turk influences.

Agriculture is the main source of livelihood for the people of Chitral. Approximately 60 per cent of the area is a single cropping zone. Some parts of Upper and Lower Chitral are in a double cropping zone. Maize, wheat, and barley are the main crops. Fruit and vegetable sales contribute to the income of several families. Almost 40 per cent of Chitral's population is engaged in government service, private jobs, trade, or some form of entrepreneurship.

Chitral is situated in a multi-hazard prone zone. Every year, life, property, and hard-earned means of livelihood are lost as a result of different kinds of natural and human-induced disasters. Flash floods, glacial lake outburst floods, earthquakes, avalanches, landslides, debris flows, droughts, heavy rain and snow, soil erosion, and riverbank collapses are common natural hazards in the district. In 2007, massive snowfall led to the loss of 78 lives and caused widespread devastation and disruption of infrastructure, with recovery efforts costing around USD 12 million. About 90 per cent of Chitral District is at risk of flash flooding.

There are limited contextualized policies in place at the national level in Pakistan to deal with flash floods as a separate category of flood. The majority of organizations, including disaster management authorities, rely on materials and plans proposed by international agencies like ICIMOD.

In 2008, FOCUS Pakistan, in collaboration with ICIMOD, implemented a community-based project on reducing flash flood risk in Chitral District. The project aimed to assess the risk of flash floods, raise awareness about flash flood risk, and strengthen the capacity of local people to manage such risk.

Flash Floods in the Study Area

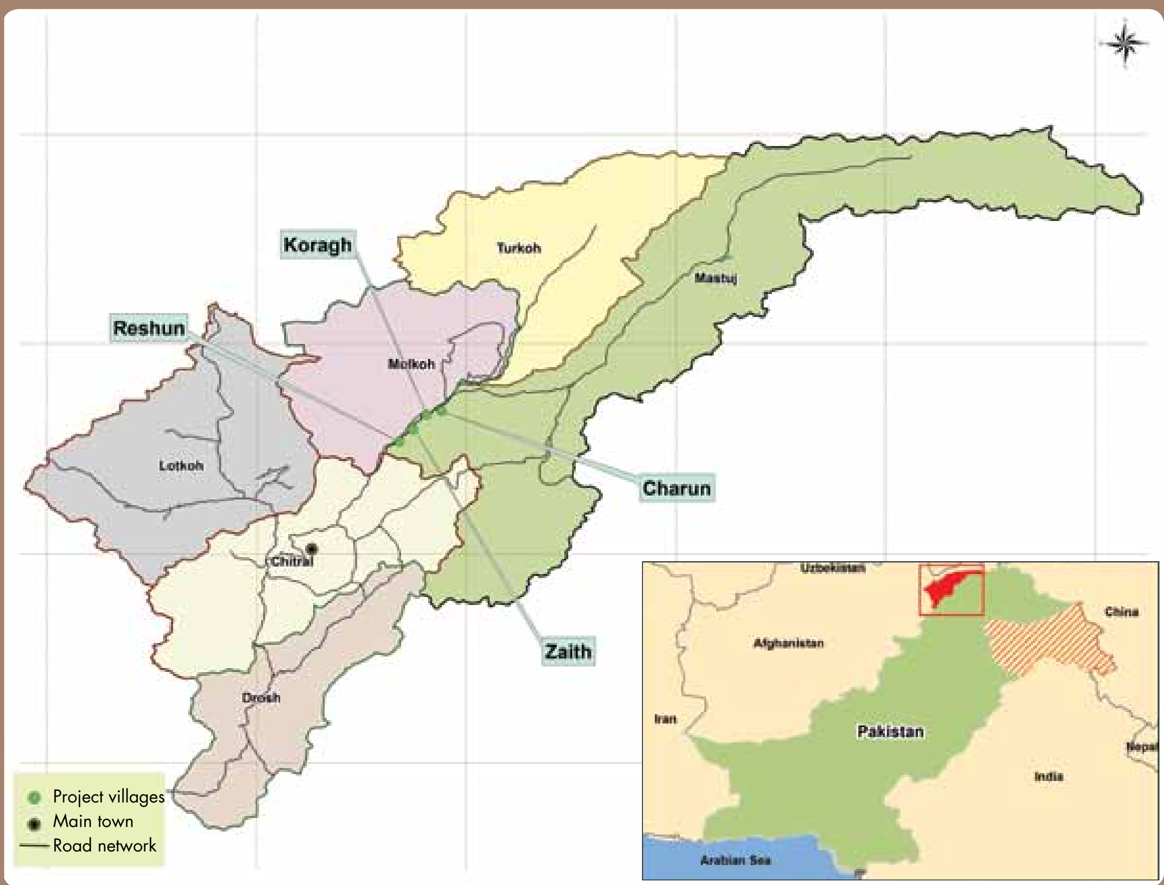
Four villages in Chitral were selected for study: Charun, Koragh, Zaith, and Reshun (Figure 6). These villages are situated in Mustuj Tehsil, on the west side of the Yarkhun River, 70 km from Chitral town, and fall into a double cropping zone. Of the four villages, Zaith is the most flash flood hazard prone. Two streams flow into the village from different directions and meet at the centre of the village. Many other tributaries also flow into the main stream and increase the volume of water, frequently causing bank collapse and eroding fertile lands into the stream. The combined population of the villages in the study area is 8,650 distributed in 1,015 households. Every year these villages are affected by flash floods. Major flash floods have occurred in 1973, 1984, 1997, 1998, 2004, and 2005, causing the loss of hundreds of lives and affecting houses, agricultural production, infrastructure, and livestock. The recurring trend of disasters has forced villagers to move numerous times to different places within the village.

As in other parts of Chitral District, the villages in the study area are surrounded by mountains and do not receive significant monsoon rain. The Drosh Valley and Chitral town, both located in Lower Chitral, receive rainfall of approximately 650 mm and 500 mm per year, respectively, falling mainly in spring and winter. During summer and autumn these areas are mostly dry, receiving barely 10–25 mm of rain per month. Temperatures are very hot in summer and extremely cold in winter, with snow falling at higher altitudes.

Methodology

The project initiated a community-level dialogue at the start of the project with government representatives, local support organizations, Community Emergency Response Team (CERT) volunteers, and local leaders. The study objectives and pilot phase were explained to the communities in the study area. The methodology and processes of project implementation were also shared and agreed upon at the implementation stage.

Figure 6: **Map of Chitral District showing target villages for flash flood mapping**



Project Activities

The study had three main components:

- **Risk assessment:** Hazard, vulnerability, capacity, and risk assessments were undertaken through the documentation of indigenous flash flood management mechanisms in the community.
- **Capacity building:** The project built the capacity of CERT volunteers as first responders for flash flood management and to develop community-based flash flood response and evacuation plans.
- **Awareness raising:** The project conducted awareness raising at the community level through an awareness-raising walk, quizzes, and a lesson sharing workshop.

Project activities included the following:

- **Technical studies:** Technical studies were conducted by FOCUS Pakistan's Hazard Vulnerability Risk Assessment Team and used for evacuation planning. Flash flood mapping was conducted to identify where flash floods may occur and where additional evaluation is needed to assess the hazard and recommend mitigation measures. FOCUS Pakistan's Regional Programme Office in Chitral, in collaboration with ICIMOD, completed flash flood hazard and risk mapping of Charun, Koragh, and Zaith. These maps can be used to develop an early warning system and for land use planning, village disaster management plan (VDMP), and to compile an inventory of scientific and indigenous knowledge on flash floods in the area to enhance the response at the community level to reduce the impact of flash floods.
- **Hazard and risk assessment:** Hazard and risk assessment was one of the key activities conducted by the project. Building on the technical assessment of hazard and risk conducted by the Hazard Vulnerability Risk Assessment Team, household surveys and focus group discussions were conducted with the help of questionnaires and pre-defined checklists to obtain data on community and government assets, gather historical data, and ensure community involvement. Community members were provided with satellite images to develop their own risk and hazard maps. Community-based risk and hazard map transect walks were conducted in the hazard prone areas identified by communities. Communities also identified evacuation routes and safe locations on the maps.
- **Social hazard mapping:** Social hazard mapping was conducted in three of the study sites – Reshum, Koragh, and Zaith (Figure 7).
- **Training needs assessment and target group profile:** A training need assessment and target group profile were conducted to select participants and assess their training needs for capacity building on flash flood response.
- **Training of trainers for community-based flash flood risk reduction:** A community-based flash flood risk reduction workshop was conducted to develop the capacity of the local CERT volunteers in flash flood response. Theoretical and practical sessions were held for all volunteers on hazard awareness, light search and rescue, first aid, and evacuation.
- **Awareness raising:** Disaster risk reduction sessions were conducted in schools and for CERT leaders (CERT leadership workshop and refreshers). A quiz on flash floods was held to share information on flash floods. The quiz contained questions on preparedness and measures to be taken during a flash flood event. Communities also participated in awareness walks to raise mass awareness about flash flood risk management, particularly among female CERT volunteers (Figure 8).

Figure 7: **Social hazard map of Charun village**

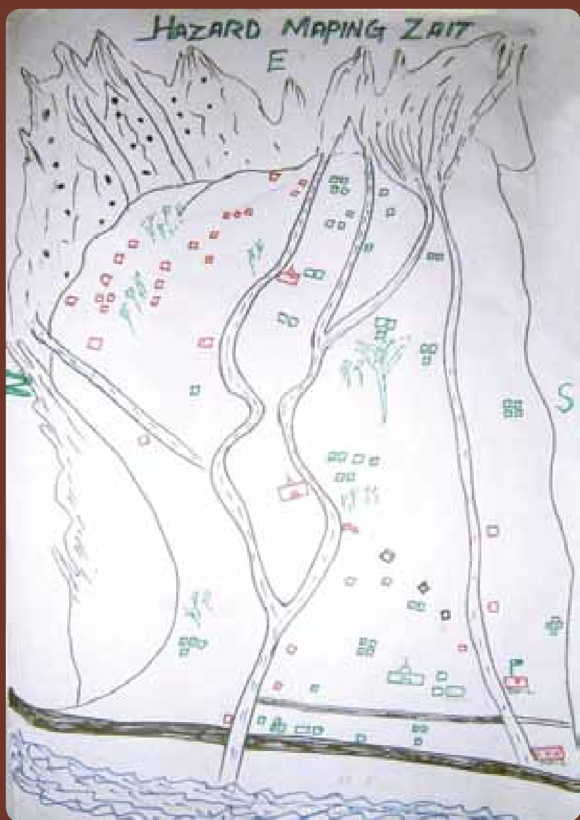


Figure 8: **Awareness walk in Koragh village**

Figure 9: **Simulation exercise in Reshun village**

- **Simulation exercises:** Simulation exercises were conducted in Reshun village to enhance community response in a flash flood disaster situation (Figure 9). One-hundred-and-twenty CERT volunteers were given skills training on how to react in an actual flash flood situation. The readiness of these teams is constantly tested through drills and simulation exercises.
- **Lesson-sharing workshop:** A lesson-sharing workshop was conducted to share key findings and lessons learnt on flash floods with relevant stakeholders, i.e., government representatives, members of the Aga Khan Development Network, members of NGOs, representatives of civil society organizations, local leaders, and CERT leaders. This workshop had two main objectives: advocacy and the capacity development of stakeholders. It also served as a platform for discussing ways of mitigating flash flood risk and how to develop institutional mechanisms to minimize hazards with community participation at various levels.

Results

The study found that short-duration intensive rainfall and cloudbursts are the main causes of flash floods in the study area (as identified in group discussions with community members and verified by technical analysis). The surface topography of the upper study area and its composition of very loose, unconsolidated soil, which is highly unstable and non-cohesive in nature, make the area prone to flash floods during intensive rainfall. Human activity and interference with the natural environment, such as overgrazing in the upper catchment and deforestation, compound the problem as lack of vegetation causes direct runoff which can trigger a flash flood. This, together with climate change, is contributing to increases in the frequency and magnitude of flash floods in the study area.

Up to 13,428 km^2 of land is at risk of flash floods in these four villages, and siltation caused by frequent flash flood events has reduced local agricultural production. Livestock are also at risk: about 200 animal sheds in the four study villages are exposed to flash flood hazard of high intensity. While community members are aware of flash flood hazard, extreme poverty and population growth is forcing villagers to build in hazard prone areas, exacerbating their vulnerability and risk.

The project's contributions to flash flood risk reduction in the study area can be summarized as follows:

- CERTs established in each study village;
- community-based flash flood response and evacuation plans developed for each study village;
- 120 CERT volunteers trained as first responders and in community-based flash flood risk management;
- community stockpiles of materials and equipment provided for flash flood preparedness and response in Charun and Reshun;
- awareness raised among community members of flash flood risk and preparedness strategies;
- early warning system set up through CERT volunteers who provide early warning to downstream people using mobile phones and

through announcements in mosques and other gathering places;
- non-structural mechanisms implemented including the formation of natural resource management committees and strengthening of indigenous social organization system; and
- structural mitigation programme implemented in collaboration with the government and NGOs including the construction of protective walls and check dams.

In addition, improved irrigation channels have also been constructed by the Aga Khan Rural Support Programme and the government.

The results of the project can be summarized as follows:
- **Improved capacity of CERT:** The project significantly improved the capacity of CERT volunteers as first responders during flash flood events. This brought with it a certain level of awareness of how to mitigate flash flood risk (Box).
- **Reduced flash flood risk and hazard:** The project activities have minimized the flash flood risk and hazard in the study. Communities are now more prepared through CERT volunteers, the early warning system, evacuation plans, and community stockpiles, which have already proved useful in flash flood emergencies.
- **Informed decision making:** The technical studies conducted as part of this project have helped policy makers in planning and decision making. Development initiatives are benefiting from the flash flood hazard and risk maps developed by the project, which are being used as a pathfinder and guideline for development practitioners.

Best Practices and Lessons Learnt

The practice of community-based flash flood risk management should be up-scaled and replicated at all levels, as well as in other parts of Chitral District, which are equally at risk of flash floods. Harnessing communities as a resource is imperative to disaster management, which is a shared responsibility between all stakeholders, and, therefore, all stakeholders must be involved.

Box: **Building community resilience: CERT volunteers respond to flash flood events**

In 2010 and 2011, CERT volunteers in the study area responded to several flash flood events. They provided shelter and relief to affected families and conducted damage assessments, which they shared with FOCUS, the government, and responding agencies. CERT volunteers have also been involved in re-construction work with families that lost their homes and other valuable asset. CERT volunteers are seen as 'blessing squads' in the study villages and their valuable contribution has been acknowledged at all levels.

The following lessons were learnt from the project and may be relevant throughout the region:
- A holistic approach and community participation is imperative for the success of any intervention.
- Structural mitigation is crucial and goes hand-in-hand with non-structural mitigation in reducing risk and ensuring safety. Non-structural measures alone are insufficient.
- Risk reduction is more complex than mitigation and requires the involvement of all stakeholders at the community level as well as district, and national levels to be effective.
- Social mobilization is needed at the grassroots level; for this, strong and motivated leadership at the community level is important.
- Revitalization of local knowledge and community organizations is important for risk management.
- Poverty compounds the vulnerability and risk faced by communities.
- Rapid population growth and overgrazing can increase risk and vulnerability to flash flood, particularly when settlements expand into unsafe areas.
- Community preparedness is pivotal for flash flood risk reduction.

Recommendations

- Implement structural measures to mitigate flash flood risk such as protective gabion walls, which have been identified as necessary to mitigate risks by the communities and through technical assessments.
- Replicate and up-scale community-based flash flood risk management in other parts of Chitral, and empower communities to withstand and minimize flash flood hazard.
- Encourage afforestation and discourage deforestation. A sustainable plan should be developed by the community, government, and other responsible agencies for dealing with the issue of deforestation and balancing the needs of the community for fuelwood.
- Strengthen indigenous social organizations and mechanisms as a way of controlling overgrazing and deforestation, and develop an effective standard operating procedure for the local committees in each village.
- Integrate scientific knowledge with traditional knowledge and indigenous practices, and establish communication channels with scientific technicians.
- Develop effective insurance/micro-insurance and credit schemes to compensate local people for the loss of crops, livelihoods, livestock, and other property as a risk sharing initiative. Government and non-governmental organizations and stakeholders working in this field could be motivated to initiate such a programme.
- Use hazard maps for land use planning to ensure that houses, animal shelters, and crops are not in hazard prone areas.
- Prioritize and mainstream disaster risk management at all levels and systematically consider risk from natural hazards for the sustainability of development activities.
- Develop and introduce school-based flash flood risk management sessions for students, teachers, staff, and management.
- Promote the conservation and preservation of natural resources, with community participation as an effective way to minimize natural disasters.

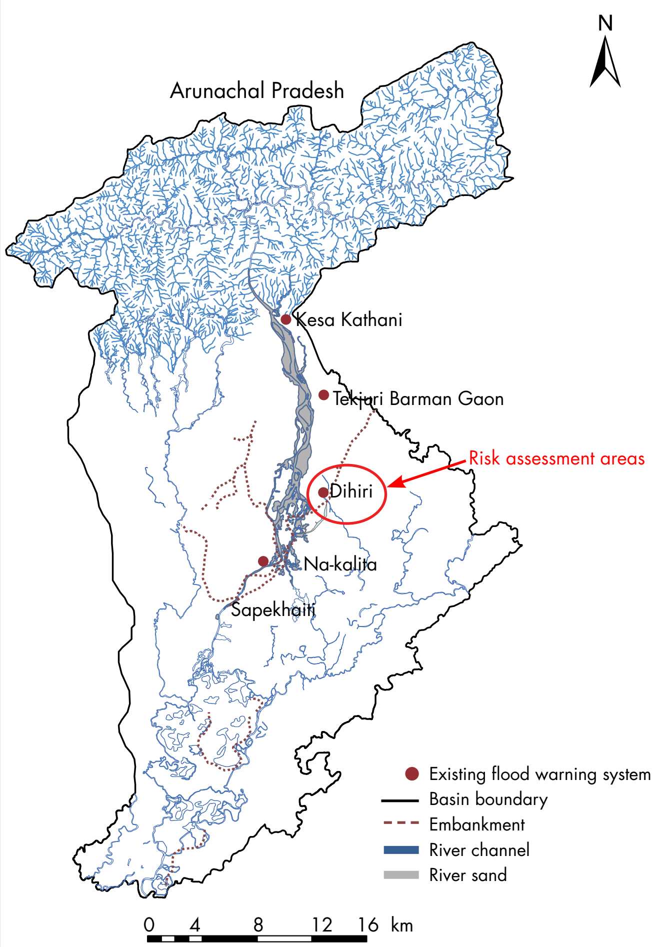
Jiadhal River Catchment, Assam, India

Building community capacity for flash flood risk management

Partha J Das, Aaranyak

Simple, community-based early warning systems installed in the Jiadhal River have enabled downstream communities to prepare better for flash floods. To make these systems more effective, improved technology and collaboration between upstream and downstream communities and state governments are needed.

Figure 10: **Location of Jiadhal River catchment**



Introduction

This case study summarizes the activities and results of a one and a half year action research project conducted in 2010 and 2011 in the Jiadhal River catchment (Figure 10). The research was conducted at three spatial levels: a geo-environmental assessment was conducted at the catchment level; a smaller core of 20 flood-prone villages lying close to embankments were selected for community capacity development at the village cluster level; and two villages on the northern part of the National Highway-52 were selected for flash flood risk assessment at the village level.

The Jiadhal River spans two states of India: Arunachal Pradesh and Assam. A north-bank tributary of the Brahmaputra, the Jiadhal River originates in the lower Himalayan ranges in West Siang District of Arunachal Pradesh and flows southward through the flood plains of Dhemaji District in Assam in a complex network of channels before meeting the Brahmaputra near Majuli Island. The Jiadhal River catchment covers an area of 1,205 km^2, of which 370 km^2 (31 per cent) lie in the hills of Arunachal Pradesh and 835 km^2 (69 per cent) lie in the plains of Assam. The sub- tropical monsoon climate may be stated as the general climate for the whole catchment, with the upper catchment moist in all seasons, with a harsh winter and shorter summers at higher elevations (Hazarika 2003). Average annual rainfall in the catchment ranges from 2,965 to 4,386 mm, with a mean annual rainfall of about 3,150 mm.

Agriculture is the main source of livelihood in the study area; other livelihood activities include fishing, sericulture, horticulture, employment in the government and private sectors, and wage labour. The study area is inhabited by a number of communities with different cultures and linguistic characteristics (Mishings, Ahoms, Chutiyas, Konches, Sonowal Kacharis, Bodos, and Deoris). Assamese, Mishing, and Bodo are the principal languages spoken. Hinduism is the religion of the majority of the people, and Islam is also practised by some.

The north bank tributaries of the Brahmaputra generally flow in shallow, braided channels with steep slopes that carry a heavy silt charge and are prone to flash floods (Goswami 1998). The Jiadhal River is a classic example of a flashy river and produces floods with a sudden, high discharge over a short time interval (a few hours to a day) and with a high sediment load and debris. The flashiness of the river can be mainly attributed to high rainfall in the upstream hilly catchment and the basin as a whole, and the steep piedmont zone between the foothills and the flat alluvial plains through which the river flows. Flash floods in this river are generally triggered by continuous heavy rainfall or extreme rainfall events (such as cloudbursts). The river doesn't always flow in a confined channel; the rising bed level caused by deposition of silt results in flood waters overtopping the banks quickly and spreading out like a sheet over a large area in the foothills and plains

The river frequently changes its course during flash floods, resulting in the breaching of embankments, widespread riverbank erosion, and massive inundation and destruction of the countryside, which consists mainly of rural settlements and farmland. The deposition of coarse sand and silt particles on the inundated plains can reduce soil quality making the land unfit for agriculture. This has emerged as the most serious impact of flash floods in the Jiadhal River catchment in the last three decades.

In recent times, devastating flash floods were recorded on the Jiadhal River in 1984, 1988, 1989, 1992, 1994, 1997, 1998, 2002, 2007, 2009, and 2011. In terms of monetary loss, the flood damage in 2002 was about USD 3.1 million (based on the rate of USD 1 = Indian rupees 45). About 680 villages, 9,885 km^2 of land, and 23 million people were affected by the floods of 1998, and 48 people died in floods between 1989 and 2002 (Hazarika 2010). The major flood in 2007 caused by failure of the right embankment near the bridge (National Highway-52) on the Kumatiya branch of the river devastated about 30 villages on the right bank. The flood in 2009 broke the left embankment and caused havoc in about 50 villages. In the year 2011, as many as five waves of flash floods occurred in the river with the most catastrophic taking place on 15 August 2011, severely affecting about 85 villages and 300 hectares of crop land, including a large area with standing crops. Most of these flash floods resulted in failure of embankments and changes in the river course in several places, making the floods more hazardous.

The most serious damage caused by these flash floods is the widespread deposition of sand on fertile agricultural land. About 5.72 km^2 of land lying in more than a hundred villages has been seriously affected by sandcasting (Deka 2008). Land use and land cover analysis conducted as part of this study indicates that in the last four decades (1973–2010), the area affected by sand has increased by 18 per cent and the agricultural area under both summer and winter crops has decreased by 34 per cent, which implies a direct impact on agricultural livelihoods and food security in the catchment area.

Conventional flood management in the Jiadhal catchment is based mainly on the construction of embankments and has failed to protect people from floods and flash floods. While structures such as dykes have underperformed or become counterproductive as a result of poor maintenance, non-structural measures such as flood forecasting, early warning, catchment treatment, and enhancement of adaptive capacity have been largely overlooked. It became necessary to demonstrate the efficacy of a community-based flash flood management system designed with adequate scientific understanding of the flood regime and socioeconomic systems combined with activities to increase community resilience. Accordingly, this project was conducted to:

- generate flash flood early warnings in four villages upstream using simple devices and disseminate the same through community networks to downstream areas to help people to better mitigate flash flood impacts;
- assess vulnerability and risk to populations in a high risk-prone area of the basin as a pilot through flash flood risk mapping using specifically designed field techniques and incorporating both scientific and local knowledge;
- raise awareness in the study area to sensitize communities as to best practices for flash flood risk management; and
- disseminate knowledge gained through the project to local, state, and national level policy makers.

Flood Management in the Study Area: Governance and Policy Perspectives

There is no separate policy for managing floods or flash floods in Assam or India. India's existing water and disaster management policies contain principles and strategies for flood management. At the national level, the first policy statement on flood control was made by the Government of India on 3 September 1954 (Mishra 2002). This statement envisaged three types of flood control measures: immediate, short-term, and long-term. Immediate measures include revetments, spurs, and embankments at selected sites. Short-term measures (second phase) include the construction of embankments and channel improvement covering large parts of affected areas. Long-term measures (third phase) will consist of building of storage reservoirs on certain rivers and additional embankments if necessary (Brahmaputra Board 1985).

The central government has created committees, commissions, and task forces from time to time to study flood and erosion in different regions of India (e.g., High Level Committee on Floods, 1957; the Ministers' Committee on Flood Control, 1964; the National Commission on Floods, 1980; the National Commission for Integrated Water Resources Development, 1999; the Taskforce on Flood Management and Erosion Control, 2004) and their recommendations and suggestions are also acknowledged as policy guidelines for flood managers in national and state agencies. Recently, the National Disaster Management Authority (NDMA) has prepared a set of guidelines for flood risk management to assist the ministries and departments of the national government, the state governments and local governance agencies (like the panchayat raj institutions and urban local bodies) in preparing flood management plans (NDMA 2008).

In India, flash floods are dealt with using the same strategies adopted for normal riverine floods. The fact that flash floods are distinctly different from normal riverine floods in terms of causes, propagation, intensity, impacts, predictability, and management is yet to be recognized by policy makers. Flash floods are generally not considered or investigated as a separate class of events, but merged with the overall seasonal flood situation in government reports.

The National Disaster Management Authority is the supreme administrative institution for disaster management in India; under it are the various state disaster management authorities and district disaster management authorities. These institutions are governed by the National Disaster Management Act, 2005, and the National Disaster Management Policy, 2009. With the enactment of the National Disaster Management Act, there has been a paradigm shift in disaster risk management, from a relief-centric response to a proactive prevention, mitigation, and preparedness-driven approach to conserve developmental gains and minimize loss of life, livelihood, and property. The National Disaster Management Policy captures recent advancements in the field of disaster management and allied disciplines. Through this policy, the Government of India seeks to build a safer and disaster resilient India by developing a holistic, proactive, multi-disaster oriented, and technology-driven approach through a culture of prevention, mitigation, preparedness, and response. If translated into action, the measures contained in this policy will be extremely useful for flash flood management.

The Draft Water Policy of Assam deals better with floods and riverbank erosion than the National Water Policy, although conventional structural measures retain their prominence. Integrated water resource management also receives more attention in this policy. Unfortunately, the present policy is not operational and, in the absence of other influential central guidelines, integrated water resource management is almost non-existent in the institutional mechanisms of water governance in Assam.

The State Government of Assam has adopted structural measures such as embankments, spurs, and porcupines to contain floods and resist bank erosion, including in the Jiadhal River catchment. The Assam State Disaster Management Authority and the Dhemaji District Disaster Management Authority follow routine measures for the capacity building of villagers to enhance flood preparedness by imparting training and awareness on how to deal with floods generally. The National Disaster Response Force is deployed to rescue people when major flood waves strike. The Dhemaji District Disaster Management Authority and the Revenue Department with support from the District Administration provide relief and rehabilitation to deal with post-flood situations. The Central Water Commission provides flood forecasts in terms of water level in different stretches of the Brahmaputra River, but such information is not available for its tributaries.

Methodology

To gain an understating of the geo-environmental and socioeconomic aspects of the study area, secondary information and data were collected from government reports, census reports, journal articles, research papers, dissertations, and newspaper reports. The critical observations of the research team during field studies contributed to this appraisal. To study the changes happening in the landscape in the catchment area, maps were prepared using multi-date satellite data and GIS-based analysis and interpretation. Mapping of hazard, vulnerability, and risk was done using a method designed for this study that integrates information about the physical environment derived from analysis of high-resolution Google Earth Pro Images and socioeconomic data derived from field studies using Participatory Rural Appraisal techniques. Ground verification of the results obtained from image analysis was done using standard methods for participatory GIS mapping.

Project Activities

The project had four distinct components: understanding of the nature and causal dynamics of flash floods in the Jiadhal River in the geo-environmental context of the catchment (research); piloting of a flood early warning system (intervention for disaster risk reduction); sensitizing people on flash flood risk mitigation (education, capacity building, and advocacy); and assessment of flood risk by mapping hazard, vulnerability, and risk (participatory research).

An attempt was made to collect and analyse available information and data on the geo-environmental, hydrological, geomorphologic, and socioeconomic aspects of the Jiadhal River catchment in order to better understand the characteristics of flash floods on this river, their causal dynamics, and impacts. However, limited information and data were available to develop an up-to-date status report on the river and its catchment. Long-term continuous time series hydrological data on discharge, water level, and sediment load were not available. Socioeconomic data and information at the catchment level were also not found. A detailed analysis of land use/land cover using remote sensing and GIS techniques conducted as part of this study pointed to significant changes such as deceasing forest cover, increasing the sand-affected area, and decreasing the area under agriculture.

Four flood early warning systems were installed in four flood-prone villages in the upstream section of the Jiadhal River: Kesa Kathani, No. 2 Tekjuri Barmangaon, Dihiri, and Na-Kalita (Figure 10). These villages were selected for their proximity to the foothills in the upstream section, cooperative villagers, and accessibility during floods. The instrument used in the early warning system was a simple flood alarm device consisting of a flood gauge and a rain gauge calibrated with risk levels by consulting the villagers (Figure 11). The installation and maintenance of this system is simple enough to be handled by the community. The members of the family hosting the instruments and other selected individuals in each village were trained to install, operate, and maintain the flood warning system as well as to interpret the warning sirens. A home light unit that works on LED, along with a mobile phone and charger, were given to each host family.

Awareness programmes were carried out in 20 villages where stakeholder communities were sensitized on relevant subjects such as health, the economy, agriculture, education, perceptions of hazard, vulnerability and risk, flood warning, flood

Figure 11: **Installation of a flood gauge at Barmaba village**

impact, flood mitigation measures, the governance system associated with flood management, role of civil society and the community in flood risk reduction, and good adaptation practices (Figure 12). Demonstration of the flood early warning system using a prototype formed an integral part of all awareness programmes. Awareness programmes were conducted for small groups as shared learning sessions so that both the project team and the community could learn from each other. Each programme was designed to be completed in three to four hours so as not to engage villagers for more than half a day. Twenty Village Flood Management Committees (VFMCs) were formed in different parts of the study area to disseminate flood warnings, support the project work, and continue capacity-building activities.

A cluster of 16 neighbourhoods belonging to two villages, namely, Dihiri (with seven neighbourhoods) and Kekuri (with nine neighbourhoods), located on the north bank of National Highway-52 was selected for the risk assessment study. Inhabited by the Mishing community, these villages are two of the most risk- prone areas in Dhemaji District with poor economic conditions, inadequate flood and erosion mitigation measures, and lack of development infrastructure. The village of Dihiri is virtually unprotected from floods since the old embankment collapsed in 1984 and has nearly entirely eroded away near the village. Of the seven neighbourhoods in this village, three are located on a small riverine island isolated from roads and nearby villages and fully exposed to the river; these villages contain the most vulnerable populations in this area. The village of Kekuri is partly protected by an embankment with villagers scattered on both sides of the dyke-cum-road. Two neighbourhoods live completely outside the embankment, four settlements are partly scattered on both sides, and three are protected by the embankment.

Figure 12: **Community awareness programme at Dihiri village**

Results and Findings

The project resulted in production of a flash flood training module, flash flood risk management guidelines in Assamese language, the publication of the proceedings of a workshop, production of a set of general catchment maps, generation of information and knowledge on the land use/land cover change scenario in the study area, production of risk maps, and the installation of flood early warning equipment supported by community networks.

Generating Knowledge: The project generated new information and knowledge on land use/land cover changes and channel shifts induced by floods in the Jiadhal River catchment over the last four decades. The project established the role of the river's high sediment load in increasing flood havoc and land degradation leading to loss of agricultural livelihoods.

Assessing flash flood risk: The pilot risk assessment exercise carried out on a small scale (in Dihiri and Kekuri) produced an understanding of the factors that determine risk to vulnerable populations and that are common to other similar situations. Examples of such factors include proximity to the river, the condition of embankments, presence or absence of safe shelter, transport and communication facilities, the state of development, and local governance and policy instruments. The risk assessment found that people in the study area are highly vulnerable to flash floods because they live close to rivers and embankments that are in bad shape and prone to breaching in a landscape where there are no roads for transport and communication, which hampers relief and rescue operations. In most cases there are no safe shelters nearby and those that do exist are in a dilapidated condition. The overall socioeconomic condition of communities in the study area is poor, with 80 per cent of villagers living below the poverty line; widespread malnutrition, and a lack of education, safe drinking water, and health and hygiene facilities, making them more vulnerable to flash floods.

Understanding the local governance situation: The performance of local governance agencies is critical to reducing risk in flood-prone areas such as the Jiadhal River catchment. However, lack of transparency, accountability, coordination, and efficiency in the government line agencies at the district level and in the panchayat raj institutions and autonomous district councils hamper flood management and rural development. There is no scope for the participation of communities or civil society in decision making or in the implementation of flood management projects. On the other hand, civil society organizations, students' organizations, and community groups (such as the Jiadhal Nadi Baan Pratirodh Oikya Mancha, Asom Jatiyatabadi Yuva Chatra Parishad, Takam Mising Porin Kebang, and Krishak Mukti Sangram Samiti) play an exemplary role through advocacy and activism as watchdogs over the government's performance in flood mitigation and rural empowerment programmes. They also carry out non-violent agitations from time-to-time to demand technically suitable flood management projects, an end to corruption in the implementation of government programmes, and proper compensation, rehabilitation, and resettlement packages for people affected by floods and erosion. In addition to compelling authorities to provide information on flood control schemes using the Right to Information Act (2005), these local organizations have succeeded in getting the Water Resources Department to attend negotiations with local people. Some of these organizations have participated in activities undertaken as part of this project and by other agencies pertaining to flood risk reduction.

Assessing the policy situation: The fact that Assam does not have a clear policy on flood or flash flood management hampers decision making, implementation, and coordination in relation to flood mitigation projects. Although flood management in a transboundary river such as the Jiadhal calls for joint river management between the state governments (of Assam and Arunachal Pradesh), especially in the upstream catchment in the hills and foothills, there is no formal mechanism in place to facilitate joint efforts for ecologically sensitive structural interventions, river training, or the exchange of flood information. The prevailing system of rehabilitation and resettlement does not meet the needs of flood-affected people. Non-structural measures for flood mitigation and other major recommendations from relevant commissions, as well as the guidelines and principles laid down in the National Disaster Management Act (2005) and the National Disaster Management Policy (2009), have not been implemented properly. Panchayats and the autonomous councils have not been empowered, either financially or functionally, to deal with local flood problems.

Mitigating flood impact: The flood warning instruments installed by the project have provided communities with early warning of flash flood waves on six occasions between August 2010 and August 2011: 21 August 2010 (early midnight, two villages), 25 August 2010 (night time, three villages), 4 September 2010 (night time, three villages), 4 July 2011 (morning, four villages), 17 July 2011 (midnight, four villages), and 15 August 2011 (early morning, three villages). In each of these flood events, the flood alarms woke villagers during the night or early morning drawing their attention to the rising water level. The villagers remained alert and disseminated the flood information to downstream areas using mobile phones. As a result, the downstream communities had lead time of one to one-and-a-half hours to move people and valuables to safe areas.

During the flash flood that occurred on the night of 25 August 2010, the flood warning system implemented under the project enabled the people of the village Dihiri to save livestock (mainly pigs and some poultry) worth about USD 3,500 and other valuables.

Increasing awareness: The awareness campaign and workshops organized by the project have enhanced people's understanding of the causes and management of flash floods in the area, and what they can do to proactively prepare for floods and deal with the impacts more effectively. The project has also made them aware of their rights and obligations in relation to flash flood management. Increased awareness has helped communities mitigate flood impact and cope with flash floods.

Reducing vulnerability: Receiving timely warnings of floods has reduced the vulnerability of communities in the study area to flash floods to a certain extent. Understanding how to survive flash floods in good health and with minimal loss of property has enhanced community resilience. Knowing the extent of locational risk, made possible by the spatial risk maps produced by the project, has enabled communities to plan and take measures to make their lives safer.

Enhancing community networks: Community networks, such as the Village Flood Management Committees and links with media people, government officials, and the project team contributed immensely to the dissemination of flood warnings, reporting of flood events, effectiveness of government flood management schemes, and coordination of relief work.

Conclusion

The instrumented hydrological database and socioeconomic information available on the Jiadhal River catchment is insufficient to provide a proper scientific understanding of the changing nature of flash floods and their impacts in the study area. Flood management in the study area is based mainly on structural measures, which have not been able to effectively mitigate flash flood hazards. Community-based flood warning systems can go a long way in helping communities, as well as flood management agencies, to prepare for flash floods. However, interstate cooperation is essential to properly manage the Jiadhal River with a judicious combination of structural and non-structural measures. States must adopt flood mitigation policies of their own with specific provisions for the treatment of flash floods and upstream-downstream cooperation. The enhancement of community resilience through socioeconomic empowerment and strengthened adaptive capacity should be the ultimate goal of disaster management and development programmes.

Recommendations

- Develop a reliable and long-term hydrological and geomorphologic database using state-of-the-art instruments and techniques.
- Forge interstate cooperation for the joint management of the river catchment to reduce flash flood risk and disseminate flood information from upstream to downstream communities.
- Promote holistic scientific research at the catchment level on flash floods, flash flood forecasting, and the development status of communities.
- Provide reliable and timely forecasts and early warning of flash floods involving communities in the dissemination of flood information.
- Adopt flood mitigation policies at both national and state levels that treat flash floods as a special class of events.
- Identify and rank vulnerable communities, assess their risk, and formulate emergency risk mitigation strategies for preparedness, rescue, relief, rehabilitation, and community empowerment and development.
- Mainstream flash flood mitigation strategies in community development programmes with emphasis on increasing community resilience.

Lal Bakaiya Watershed, Nepal

Challenges and opportunities in flash flood risk management

Adarsha P Pokhrel, ADAPT-Nepal; **Narendra Raj Khanal**, Tribhuvan University; **Khadananda Dulal**, Kathmandu University; **Rishi Rijal**, ADAPT-Nepal; **Salikram Sigdel**, Tribhuvan University; **Bijaya Raj Khanal**, **Yadav Subedi**, **Chitra Acharya**, **Dhruba Thapa**, and **Bipin Acharya**, ADAPT-Nepal

Flash flooding from the Lal Bakaiya watershed, which lies in the Terai and inner Terai – the granary of Nepal – could result in the loss of fertile land, crops and infrastructure valued at USD 502 million. Development of a community-based early warning system with strong linkages between highland and lowland areas, coordination among institutions responsible for disaster risk management, and improved watershed management practices are needed immediately to reduce flash flood risk.

Introduction

The Lal Bakaiya watershed is located in the Terai and inner Terai, also known as the granary of Nepal. Highly concentrated monsoon precipitation together with frequent cloudbursts over the Mahabharat range and the presence of the geologically weak Chure hills make the Terai naturally vulnerable to flood disasters. Hundreds of lives, millions of dollars worth of property and infrastructure, and large tracts of cultivated land are lost every year. Flood risk is likely to increase in the region as a result of high population growth and an increase in infrastructure development, combined with more frequent extreme precipitation events as a result of global warming. This risk is compounded by the very low capacity of the people to manage flood risk. Flood hazard and risk mapping and assessment in the Terai is limited in terms of coverage (only a few rivers) and scope (focus has been on inundation without due consideration of other associated processes such as riverbank cutting and river channel shifting, and it has also been technically oriented without involving key local stakeholders).

Although there is no specific policy on flash flood risk management in Nepal, there are national policies and strategies in place to deal with disaster and flood management that encompass flash flood risk management. The Sustainable Agenda for Nepal, 2003; Irrigation Policy, 2003; Water Resource Strategy, 2002 and National Water Plan, 2005; Water Induced Disaster Management Policy, 2005; National Strategy for Disaster Risk Management, 2009; Hydropower Development Policy, 2011; and Climate Change Policy, 2011, all emphasize the need to adopt an integrated water resource management approach to flood risk management at the river basin level. Risk assessment and the analysis of each disaster to draw lessons to allow faster and more effective deployment in future disasters are some of the important strategies mentioned in these policies.

Accordingly, this project (jointly supported by ICIMOD and the United Nations Educational, Scientific and Cultural Organization (UNESCO)) was conducted to:

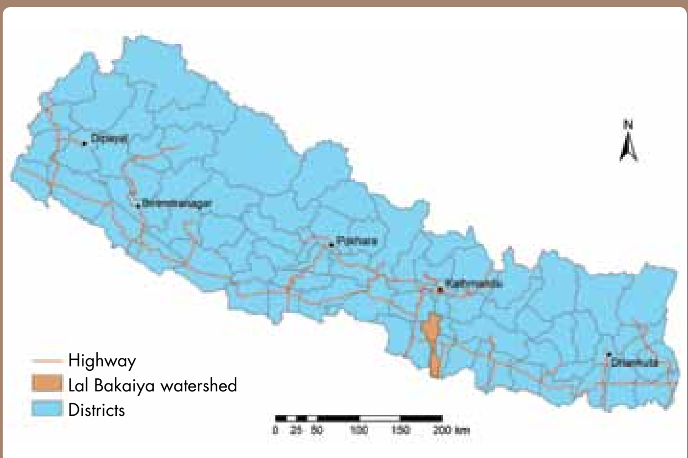
- study the causes and impacts of flash floods associated with meteorological, geomorphologic, and anthropogenic factors in the Lal Bakaiya watershed;
- prepare hazard and risk maps;
- conduct awareness programmes and create a group of rural volunteers to be involved in flash flood risk management;
- establish a community-led flood warning system; and
- disseminate research findings through meetings and workshops at the central, watershed, and community levels.

Study Area

The Lal Bakaiya watershed is located in the central southern part of Nepal and covers a total basin area of 868 km^2 (Figure 13). Geologically, the watershed can be divided into three major units – the Terai and Bhabar in the south; Chure including Dun Valley in the middle; and the Mahabharat range in the north. The mean annual precipitation is 1,434 mm at Gaur (in the south), 2,040 mm at Nijgad (Bhabar area), and 2,306 mm at Makawanpurgarhi (Mahabharat range). Mean annual precipitation seems to increase with altitude. The area frequently experiences high intensity rainfall and flash floods. The maximum 24-hour precipitation recorded in the watershed ranges from 236 mm at Gaur to 444.6 mm at Nijgad. This high intensity precipitation is highly localized. The recurrence interval of rainfall within a 24-hour period is 1.2–1.5 years for rainfall exceeding 100 mm; 3.1–6.1 years for 200 mm; and 18 years for 300 mm. All five meteorological stations located within and nearby the watershed show increasing levels of precipitation for July, which is the start of the monsoon (based on the historical data from 1970 to 2009). This may lead to more flood and flash flood events in the Lal Bakaiya River. Rivers originating from the Mahabharat and Chure ranges are generally wide, particularly in the Bhabar area, and these rivers are prone to flash floods.

There has been a significant change in land use and land cover in the Bhabar area and Chure hills including the Dun Valley. Coverage by forests and shrubs has declined from 60 per cent in 1954 to 49 per cent in 1995 and 47 per cent in 2009. At the same time, the percentage of cultivated land has increased from 34 per cent in 1954 to 44 per cent in 1995, remaining more or less the same in 2009. After the eradication of malaria in 1956, people started to migrate to Chure, Bhabar, and the Dun Valley on a large scale. Population density has increased by 7.8 times in Makawanpur District, 1.3 times in Bara District, and 2.5 times in Rautahat District since 1954. This encroachment for settlement and cultivation has intensified runoff and sediment transportation processes, increasing the frequency and magnitude of flash floods and, consequently, loss of property.

Figure 13: **Location of Lal Bakaiya watershed**



The Lal Bakaiya watershed has a total population of 421,230 across 68 Village Development Communities (VDCs): seven in Makawanpur District in the northern part of the watershed; four in Bara District in the middle; and the remaining 57 in Rautahat District in the south. Out of the total watershed area, 42 per cent lies in Makawanpur District, 20 per cent in Bara, and 38 per cent in Rautahat District.

Methodology

The project adopted a seven-step methodology for project work (Table 3). Three approaches were adopted for hazard and risk mapping: a geomorphic approach based on analysis of channel morphology and terrain using GIS and RS tools; inundation hazard zoning based on river discharge and micro-topographic variation using a HEC-RAS (Hydrologic Engineering Center-River Analysis System) model; and social flood hazard zoning based on the experiences of local communities. Discharge was estimated based on rainfall and catchment characteristics. A frequency analysis of maximum daily rainfall was conducted in order to estimate discharge for different return periods.

An inundation map was prepared using the following steps: preparation of DEM (digital elevation model) in Arc View GIS; GeoRAS (geographic river analysis system) pre-processing to generate HEC-RAS import files; running of HEC-RAS to calculate water-surface profiles; post-processing of HEC-RAS results and flood plain mapping; and flood risk assessment.

The assessment of hazard, risk, and vulnerability was based on primary data collected in the field through direct observation and measurement, group discussions, and key informant interviews. Field measurement of the river channel and water discharge was carried out at different reaches of the river. A total of 68 focus group discussions (one in each VDC in the Lal Bakaiya watershed) were organized to collect information on socioeconomic conditions, the frequency of natural disasters, and extent of past losses from natural hazards focusing on water-induced disasters. Tools to record field data, such as checklists, were prepared and used.

Analogue and digital maps for different periods were collected and analysed using RS and GIS techniques to assess existing conditions and processes of change in the watershed. Land use and land cover information was generated through toposheet maps prepared in 1956/57 and 1994, land utilization maps prepared in 1986, and recent satellite images taken in 2009.

Two workshops, one at the local level and another at the national level, were organized to communicate the findings of the research and obtain feedback for use in the finalization of the report.

Results

Floods, riverbank cutting, shifting of the river channel, water logging, sedimentation, droughts, fires, hailstorms, windstorms, lightening strikes, pests and diseases, debris flows, landslides, heat waves, and cold waves were reported as the major disasters causing loss of life and property and occurring frequently in the Lal Bakaiya watershed. Riverbank cutting, shifting of river channels, water logging, and sedimentation are some of the major geohydrological processes that are intensified during flash floods. Although landslide dam outburst floods are not common, the local people remember one landslide dam outburst flood event. Between 1954 and 2010, damages from floods were reported 21 times, which indicates that a damaging flood occurs in the watershed every 2–3 years. Out of the 21 years in which flood damage was reported, eight events (38 per cent) were highly localized covering only one or two VDCs. Only three events (14 per cent) in 1971, 1993, and 2010 were regional in terms of areal coverage.

On average, property and infrastructure valued at USD 225,700 is lost annually in different types of natural disaster in the watershed, 83 per cent of which is from floods alone, including water logging. Between 1954 and 2010, 54 per cent of the lives lost, 84 per cent of the damage to houses, 78 per cent of crop loss, and 99 per cent of the damage to cultivated land from disasters was caused by floods and inundation.

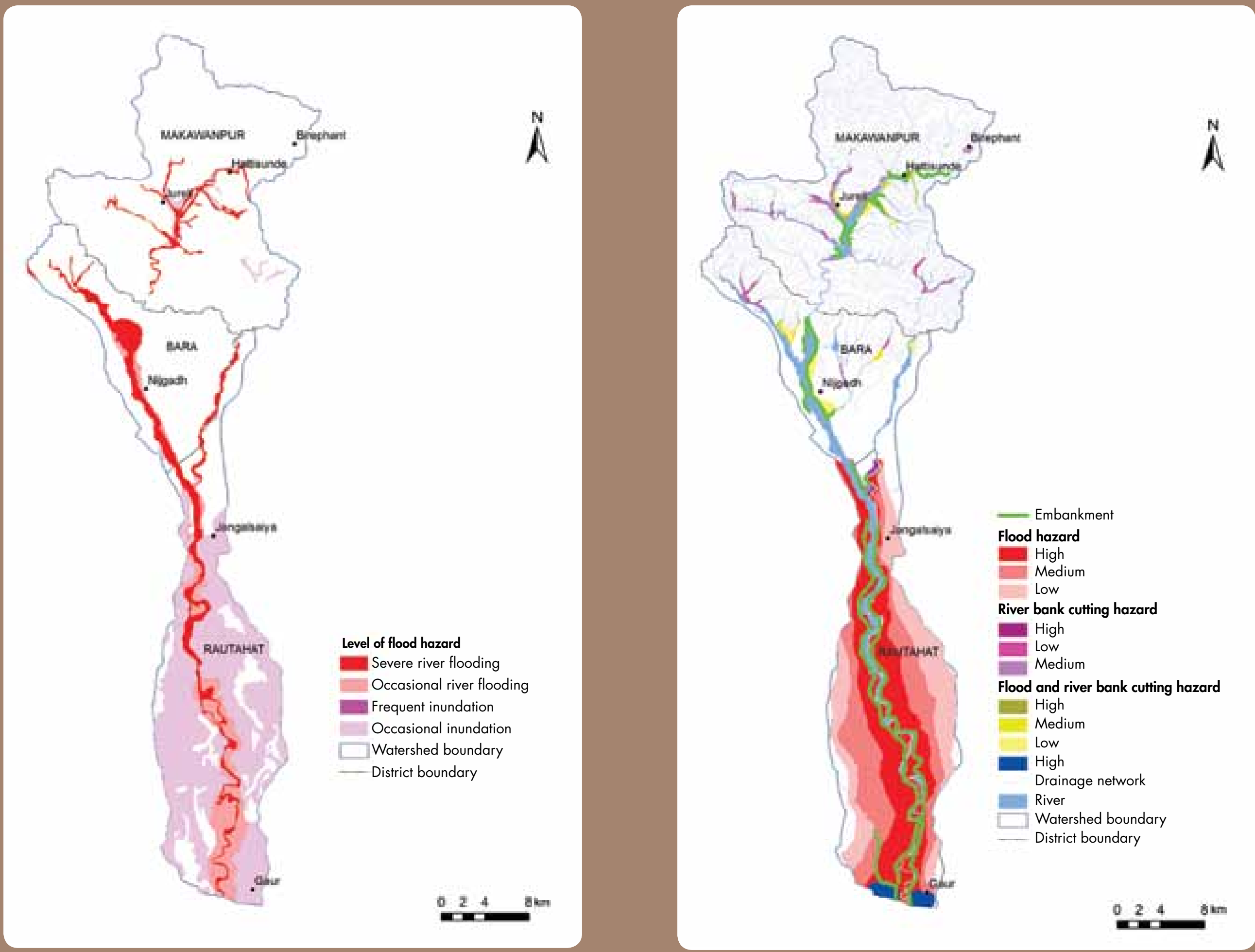
The results of hydrological modelling show that the depth of inundation is generally more than 5 m high in some parts of the Terai. The extent of inundation is less in upstream parts, such as the Siwalik hills, and extensive in the lower Terai, even in floods with a two-year return period.

Flood hazard maps based on land system units and prepared by communities during group discussions show that large areas in the lower part of the watershed are prone to flood hazard (Figure 14).

Table 3: **Seven-step project methodology**

Step	Description	Method
1	Contextualization and design of research method and tools	Literature review
2	Collection of secondary data and digitization of analogue maps	Collection of hydrometeorological and socioeconomic data, and analogue and digital maps from different sources
3	Preparation of land use maps, flood and inundation hazard maps, and landslide hazard maps based on secondary data	Frequency analysis of precipitation, estimation of flood discharge and height, flood routing and flood hazard mapping based on recorded daily precipitation data, preparation of topographic maps using the HEC-RAS model; preparation of a geomorphic hazard map based on analysis of a land system units and land use map using remote sensing and GIS
4	Verification of hazard maps, preparation of social hazard maps and a collection of relevant biophysical and socioeconomic data including the exposure of population and property to flood and landslide hazard from the field	Direct observation and measurement, focus group discussions, key informant interviews
5	Preparation and finalization of relevant maps and assessment of exposure and vulnerability	Use of data processing software such as Arc View, Microsoft Excel, and SPSS (Statistical Package for the Social Sciences)
6	Risk communication and capacity building	Workshops at local and national level, discussion with local people and establishment of network for early warning system and risk management at watershed level
7	Finalization of report	Drawing on comments and suggestions from workshops and discussions with local people and external reviewers

Figure 14: **Geomorphological flood hazard map (left) and social flood hazard map (right)**



A total of 40,657 households are exposed to flood hazards in the watershed (1,525 in Makawanpur District, 1,762 in Bara District, and 37,370 in Rautahat District) and a total population of 265,101 is likely to be affected (9,426 in Makawanpur, 10,145 in Bara, and 245,530 in Rautahat). Of the households exposed to flood hazard, 45 per cent are in high hazard zones, 36 per cent in medium hazard zones, and 18 per cent in low hazard zones.

The types of property exposed to flood disasters in the watershed include cultivated land, crops, private and public buildings, and other infrastructure. Although it is difficult to determine the probability of floods of different magnitudes and the resilience or resistance capability of the elements exposed, people and property in the area are highly likely to be affected by floods in the future (Table 4).

Property valued at USD 502 million is exposed to flood hazard in the Lal Bakaiya watershed. Of this, property valued at USD 215.4 million is in a high hazard zone, USD 177.1 million in a medium hazard zone, and USD 109.5 million in a low hazard zone. Real estate (houses, cultivated land, and housing plots) comprises about 73 per cent of exposed property, agriculture (crops and livestock) about 20 per cent, and infrastructure 7 per cent. Of the exposed property, 43 per cent is in a high hazard zone, 35 per cent is in a medium hazard zone, and 22 per cent in a low hazard zone.

The main flood and landslide hazard mitigation measures carried out in the watershed are gully and torrent control, plantation, water source conservation, trail improvement, the conservation of cultivated land, distribution of seedlings for plantation, landslide control, and river training. Interventions for the management of flash flood risk are focused on structural measures such as the construction of embankments and gully control on a limited scale (Figure 15). Embankments have been constructed on both sides of the riverbank in the lower reaches of the watershed with financial support from the Government of India.

Environmental management activities have been carried out in different parts of the watershed under the Biodiversity Sector Programme for Siwalik and Terai (BISP-ST) including the preparation of a sub-watershed management plan, control of natural calamities (landslides, floods, gullies), protection of infrastructure, implementation of a community-based soil conservation programme, organization of training and tours, school education programmes on conservation, and the production of communication materials. The Presidential Chure-Bhabar Area Preservation Programme has recently been implemented to control deforestation and improve socioeconomic and environmental conditions. However, preparedness planning for the management of flood and landslide risk, such as the establishment of an early warning system, development of public shelters, and skills development for rescue and relief operations, has not yet received high priority in the area.

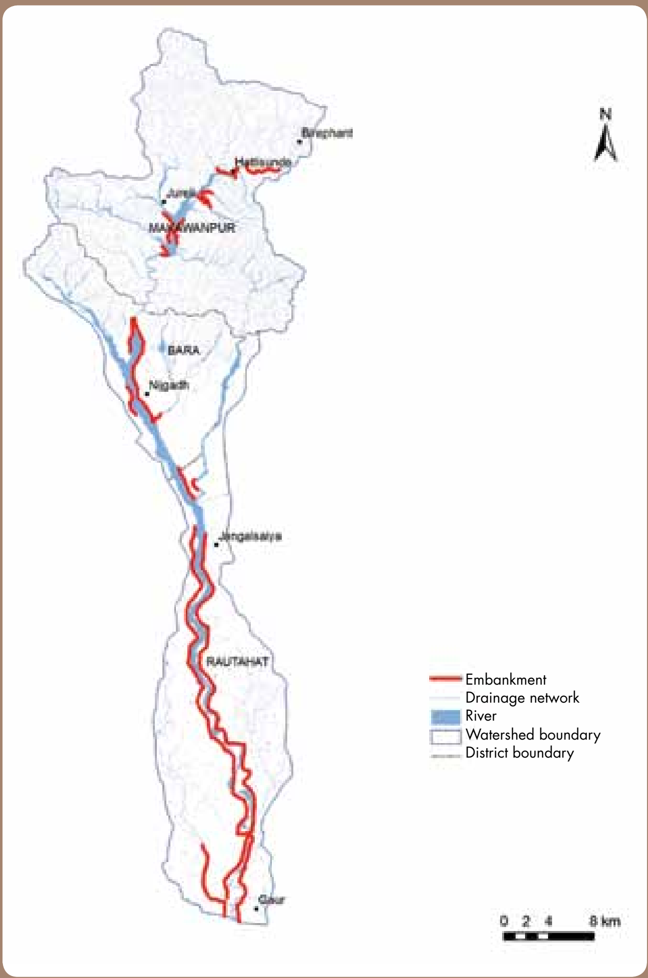
The capacity of local people to manage flash flood risk is weak as many people are poor and lack the skills and institutions to develop and implement preparedness planning for the reduction of flash flood risk. From the beginning the project built capacity by raising the awareness of flood risk and hazards among local people. Group discussions were held in 68 VDCs for data collection. Before starting the group discussions, participants were informed of the increasing risk of flash flood and the importance of flash flood risk management. An interaction workshop was held at the local level in Chandranigahapur in Rautahat District to communicate information on flood and landslide risk and obtain feedback. During the workshop, it was recommended that two VDCs – Shreepur Chhatiwan, located in the upper part of the watershed, and Nijgad, located in the middle – be made responsible for monitoring floods and providing flood warning information to communities downstream. Accordingly, a mobile set was given to the VDC secretaries of Shreepur Chhatiwan and Nijgad to initiate a flood warning system for the communities along the Lal Bakaiya River. This system was functioning well during the project period, but the current situation of this flood warning system is not known.

A national workshop was organized on 26 August 2011 in Kathmandu to disseminate the findings of this study and obtain feedback. The workshop was chaired by the Minister of Environment of the Government of Nepal and attended by representatives from relevant government ministries and departments, NGOs and INGOs, and

Table 4: **Property and infrastructure exposed to flood hazard in Lal Bakaiya watershed**

Type of property or infrastructure	Flood hazard zone			
	High	Medium	Low	Total
Irrigated land (ha)	10,385	9,227	3,551	23,163
Unirrigated land (ha)	0	47	410	457
Housing plots (ha)	6.7	5.7	12	24.4
Agricultural crops including fruits (tonnes)	84,629	69,365.7	25,279	179,273.7
Concrete houses (number)	1,662	1,042	429	3,133
Non-concrete houses (number)	14,431	12,173	5,444	32,048
Sheds (number)	4,311	4,244	2,793	11,348
School buildings (number)	94	84	31	209
Office buildings (number)	159	135	24	318
Road length (km)	58.5	45.3	21	124.8
Trail length (km)	193.3	204.7	100.2	498.2
Embankment length (km)	51.5	2	0	53.5
Bridge (number)	6	1	1	8
Watermills (number)	2	2	1	5
Pump sets (number)	172	165	39	376
Culverts (number)	0	2	1	3
Transmission lines (km)	72.5	51.8	20.6	144.9
Telephone lines (km)	21.3	6.5	0.8	28.6
Sewerage lines (km)	15.5	1	0	16.5

Figure 15: **Embankments on Lal Bakiaya River**



academicians. The workshop emphasized the importance of the effective implementation and extension of the community-based early warning system initiated by this project, formulation and enforcement of land use policies, establishment of a basin-level organization to pursue integrated water resource management, and awareness raising among local people about disaster risks and community-based disaster management practices.

Lessons Learnt

Flash floods are common in the Lal Bakaiya watershed and are often associated with highly localized extreme precipitation events. Lack of an institution to design, implement, and coordinate programmes at the watershed level for the management of flood and landslide risk is a constraint on the management of flash flood risk.

Furthermore, the lack of land-ownership certificates ('lal-poorja') means that farmers are not motivated to invest in the improvement of the land and change land use patterns, including the development of agro-forestry and other permanent crops on slopping terraces.

Structural measures alone (such as embankments) are not sufficient for flash flood risk management. Improvement of the sub-watershed condition, implementation of gully control activities, and discouragement of haphazard grazing in forest areas should be prioritized.

Recommendations

- Establish an institutional (government, non-governmental, and community) mechanism to manage flash floods at the watershed level.
- Enhance the capacity of local communities in managing flash flood events through awareness raising and training.
- Build a community-based early warning system that covers the whole watershed.
- Conduct a hydrological study and monitor floods during the rainy season in order to characterize flash floods in the rivers originating from the Mahabharat range.
- Prepare and implement a watershed management plan that adopts an integrated water resource management approach.
- Develop a comprehensive land use policy that includes distributing land ownership certificates to farmers so that local people are motivated to invest in the improvement of the land and to change land use patterns in a sustainable way.

Lumu Chimi Lake, Poiqu/Sun Koshi Basin, China and Nepal

Glacial lake outburst flood modelling

Pawan Kumar Ghimire and **Bishwanand Misra**, Geographic Information System and Integrated Development Center (GISIDC)

Modelling based on secondary data indicates that a glacial lake outburst flood from Lumu Chimi Lake could release a peak flow of over 7,500 m^3 per second at the trading centre of Barhabise with catastrophic impacts on the settlements and infrastructure downstream including two hydropower plants and two major bridges. This peak flow would be three times greater than the GLOF of 1981, which caused significant loss of property and life, swept away two highway bridges, and damaged 27 km of highway and transmission lines.

Introduction

Himalayan glaciers have experienced rapid retreat in the past few decades. This has resulted in the formation and growth of many glacial lakes. These lakes are retained by unstable moraine materials, which can break leading to a type of flash flood known as a glacial lake outburst flood (GLOF). It is estimated that there are around 200 potentially dangerous glacial lakes in the HKH region (Ives et al. 2010).

This case study was conducted in the Poiqu/Sun Koshi basin, a transboundary basin that spans the Tibet Autonomous Region of China and Nepal (Figure 16). Nine potentially dangerous lakes have been identified in terms of GLOF risk on the Chinese side of the basin (Mool et al. 2005).

The basin covers an area of 3,393 km^2; 60 per cent of the area is in China and 40 per cent in Nepal. The river that runs through the basin is called the Poiqu in Tibet and the Bhote Koshi and then the Sun Koshi in Nepal. The basin has experienced at least three GLOF events in the past, all originating in the Chinese part of the basin, but causing damage in both countries.

Over the last four decades, with the construction of the Kathmandu-Kodari Highway, many settlements in the basin have moved from the hilltops to the roadside and the number of settlements and population has increased. Roads, bridges, and hydropower stations have also been constructed. This development in the flood plain has exposed more elements to risk from a GLOF event.

Figure 16: **Poiqu/Sun Koshi basin**

Lumu Chimi Lake is the second largest end moraine dammed lake in the Poiqu/Sun Koshi basin and a potential dangerous lake. The lake surface area is expanding: the total surface area increased from 1.67 km^2 in 1977 to 3.64 km^2 in 2003 (Mool et al. 2005). From the latest satellite image, the total lake surface area is estimated to be about 3.84 km^2 and average length is 3.2 km. The present study was conducted along a 104 km section of the river corridor from the lake's end in China to a town called Dolalghat in Nepal (45 km in the Tibet Autonomous Region of China and 59 km in Nepal).

The main objective of the study was to model a GLOF from Lumu Chimi Lake and simulate the propagation of the flood downstream along the river valley to develop flood inundation maps and assess the potential impact of the GLOF.

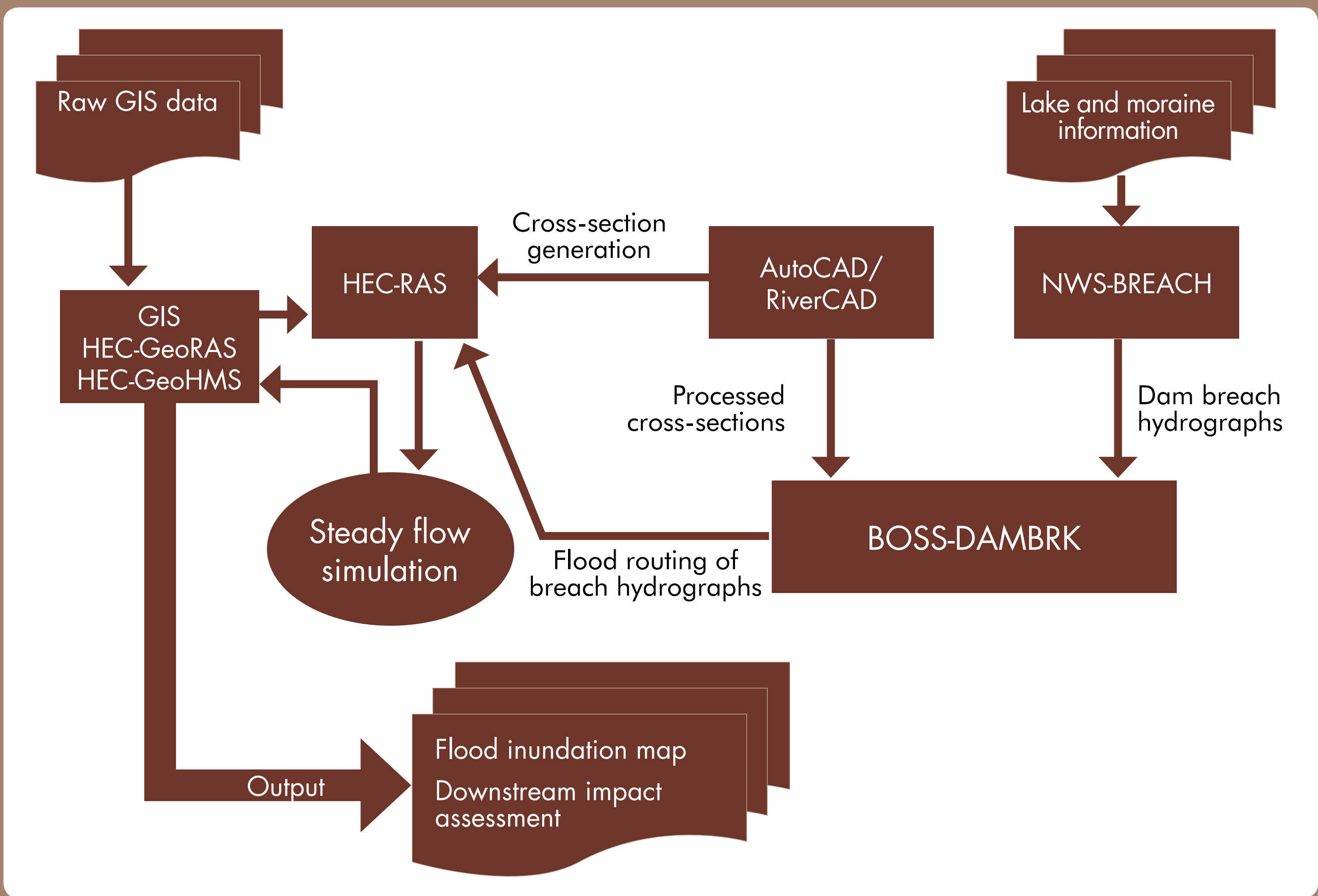
Methodology

The study was conducted in three stages: the modelling of outburst scenarios, the modelling of flood propagation along the Poiqu/Sun Koshi Valley, and flood hazard mapping with downstream impact assessment. A schematic diagram of the study methods is shown in Figure 17.

NWS-BREACH, a dam breach model developed by National Weather Services, was used to simulate the outburst hydrograph. After the GLOF hydrograph was derived from the breach model, flood propagation in the downstream areas was simulated using BOSS-DAMBRK (a software used to analyse dam failures and flood wave attenuation), which was used to simulate the failure of the dam, compute the resulting outflow hydrograph, and simulate the movement of the dam-break flood wave through the downstream river valley. NWS-BREACH is intended to be an auxiliary method for determining the breach parameters. In this study, NWS-BREACH results were used as a reference for inputs in BOSS-DAMBRK.

Twenty-nine runs of the BREACH model and 15 runs of the BOSS-DAMBRK model were carried out. Twenty-nine cross-sections of river reach were used in the BOSS-DAMBRK model to simulate dam break outflow and its impact from the lake downstream to Dolalghat. BOSS-DAMBRK was used to estimate flood wave travel time, time to flood stage, time to peak elevation, and corresponding water surface elevations.

Figure 17: **Schematic representation of the study methodology**



The output of the hydrographs at various cross-sections was used as input for steady flow data in HEC-RAS (software for River Analysis System). Results from HEC-RAS were used to prepare inundation maps after exporting them into HEC-GeoRAS (GIS tools for support of HEC-RAS) and using GIS. The final flood hazard maps were prepared in ArcGIS (GIS software). The land cover in flood hazard zones was quantified and mapped in ArcGIS. Specific sites at risk were identified and a field visit was conducted to check the results at certain vulnerable points.

The study relies mostly on secondary data and information for modelling. In hydrodynamic modelling, the quality of the topographic information determines the accuracy and reliability of the model. In this case, part of study area is in the Tibet Autonomous Region of China and information about the lake, moraine, topography, and socioeconomic conditions was difficult to acquire.

Table 5: **Summary of sensitivity analysis, dam breach erosion model**

Input parameter	% Variation	% Variation in output parameters (sensitivity in brackets[a])		
		Breach peak flow	Time to peak	Breach top width
Average particle size	100	+1.7 (NS)	-1.2 (NS)	+1.8 (NS)
Uniformity coefficient of dam material	60	+4.6 (SS)	-1.0 (NS)	+4.0 (SS)
Porosity	40	+10.0 (S)	-5.6 (S)	+7.2 (S)
Upstream side slope	75	-9.0 (S)	+3.0 (SS)	+7.0 (S)
Downstream side slope	29	-1.8 (S)	+1.0 (SS)	–
Internal friction angle	0	-2.0 (S)	+3.0 (SS)	+4.0 (S)

[a] NS = not sensitive; SS = slightly sensitive; S = sensitive.

Results

Dam breach erosion model

Various scenarios were developed for the dam breach erosion model in NWS-BREACH using varying values of vulnerable dam height, piping failure at different heights, particle size 50 per cent finer (D_{50}), porosity, uniformity coefficient (D_{90}/D_{30}), dam upstream side slope, dam downstream side slope, and internal friction angle. The sensitivity analysis was done to evaluate the role of these input parameters in peak discharge (Q_p), time to peak flow (T_p), and top width of trapezoidal shape breach. The sensitivity results are shown in Table 5.

Dam break analysis

Various scenarios were developed for the BOSS-DAMBRK model using depth of 20 m, time of failure of 0.75 hours, side slope of 1:1.15 (vertical:horizontal), Manning's *n* of 0, and varying values for the width (Table 6). However, only a few

Table 6: **Results of dam break analysis**

Location	Distance from Dolalghat (km)	Distance from dam (km)	Scenario 1 (width = 41 m)			Scenario 2 (width = 82 m)			Scenario 3 (width = 0 m)			Scenario 4 (width = 56 m)		
			Peak flow (m^3/s)	Peak depth (m)	Peak time (hr)	Peak flow (m^3/s)	Peak depth (m)	Peak time (hr)	Peak flow (m^3/s)	Peak depth (m)	Peak time (hr)	Peak flow (m^3/s)	Peak depth (m)	Peak time (hr)
Downstream of dam	104	0	7,909	5,014.3	0.3	12,286	5,015.4	0.2	2,677	5,012.2	0.5	9,611	5014.2	0.3
Near Chuhsiang	80	24	6,983	3,778.4	0.8	10,564	3,779.3	0.8	2,469	3,776.7	1.1	8,387	3778.8	0.8
Friendship Bridge	60	45	6,712	2,124.8	1.1	10,051	2,126.1	1.1	2,408	2,122.3	1.4	8,040	2125.3	1.1
Panlan	42	62	6,499	1,191.9	1.4	9,651	1,193.9	1.4	2,360	1,187.9	1.7	7,746	1192.8	1.4
Barhabise	30	75	6,319	861.1	1.7	9,328	863.8	1.5	2,322	858.1	2	7,513	862.7	1.6
Balefi	14	90	5,886	708.8	2.1	8,334	711	2	2,236	704.2	2.6	6,804	709.7	2
Dolalghat Bridge	0	104	5,492	641.4	2.6	7,599	643.3	2.4	2,138	637.4	3.2	5,967	641.9	2.5

Figure 18: Attenuation of flood at selected locations

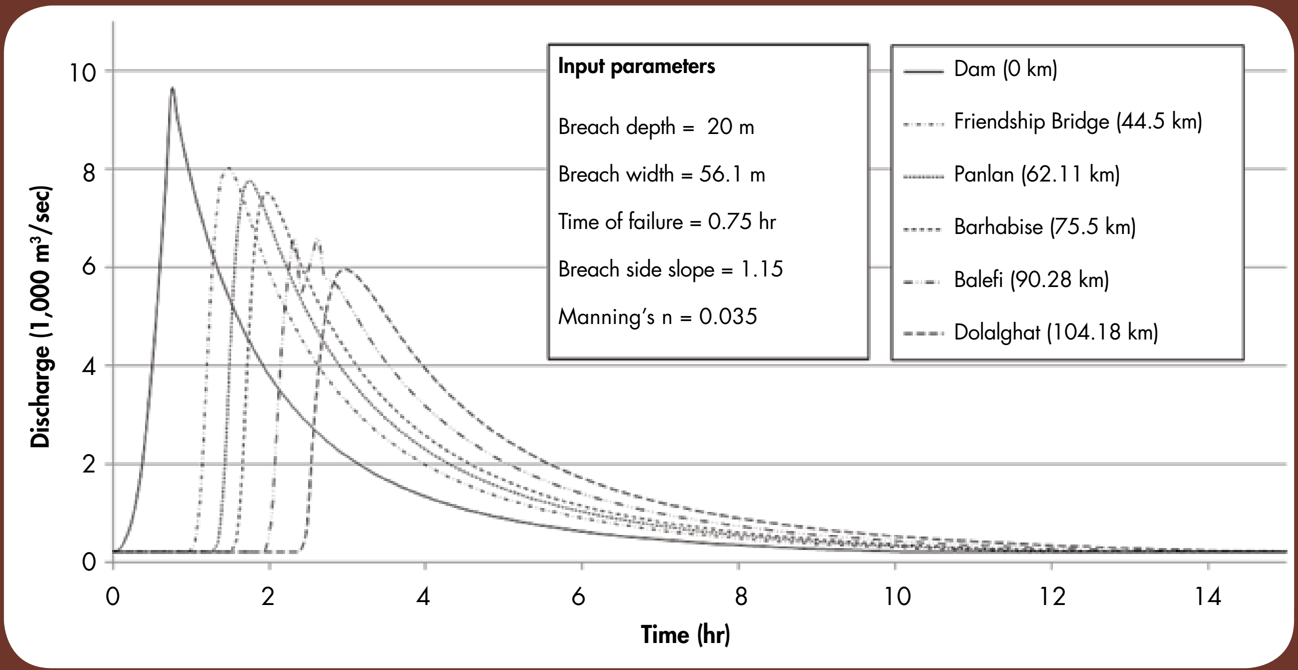
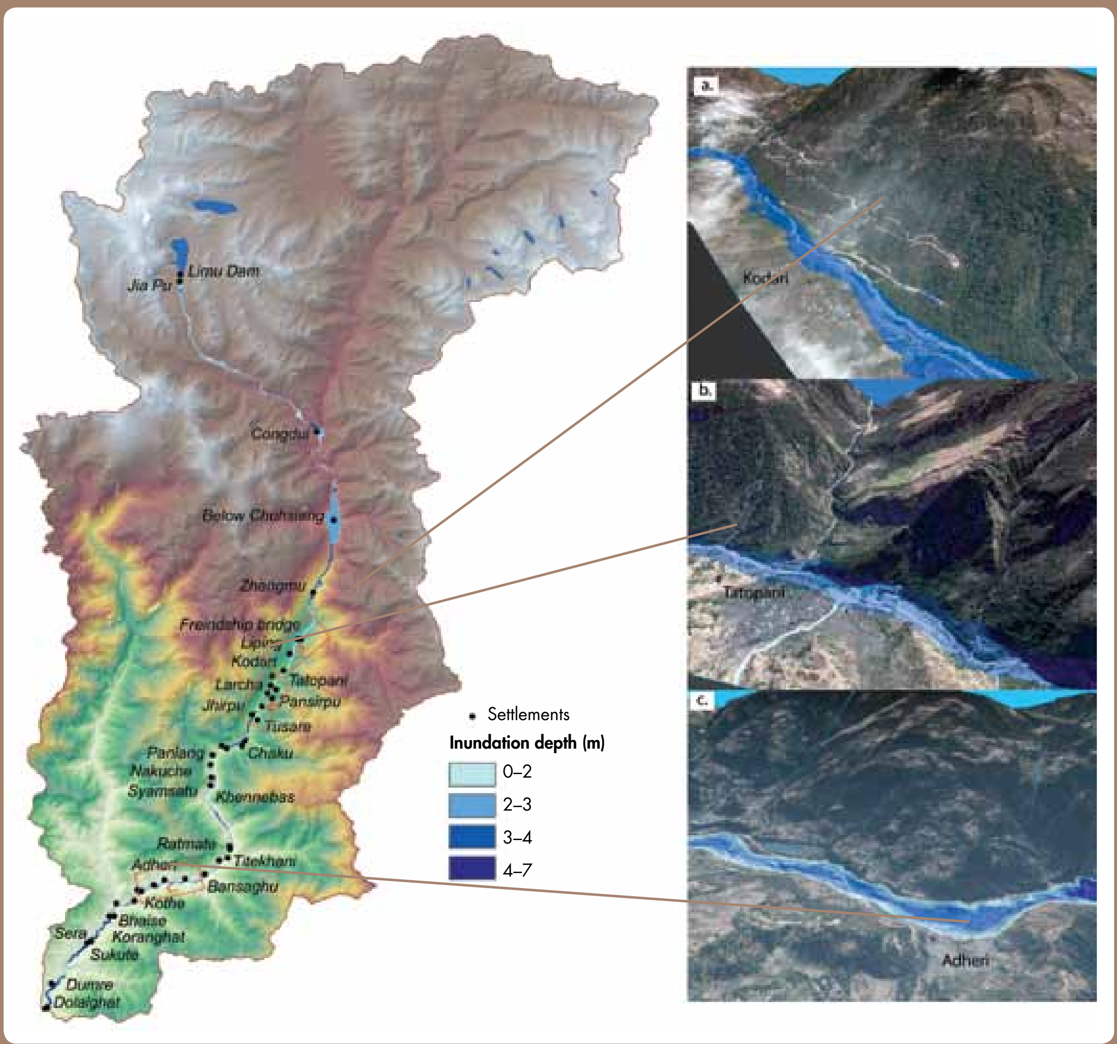


Figure 19: **Flood inundation map**



scenarios are realistic. It was assumed that the lower part of the dam is more stable due to its compactness and greater dam width. Thus, a 20 m breach of the dam was considered for the dam break analysis. The result shows that the peak outburst flood from a 20 m breach could be as high as 9,611 m^3 per second at the dam breach location (Figure 18). Under this scenario, the peak flood at Barhabise in Nepal (75 km downstream from the dam) would be 7,513 m^3 per second with 1.6 hours of lead time. This magnitude of flood at Barhabise is more than three times greater than the flood of 1981 from the outburst of Zhangzanbo Glacial Lake (Xu 1985).

The results from various scenarios developed in BOSS-DAMBRK indicate that the peak flood is determined by the dam breach width, time of failure, breach shape, and Manning's *n* as the flood propagates downstream from the dam.

Flood inundation and impact assessment

The outputs of the one-dimensional unsteady flow simulation and dam break analysis were used to prepare flood inundation maps. The impact of GLOF risk on the Nepal side was only estimated due to limited data availability.

The results show that the settlements along the river, such as Maghi Gaun and Belgaun near Dolalghat, and Sukute, Andheri, Khadichaur, Lamosangu, Barhabise, and Tatopani are at risk of GLOF. (Figure 19), It is also estimated that over 21 km of the Arnico Highway at various locations (from Dolalghat to the Friendship Bridge at the border of Nepal and China), the Khandichaur and Barhabise bridges, and many suspension bridges are also exposed to GLOF risk. Similarly, the Bhote Koshi and Sun Koshi hydropower dams and their powerhouses are exposed, as well as various land cover types (Table 7).

Table 7: **Land cover exposed to GLOF risk in Nepal**

Land cover type	Area (ha)
Agricultural land	234.8
Forest	161.3
Grass	60.2
Bush	123.4
River course	364.4
Cutting cliffs	0.2
Total	944.3

Recommendations

- The results of this study should be used to create land use and flash flood risk management plans.
- More modelling should be conducted with data of a greater degree of certainty for fuller understanding of flash flood risk and impacts based on field data and for enhanced flash flood risk management.
- The methodology in this study can be applied to other potentially dangerous glacial lakes in similar river valleys to understand the nature and extent of GLOF impacts for effective flash flood risk management.

Madi River, Nepal

Landslide dam outburst flood risk management

Narendra Raj Khanal, Tribhuvan University; **Achyuta Koirala**, Fulbright Consultant; **Sher Bahadur Gurung**, Tribhuvan University; **Umesh Kumar**, Geometics Solutions Pvt. Ltd; **Rishi Rijal**, Consultant; **Salikram Sigdel**, Tribhuvan University; **Chitra Acharya**, Consultant; and **Upendra Prasad Yadav**, Geometics Solutions Pvt. Ltd

The Madi River is at risk of landslide dam outburst flood, with potential property loss estimated at between USD 25 million and 68 million. With 14 hydropower projects proposed in the area and numerous settlements downstream, mitigation in terms of landslide control is needed urgently.

Introduction

Landslide dam outburst floods (LDOFs) are common in Nepal's high, steep, and fragile mountains with their deep and narrow gorges (Shrestha 2008). More than 12 major LDOFs resulting in loss of life and property were reported in Nepal between 1967 and 1996. Despite this, Nepal has no specific policy or programme for managing LDOF risk. Although very different in nature (and in the strategies required to manage them), LDOFs are considered together with other water-induced disasters in national policies.

On 3 August 2010, the Madi River in western Nepal was dammed by a landslide at Naune village in Sildjure VDC, Kaski District putting people in Kaski, Lamjung, and Tanahun districts at high risk (Figure 20).

Photographs taken during a reconnaissance survey of the landslide dam and inundated area in February 2011 show numerous cracks along the crown of the landslide and a large volume of hill slope materials that are likely to fail in the future and dam the Madi River again. Accordingly, a study of the risk of landslide dam outburst flood (LDOF) was proposed to:

- estimate the volume of materials damming the river, the potential volume of materials that may slide down in the future, the volume of water stored behind the dam, the potential volume of water that may be stored in the future, and the area at risk of inundation;
- assess slope stability and estimate the probability of failure, including process and causes, in and around the Nanung landslide;
- identify other potential landslide damming sites along the Madi River;
- assess community vulnerability;
- estimate sector-wise and reach-wise the monetary value of likely damage from a LDOF along the Madi River; and
- make recommendations for LDOF risk management.

The outcomes of the study were a comprehensive report on vulnerability to landslide dam outburst flood with recommendations for risk management, a landslide hazard map, and a detailed topographic map.

Figure 20: **Location of Madi River landslide dam**

Methodology

The study was carried out in three phases: deskwork, fieldwork, and data analysis. As part of the deskwork, aerial photographs, satellite images, analogue maps, and photographs of the study area were collected and interpreted. A landslide inventory map was prepared to identify potential areas of landslide initiation and damming. A total of 10 parameter maps – slope gradient, slope aspect, land use and land cover, elevation zone, geology, lineament, distance to river, distance to road, slope shape, and precipitation – were prepared. A bivariate statistical approach using remote sensing and GIS for data input generation was used to produce a landslide hazard map along the Madi River. Checklists were prepared for the collection of socioeconomic data to quantify elements at risk of LDOF on the Madi River; these were administered during focus group discussions and key informant interviews.

Fieldwork consisted of three components: the verification of potential landslide hazard maps and potential sites for landslide damming; the geotechnical investigation of hill slopes and landslides including a total station survey; and the collection of socioeconomic data. Field mapping and the measurement of the morphometric characteristics of the landslide, landslide dam, and channel geometry were carried out around the 3 August 2010 dam site. Soil samples were collected and analysed in the laboratory to assess the soil properties of the slip plane. The causes of landslide were determined by analysing precipitation data, the morphometric profile of the landslide, the hill slope materials of the landslide and its surrounding areas, and local people's perceptions.

After determining the height of the dam likely to be formed (based on the results of the total station survey) and volume of materials likely to be moved from the landslide (through geological and geotechnical survey), three landslide dam outburst flood scenarios were fixed: up to 5 m, 5–10 m, and 10–15 m. These three flood zone scenarios were delineated in topographical maps and information was collected to assess the risk in each zone.

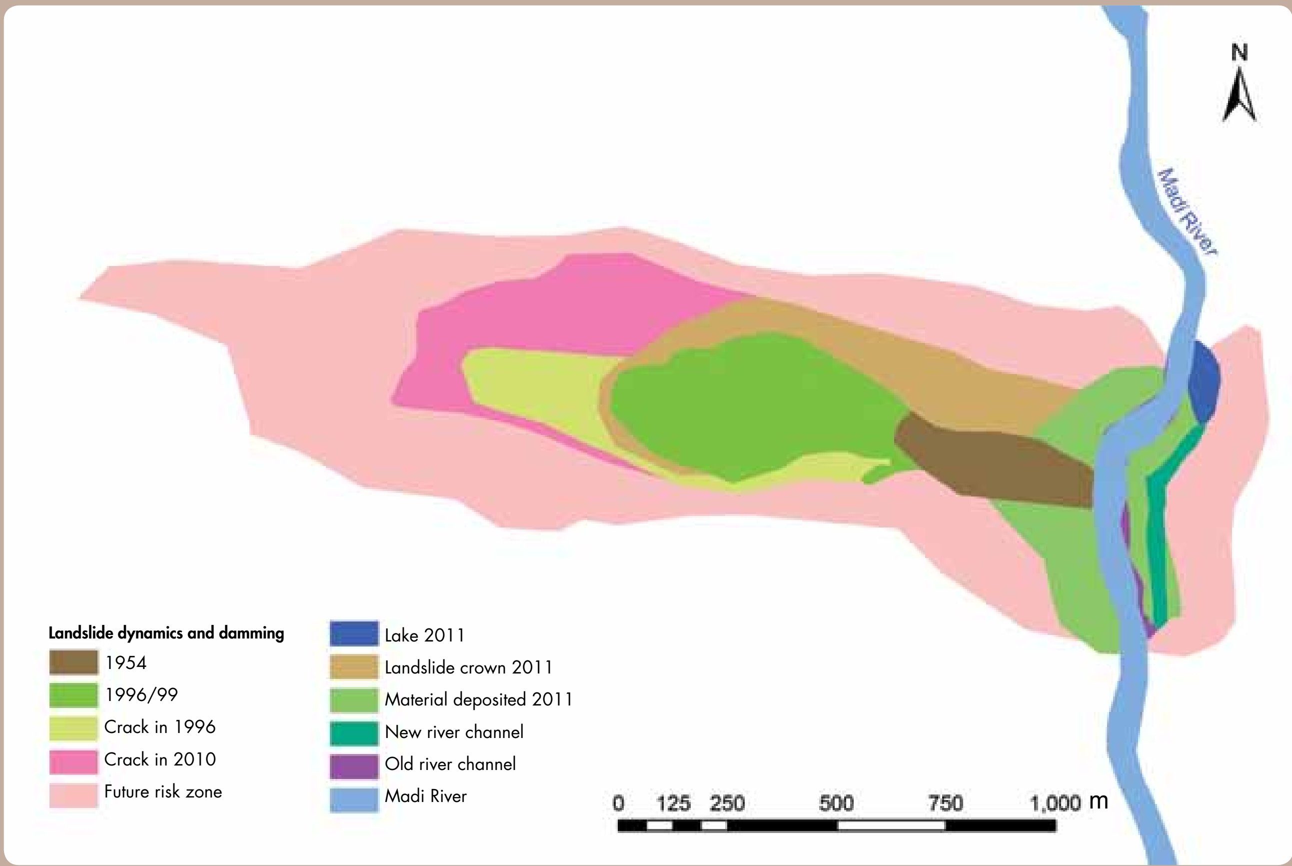
Information on the frequency of landslides, landslide dams, floods, and debris flows; their causes; past loss/damage from such events; socioeconomic vulnerability; and past risk reduction activities were collected through focus group discussions, key informant interviews, transect walks, direct observation, and social mapping. During focus group discussions, locals were asked to map the area likely to be affected by landslide dam outburst flood based on past experience and quantify the elements (tangible and intangible) exposed in these flood prone areas. Finally, they were asked to map and describe risk reduction activities carried out in the past and were recommended activities to reduce the risk of LDOF, in particular, and flood and landslide and debris flow, in general. The monetary value of exposed elements likely to be affected by LDOF was quantified using local prevailing purchase values for household assets (land, crops, and livestock) and replacement cost for infrastructure. A per unit cost at the national average was used to estimate the replacement cost of larger infrastructure such as roads and hydroelectricity facilities. All values were expressed in current prices.

The river reach from the damming site to the confluence of the Madi and Seti rivers near Damauli was divided into 16 blocks for the collection of relevant socioeconomic information. At least one focus group discussion with 7 to 13 community members was organized in each block. An integrated sustainable livelihood approach was adopted to assess the socioeconomic vulnerability of communities likely to be affected. Vulnerability as a result of low adaptive capacity was determined by access to physical, natural, social, and financial capital and assets. Information was collected on access to such capital and assets, and on demographic characteristics, size of landholdings, employment and income diversification, level of food sufficiency, social networks, and access to health services, water supply, and markets.

Results

The Nanung, which is also known as Naune or Taprang, landslide was initiated in 1933 and reactivated and extended in 1946, 1952, 1985, and 1996 (Figure 21). It started to move again on 3 August 2010, completely blocking the river for about five hours. The lake that formed behind the dam was 40 m deep and extended about 0.8 km upstream. When the water overtopped, it flowed through the landslide mass blocking the old river channel, inundating irrigated paddy fields about 50 m east of the riverbank. Eighteen days later, on 21 August 2010, the river cut the dam and formed a new channel a few metres east of the old channel with a flood wave about 4 m high. On 23 August 2010,

Figure 21: **Dynamics and damming of the Nanung landslide**



the river cut the dam and the left bank of the river generating a 5 m flood downstream, which damaged a suspension bridge at Chasu, among other things.

Precipitation data recorded at Sikles about 6 km north of Taprang and the discharge recorded 39 km downsteam at Sisaghat were analysed revealing that the landslide reactivated because of high volume precipitation in July and the improper management of surface and irrigation water. The impact of the landslide dam and outburst flood can be seen as far as 39 km downstream from the damming site.

Based on the assessment of landslide susceptibility, the study identified potential sites of damming (Figure 22), although it is difficult to estimate the duration and magnitude of future flooding. Three processes of river damming were identified by the study: damming by flooded tributaries joining at a right angle with sharp bend; damming by logs and debris brought by the river along the narrow river channel section; and damming by material moved from the landslide and debris flow. To date, only landslides and landslide dam outburst floods have resulted in a threat to the downstream study area.

Figure 22: **Potential sites for damming**

The Nanung landslide is 1,744 m long from the bank of the Madi River to the active crown on the top of the landslide and 1,110 m wide at its end on the Madi riverbank. Its minimum width is 672 m slightly below the middle part of the landslide. The landslide is mainly composed of sand and silt with gravel and a little clay.

The maximum possible volume of landslide debris from the Nanung landslide (worst-case scenario) was estimated to be about 18.82 million cubic metres. It was assumed that 50 per cent of the total volume of debris derived from the landslide would reach the accumulation zone and spread homogeneously. The rest of the material is likely to be adjusted in maintaining the future slope morphology of the landslide. However, a nominal volume of the finest components of soil particles is likely to be washed away by the Madi River. Hence, the total volume of the material to reach the accumulation area is estimated to be 9.41 million cubic metres. The area of the accumulation zone on the bank of the Madi River is estimated to be 395,549 m^2. The height of the dam formed by the landslide in the Madi River (worst-case scenario) would be 23.8 m. Based on this estimated dam height, and the width and slope of the riverbed, the peak discharge in the event of landslide dam outburst flood is estimated to be about 726 m^3 per second. This would result in a catastrophic flood extending far downstream.

An estimated 2,584 households, with a corresponding population of around 14,059, would be affected by a 15 m high LDOF in the Madi River (Table 8; Figure 23). The market centres of Gumle, Satrasaya, Rambazar, Mugrebesi, Birdi, Duipiple, and Damauli (Shantinagar) are at the risk together with 19 hotels and one industrial unit (in the event of a 5 m high LDOF); 47 hotels and three industrial units (10 m high LDOF); and 93 hotels and 10 industrial units (15 m high LDOF). Sabi, Bhaise, Ghumlebazar, Rambazar, and Satrasay areas are more susceptible to LDOF in terms of likely damage to hotels and industrial units. A total of 14 hydroelectricity projects with a total capacity of 386.9 megawatts have been proposed in different reaches of the Madi River. These projects are also likely to be affected if proper mitigation and adaptation measures are not taken.

The estimated total value of all the elements exposed to LDOF of the Nanung landslide on the Madi River is between USD 24 million (5 m high LDOF) and USD 68 million (15 m high LDOF) (Table 9).

Table 8: **Elements exposed to potential LDOF on the Madi River**

Elements exposed	Flood level		
	5 m	10 m	15 m
Households (number)	963	1,736	2,584
Population (number)	5,276	9,491	14,059
Irrigated land (ha)	265	473	678
Unirrigated land (ha)	6	34	80
Crops (tonnes)	1,749	3,512	5,328
Livestock (number)	1,496	6,681	15,270
Concrete houses (number)	4	44	179
Non-concrete houses (number)	50	214	400
Sheds (number)	53	145	277
Housing plots (ha)	0.6	2.5	6.4
Roads (km)	1.8	5.4	14.4
Trails (km)	5.3	8.9	13.5
Transmission lines (km)	1.6	3.8	8.4
Motorable bridges (number)	2	3	5
Suspension bridges (number)	3	8	11
Temples (number)	14	24	42
School buildings (number)	1	4	8
Office buildings (number)	4	13	30

Although, local people are aware of the risks posed by landslides, debris flows, and floods, control and management activities have not received priority in an organized way. When a landslide first occurs, it is usually seen as the problem of the individual landowners directly affected. After a few years, the landslide and gullies become enlarged and the problem starts to affect more people, requiring huge amounts of resources and technology to control. Government efforts to manage the risk of landslide, LDOF, and flood are mainly focused on rescue and relief operations. The distribution of food, clothing, tents, medicine, and, in some cases, cash is the main activity so far implemented in the area. At the community level, the main activities include afforestation and the construction of retaining walls and spurs. However, these activities are scattered and not properly planned keeping in mind the need to improve the watershed condition. Measures adopted at the household level to control landslides and debris flows include diversion of surface runoff near the crown, the draining of water from the main body of the landslide, construction of retaining walls, plantation, and protection from livestock grazing. These activities are generally practised on private land.

Janajatis (indigenous ethnic groups) and Dalits (so-called 'untouchable' Hindu caste groups such as

Figure 23: **Number of households exposed to LDOF of different flood levels**

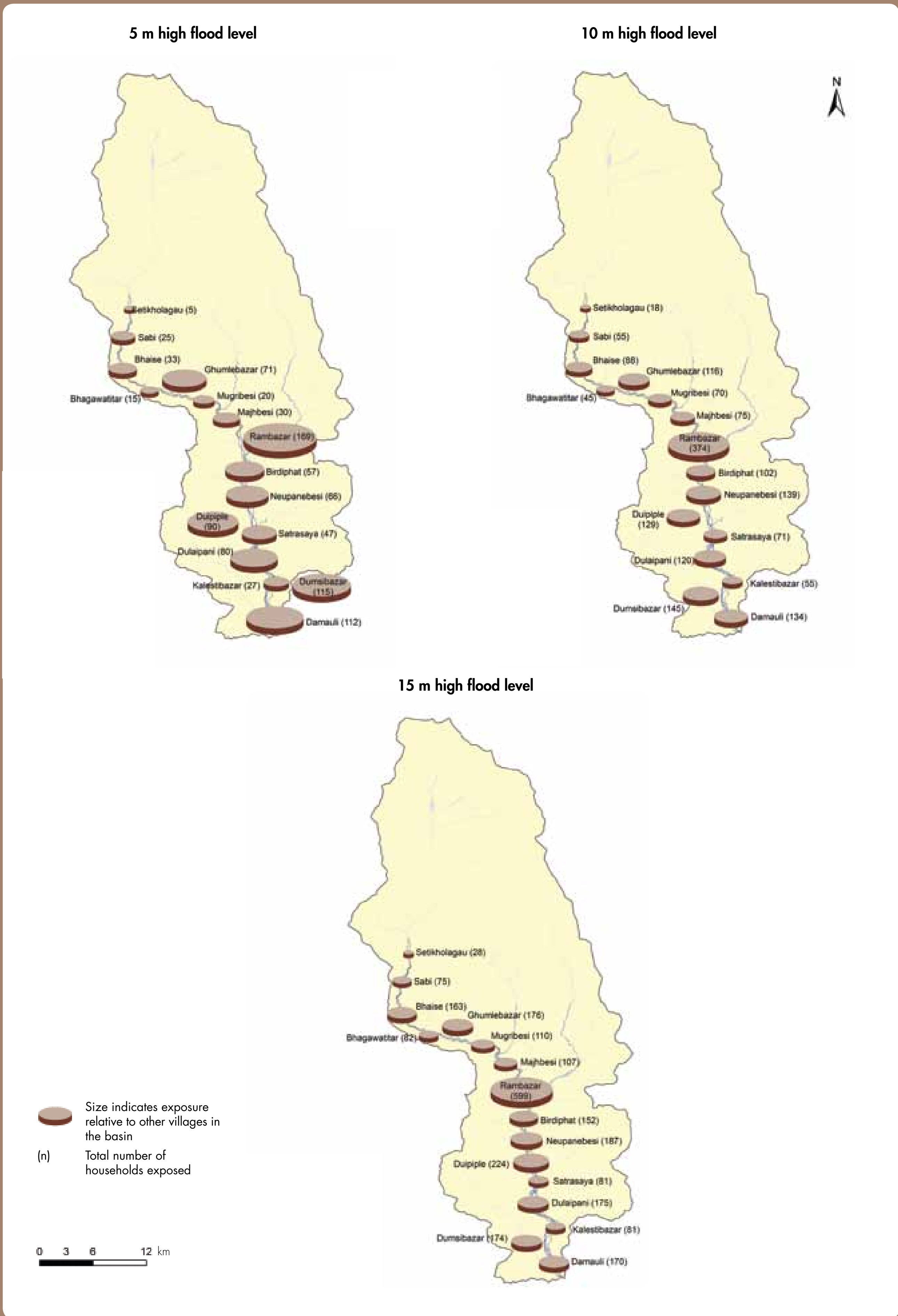


Table 9: **Estimated monetary value exposed to LDOF on the Madi River**

Type of property	Value (USD 1,000)		
	Up to 5 m	<10 m	<15 m
Real estate	18,804.5	35,423.6	55,793.6
Agriculture	853.7	2,023.4	3,444.5
Infrastructure	3,929.3	5,239.9	8,676.1
Total	23,587.5	42,686.9	67,914.2

Damai, Kami, Sunar, and Sarki) comprise about 49 per cent of the families exposed to LDOF hazard in the area. These groups are generally marginalized with limited access to resources and decision making. The literacy rate among exposed households is low and dependency ratio high. Landholding size is also low. Nearly 5 per cent of families are landless, 15 per cent are marginal, and 40 per cent are small farmers. Only 45 per cent of families produce enough food from their own land. Hence, the investment capacity of local people to mitigate and manage potential LDOF risk is minimal, although the area is highly accessible from roads and connected with major market towns and cities.

Key Findings

- The impact of the landslide dam outburst flood on the Madi River on 3 August 2010 can be seen as far as 39 km downstream from the damming site.
- If the Madi River is dammed again, the dam could be up to 24 m high with a potential peak discharge of 726 m^3 per second, which would have catestrophic effects far downstream.
- An estimated 2,584 households would be affected by a 15 m high LDOF in the Madi River, with a corresponding population of around 14,059.
- The economic value of elements exposed to LDOF on the Madi River is between USD 24 million and USD 68 million.
- Although local people are aware of LDOF risk, their capcity to mitigate and manage the risk is weak.
- The government has not prioritized risk management, focusing efforts on rescue and relief rather than preparedness or mitigation.

Recommendations

- Identify potential sites of damming using remote sensing and GIS technology and inform local people about the risk of potential LDOF.
- Monitor landslides along rivers such as the Madi River, including the type, volume, and movement of materials, to estimate the extent and duration of future damming and the magnitude of any outburst flood.
- Take action to control landslides along the riverbank at the initial stage of failure to save resources and reduce risk.
- Conduct proper land use planning; manage surface and irrigation water through the construction of catch drains and flexible spurs; and undertake bioengineering measures to stabilize landslides and guide debris flows.
- Develop and implement land use guidelines and building codes to reduce the risk posed by floods, including LDOFs.
- Develop an institutional mechanism at the watershed level to control landslides, improve watershed condition, and establish an early warning system, together with cost-benefit sharing mechanisms between local communities, those downstream, and hydropower development projects.
- Prioritize preparedness planning for landslide and flood risk management and coordinate and properly plan efforts to manage risk keeping in mind the need to improve the watershed condition.
- Make local people, particularly in high-risk zones, aware of the risk of LDOF and provide them with skills development training for preparedness planning and rescue and relief operations.

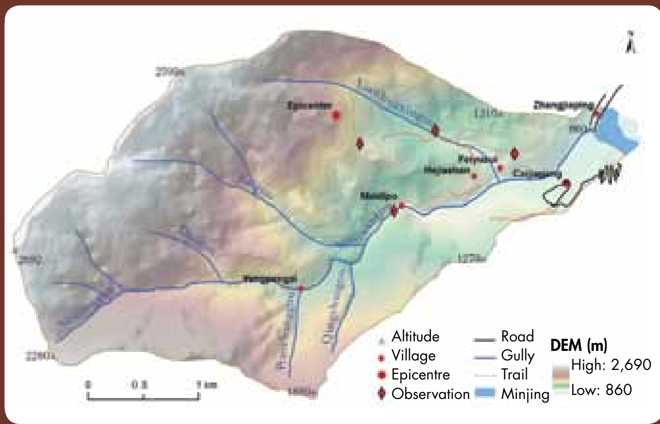
Niujuangou Gully, China

Flash flood monitoring and risk management

Yongshun Han, Institute of Natural Hazards Prevention, Hunan University of Science and Technology, and
Arun Bhakta Shrestha, ICIMOD

The Wenchuan earthquake completely changed the topography of the Niujuangou gully. The processes and formation mechanisms that could now lead to flash floods in the area must be understood to assess altered vulnerability and risk. Research into the hydrological process and monitoring are needed to understand the critical rainfall that would trigger a flash flood so that floods can be forecasted and an early warning system developed.

Figure 24: **3D digital map of the study area (top) and ADS40 areal image of the study area (bottom)**



Introduction

Niujuangou gully is located in Yingxiu town, Wenchuan County, Sichuan Province (E103°25′12″ to 103°28′31″ and N31°01′21″ to 31°03′16″), 78 km from Chengdu. The terrain of the study area is low in the southwest and high in the northeast, ranging from 860 m above mean sea level to 2,693 m above mean sea level, a difference of 1,833 m. The gully is flanked by high mountains with steep slopes and a deep valley with a mean gradient of 3.16 per cent. It has a total drainage area of 10.46 km^2 and main channel length of 5.8 km. The gully contains six branches and is 3.77 km in length. Niujuan gully is part of the Minjiang River system (Figure 24).

The study area has a subtropical moist climate, with high annual rainfall. It has long-term annual mean rainfall of 1,253 mm, annual maximum rainfall of 1,688 mm, and daily maximum rainfall of 270 mm. Sixty-eight per cent of the annual precipitation falls from June to September.

Flash floods in the study area are caused by intense rainfall, earthquakes, and landslide dam outbursts. Intense rainfall is perhaps the most common cause of flash floods. The topography, geology, and land use in the study area make it particularly prone to flash floods. Abrupt slope gradients and poor and fragile watersheds in the hills produce very high flow velocities and centralized discharge. The study area was at the epicentre of the Wenchuan earthquake in 2008, which radically changed the natural conditions triggering rock falls, landslides, debris flows, and dammed lakes (five in Niujuan gully alone), making the area more prone to flash floods. The mechanisms for the formation of flash floods and the critical level of rainfall to trigger a flood event in the post-earthquake environment are different from that before the earthquake. Flash floods are occurring in new gullies with low frequency, but on large scale. For example, as a result of the flash flood in Zhouqu County on 8 August 2010, 1,510 people died, 255 people went missing, 47,000 people were affected, and 6,000 houses were damaged (Figure 25). This natural disaster was the most serious flash flood since 1949. A flash flood also occurred in the Hongchun gully on 13 August 2010, which killed more than 200 people and destroyed Yingxiu town (Figure 25). There had never been a flash flood in this gully before the earthquake.

Economic and social factors, including the development of local society and the economy, also contribute to flash flood risk and vulnerability. There are two towns in the study area, Yingxiu and Xuankou, and three villages, Zhangjiaping, Caijiagang, and Hejiasha. The population lives in mostly rural areas and consist of Han Chinese and Tibetan people. The Wenchuan earthquake seriously damaged the socioeconomy of the study area. Before the earthquake, Zhangjiaping village had 389 people in 105 households, with 0.4 ha of farmland per capita, annual income per capita of RMB 6,000–7,000 (USD 953–1,112), and five pigs per household. The earthquake killed 52 people and injured 120; it also led to the loss of all but 90 of the village's 1,800 sheep, and destroyed all of the houses and arable land rendering the villagers homeless. Before the earthquake, Caijiagang village had a population of 279 in 68 households, with farmland per capita of 0.2 ha, annual income per capita of RMB 1,000 (USD 159), two pigs and five chickens per household, and more than 300 sheep. The earthquake killed 16 people and injured 48; it also killed about 10 per cent of livestock, and destroyed more than 40 ha of farmland, all houses, and all schools rendering the villagers homeless.

The study was conducted to:

- summarize flash flood control measures and practices in the study area;
- establish flash flood monitoring and early warning;
- share information and disseminate knowledge;
- build the capacity of stakeholders in the flash flood risk zone; and
- implement flash flood risk management.

Method and Approach

Data collection

A large amount of data were collected for the study including spatial data, attribute data, time data, thematic data, socioeconomic data, statistics, and loss and damage data. Secondary data were collected through a review of literature on flash floods from China and abroad. Experts, scholars, and professionals were also approached for data and reports. This was supplemented by local government documents and materials from the study area. Large-scale digital maps and high-resolution remote sensing images were also purchased. Field surveys, observations, and investigations were used to obtain primary disaster data, meteorological and hydrological parameters for flash flood monitoring, data for warning and forecasting, and data for risk assessment and mapping. A questionnaire survey was conducted to obtain socioeconomic data and disaster-loss data, and assess the needs of

Figure 25: **Flash floods in Zhouqu County on 8 August 2010 (left)** and **Yingxiu town on 13 August 2011 (right)**

stakeholders and identify gaps for flash flood capacity building. Local residents and stakeholders were also interviewed to document local knowledge and practices. In addition, experts were commissioned to prepare some of the materials for capacity building.

There were some problems and constraints in the course of data collection. For example, it was difficult to obtain government data, relevant research reports, large-scale geologic maps, and high-resolution images. The language barrier made it difficult to communicate with minority nationalities and isolated residents, making it difficult to understand and document indigenous knowledge and practices.

Stakeholder participation

The stakeholders involved in the study included local government, private enterprises, financial institutions including banks and insurance companies, non-governmental organizations, and local residents (Table 10).

Activities

The project worked with and through the local communities, government and other local stakeholders to implement its activities. Community-based preparedness and risk management is a separate policy for managing floods and flash floods in the study area. The community participates in flood risk identification, prioritization, plan formulation, implementation, monitoring, and evaluation. The community and the local government are involved in all aspects of flash flood management.

Activities undertaken as part of the study include:

- **Awareness raising:** Awareness raising of flash flood risk was conducted at the community level through the dissemination of booklets and posters, lectures, expert consultations, and knowledge contests. Information on flash flood risk was also incorporated into the primary and middle school curriculum (Figure 26).
- **Capacity building:** Community members participated in flash flood control drills and flash flood prevention training, workshops, and forums.

Table 10: **Stakeholders and their role in flash flood management in the study area**

Stage	Government	Private enterprises	Financial institutions	Residents
Rescue and relief work	Conducting rescue and relief work, provision of emergency living allowance	Relocation of enterprise property to safe zone and self-help	Banks, insurance companies, tax department, and flood risk investment companies donate funds for emergency rescue	Self-help
Recovery	Disaster investigation, formulate plans, provide funds for recovery operations	Raise funds and resume production	Provision of materials, social mobilization	Recovery of property and rebuilding of lives and livelihoods
Development	Development of the economy, improving risk awareness, and building the capacity of stakeholders	Improving economic capacity and contributing to economic resilience	Building the capacity of stakeholders to enhance their risk awareness of flash flood	Participation in training, community-based risk management, and disaster reduction activities
Flood prevention and mitigation	Construction of flood prevention and mitigation projects	Contribute to prevention capacity by storing and allocating flood prevention goods and materials and by putting in place own structural engineering measures	Offer social security and disaster relief, including relief payments, disaster insurance, reconstruction funds, financial transfer payments, and tax-exemptions.	Involved in monitoring, early warning, and water conservancy project construction
Flood preparedness	Organizing materials, technology and manpower for flood preparedness, forecasting and warning and building a materials reserve base for flood prevention and control	Provision of equipment for flash flood preparedness	Provision of facilities and reserves of materials and medicines for preparedness	Involved in risk awareness raising and prevention work
Roles and contribution to the study	Provision of leadership and decision-making, support for activities, administrative management	Provision of funds and data support, participation in capacity building and risk management	Provision of financial assistance, disaster insurance, tax policy, and fund audits	Major participants/ stakeholders, contribution of local knowledge and practices

Figure 26: **Creating awareness among school children**

- **Warnings:** As part of the project, flash flood warnings are disseminated through television and radio broadcasts, by email, mobile telephone text messages, the Internet, blogs, and satellite telephones. In the local area, communities use fireworks, smoke, warning lights, torches, signal lights, flag signals, audio frequency amplifiers, gongs/drums, and public announcements .
- **Flood risk mapping:** A flood survey was conducted in the study area, flood data were collected and processed, and a database was established. This was used to calculate the flood submerging range, assess flood disaster loss, and conduct flood risk mapping. The project produced eight map groups with 40 sheets of maps: hazard-inducing environment map group, flash-flood investigation map group, post-flood reconstruction map group, flood-control engineering map group, monitoring and warning map group, risk management map group, capacity building map group, and information-sharing and knowledge-dissemination map group. This series of maps demonstrates the status, achievements, and needs in relation to flash floods in the pilot site as well as the outcomes and effects of the cooperative project from different angles.
- **Impact evaluation:** A hazard assessment, vulnerability assessment, risk assessment, and assessment of loss and damage were conducted to evaluate the potential impact of a flash flood on the study area.

Flash Flood Management in the Study Area

Flash flood management in the study area combines structural engineering measures with non-structural measures including capacity building.

Structural measures

Structural engineering is the major measure taken to prevent and control flash floods in the study area. After the Wenchuan earthquake, large-scale structural engineering reconstruction was conducted including the construction of sand-sediment dams, check dams, dikes, drainage canals, culverts, and slope land control engineering (Figure 27). Slope land control and soil conservation engineering measures, for example, have been undertaken at the source of the gully. Two check dams with 2–5 step dams are being built in the upper stream of the Lianhuaxin channel and in the major Niujuangou channel to stabilize the slope and channels. Three large sand-sediment dams are being built in the middle reaches and three small-scale sand dams have already been built in the lower reaches to block and deposit sediment. A 1.8-km dike in the downstream reaches of Niuguangou gully and 3.5 km dike along the Minjiang River are in place to control flash floods and protect Caijiagang village, Zhangjiaping village, and Yingxiu town. A 1.2-km drainage canal is currently under construction in the downstream reaches of Niujuangou to control debris flow.

Despite the existence of these measures, the standard of existing structural engineering is low. The flood control capacity of cities and important towns is only defensive against floods of 3–20 year frequency and the drainage ability of those cities or towns is only defensive against floods of 3–8 year frequency. There is no structural engineering in most of the riverine and mountain areas in the study area. In addition, some channels are severely silted and flood levels are increasing.

Non-structural measures

Non-structural measures are also in place in the study area and supplement structural engineering measures by restricting human activities and harmonizing the relationship between man and nature. The major non-structural measures in place include integrated watershed management to control flood-inducing processes through land

Figure 27: **Structural measures for flash flood control, Niujuangou gully, Wenchuan County, China**

Dam construction

Check dam

Sand sediment dam construction

use management, forest conservation, ecological rehabilitation, reconstruction and land use planning; resettlement; the provision of support by developed provinces to affected counties with counterpart aid (e.g., Shanghai helped to reconstruct affected areas in Guangdong Province); the adjustment of industrial structures; and supply of labour. Preparedness measures have been undertaken including flood risk assessment, socioeconomic flood hazard mapping and assessment, monitoring, forecasting, and warning, and emergency relief planning. Response measures in place include evacuation plans, search and rescue plans, the placement of temporary shelters, and health measures.

Post-disaster measures are in place for damage and needs assessment, recovery and rehabilitation, and evaluation. Originally, stations and equipment for flash flood monitoring and alarms were scarce, and almost all of them were destroyed by the Wenchuan earthquake. New techniques and equipment for flash flood monitoring and warning were adopted and installed in only a few important sites/gullies (Figure 28). Most of the risk zones in areas severely afflicted by the Wenchuan earthquake lack flash flood monitoring and warning.

A Flash Flood Risk Management Committee was established in the study area with 15 members elected by a general assembly and representatives from different sectors. There are seven work teams in the committee including a flood management headquarters team, consultant team, flood monitoring team, communication team, emergency response team, hydrologic and meteorological team, and logistics team. The committee operates at the village/community level and takes the lead in organizing, coordinating, and implementing flash flood management in its jurisdiction.

Capacity building activities

Capacity building activities for flash flood risk reduction in the study area include:

- **Emergency response plans:** There are three types of emergency response plans at the county, town and community/village levels. In addition, there are special emergency response plans for schools, key zones, and key units. All of these plans comprise a comprehensive emergency response network.
- **Emergency response drills/exercises:** Emergency response drills are conducted once

Figure 28: **Alarm system installed in the headwaters of Niujuangou gully**

or twice a year by the local government for local residents, units, and volunteers. Community emergency rescue teams have been set up and are comprised of members of the armed forces, local community members, administrative staff, and volunteers. The needs of vulnerable groups such as children, the elderly, pregnant women, and people with disabilities are considered and incorporated into drills and evacuation plans.

- **Evacuation and rescue:** In order to move people away from flooding and associated hazards and minimize loss and damages, emergency response teams under the Flash Flood Risk Management Committee, together with local community members and government staff, have determined three safe areas, set up five evacuation camps and temporary shelters, prepared socioeconomic flash flood risk maps, and marked alternative evacuation routes. The plan is clearly explained using cards and caution boards.
- **Victim-aid system:** The victim-aid system mainly consists of local reserve storehouses, emergency material supply stations, disaster-relief resources, emergency equipment, and emergency reserve funds. This system was established by local governments, communities, non-governmental organizations, adjacent communities, and volunteers.
- **Awareness raising, education and training:** Two information and education centres were built in the study area to carry out education, training, and information sharing about floods. Activities conducted at the centres by the project team and local government include display and distribution of popular science knowledge booklets and posters, primary and middle school classroom instruction, local television announcements, videos, training classes, knowledge contests, interviews, and consultations. The anniversary of the Wenchuan earthquake is used to raise awareness about disaster prevention and mitigation.
- **Monitoring and warning:** With the help of local communities and local government, the project team purchased flash flood monitoring and warning instruments, set up one field surveying network and four automatic weather stations, and developed and established two flash flood warning systems. In addition, three community-based flash flood preparedness teams have been formed with professional and amateur members.

Outcomes and Results

The project achieved five major outcomes:

- **Database:** A comprehensive database was set up by collecting and compiling data, materials, practices, literature, and indigenous knowledge on flash floods in the study area. The project summarized national and regional flash flood policies, strategies, plans, and countermeasures, and documented indigenous knowledge and practices, to produce an enormous database including maps.
- **Piloting and installation of an early warning system:** A flash flood monitoring and early warning system was piloted in the study areas and encompasses weather monitoring, water and soil monitoring, field surveys, flash flood forecasting, and flash flood warning. One automatic meteorological station, two automatic rain gauges, three soil moisture sensors, three water level measurements, and one video camera have been installed as part of the system. The system has a signal transmission instrument to notify communities of a flash flood event, together with an operating system and information management system.
- **Flash flood information management system:** A flash flood information management system was developed and implemented for flash flood data storage, risk mapping, information sharing, and knowledge dissemination.
- **Flash flood risk maps:** Hazard maps were developed for eight map-groups containing a total of 40 sheets of maps.

- **Capacity building:** Capacity building was conducted at the community level including awareness raising through the distribution of booklets and posters; lectures on relevant topics; professional consultations; a knowledge contest on flash floods; programmes for primary and middle school students; training and drills for local residents and volunteers on flash flood risk and preparedness; and knowledge dissemination and information sharing. Communities were provided with materials on flash floods including popular-science booklets, records, videos, and reports, as well as tools kits contained equipment for use in the event of a flash flood event (emergency bags) and information cards explain how to use the equipment and what to do.

As a result of these five outcomes, the project contributed to:

- **Reducing vulnerabilities:** The project contributed to reducing the vulnerability of people in the study area to flash floods by conducting flash flood risk assessment and management, raising risk awareness, building the response capacity of the community, and through risk sharing and risk transfer.
- **Community resilience:** The project contributed to community resilience to flash floods by mobilizing communities for mitigation and recovery with the use of local resources and labour for reconstruction, and by facilitating and strengthening linkages and partnerships for external support and relief.

Lessons Learnt

- The processes causing flash floods in the study area have changed since the Wenchuan earthquake. There is a lack of relevant research and findings on these processes making it difficult to forecast flash floods and identify potential flash flood gullies in the study area.
- Indigenous knowledge and local practices are important, but often overlooked by external agencies and governments who tend to favour scientific and specialized knowledge, most of which is not in tune with local contexts and realities. The majority of the people in the study area live in remote villages and suburbs of Yingxiu town and are usually the first victims of flash floods. Ignoring their knowledge and practices may cause serious social and economic loss in the future, and result in the failure of some flash flood management projects and activities.
- Existing structural measures are inadequate for flash flood prevention and control, and capacity to manage flash flood risk is limited.
- There is a lack of technology and equipment for flash flood monitoring and warning systems in the affected areas.
- Diversity between stakeholders in the study area and differences in their needs is a challenge in implementing integrated flash flood risk management. For instance, local residents need a safe settlement or shelter far from flash floods, while governments have focused on large-scale restoration and reconstruction, which was finished three years after the Wenchuan earthquake, but without thorough scientific planning. The residents in and near Yingxiu town have greater awareness and capacity to deal with flash flood risk, while those in remote and isolated areas have less, making it difficult to identify common gaps and demands in capacity and to design capacity-building modules.

Recommendations

- Conduct new assessments of flash flood processes and formation mechanisms, as well as vulnerability, after major natural disasters such as earthquakes.
- Monitor flash floods and determine the critical rainfall and soil moisture levels. Based on this, develop an effective flash flood monitoring, forecasting, warning, and alarm system for the whole catchment area, which includes Niujuangou gully in Wenchuan County, Beichuan County, and the city of Dujiangyan. This requires strengthening the national and local network of hydrological and meteorological observations, weather radars, the acquisition and processing of modern satellite derived products, and field surveys and experiments.
- Stimulate the government and local communities to be actively involved in flood management and capacity building. Actively strive for external support and cooperation at the local, government, and organizational levels.
- Combine advanced science, technology, and equipment with indigenous knowledge and local practices that take into account local contexts and realities.
- Develop a standard methodology and format for documenting flash flood events.
- Strengthen structural measures of flash flood management and enhance defensive standards in the study area.
- Strengthen non-structural measures of flash flood management, including raising awareness and building the capacity of communities to manage flash floods.

Xichang, China

Risk assessment and cartography of flash floods

Yongshun Han, **Peng Huang**, and **Longwei Li**, Institute of Natural Hazards Prevention, Hunan University of Science and Technology; **Arun Bhakta Shrestha**, and **Sagar Ratna Bajracharya**, ICIMOD

Risk maps developed for the city of Xichang in China reveal that property valued at more than USD 1 billion could be damaged in the event of a flash flood. These maps have been used to inform land use planning, policy makers and communities, for example, to avoid construction in at risk areas.

Introduction

Xichang is the capital of Liangshan Yi Autonomous Prefecture, Sichuan Province, in southwest China. In 2010, the permanent residential population of Xichang was 666,200, including six sub-districts, 37 towns and countryside residents. There are three sub-district offices in the study area, Changan, Xincun, and Changning, and four administrative villages. In the upstream portion of the West River in Xide County, there is one township, five administrative villages, and 15 groups. The Yi are the dominant population group in Liangshan Yi and Xichang. At the end of 2009, the urban population of Xichang was about 356,300 people (composed of people from 28 ethnic groups, with 18.77 per cent of the population belonging to minority ethnic groups); the built-up area covered 35.51 km^2; there were 108 km of city roads; and the rate of urbanization was 53.4 per cent.

The West River is a very hazardous river running through Xichang and Xide County belonging to the Jinshajiang River system (E102°14′27″ to 102°30′24″ and N27°48′28″ to 28°05′45″). The West River watershed is rich in natural resources, making it one of the more economically developed areas with industrial and mining establishments, as well as one of the densest populated areas in the Panxi region of Sichuan.

Precipitation in the study area mainly falls between June and October; the rainfall in these five months accounts for 85–92 per cent of the annual rainfall. The mean annual rainfall is around 1,013 mm and mean annual evaporation is 1,945 mm – the difference being 932 mm. The index of aridity is 1.38. Rainfall tends to increase by about 30 mm with every 100 m in altitude.

Ordinary hazardous floods occur frequently (every year), with serious floods occurring every three to four years and flash floods occurring occasionally compared to riverine floods. The area's unique hydro-meteorological conditions, terrain, and unsustainable human activities aggravate soil erosion in the West River watershed, contributing to the frequency and severity of flash floods, which seriously endanger communities in the watershed. According to incomplete statistics dating back to the 1990s, no less than 24 flash floods have occurred in the West River watershed, destroying towns and bridges, endangering people and livestock, doing great harm to the regional economy, and resulting in loss of life and property. These calamities have even affected Xichang.

Accordingly, this study was conducted to:

- summarize the flood prevention measures that have been taken in the study area and local experiences in relation to this;
- train and educate key stakeholders and generally raise community awareness about flash flood hazards;
- establish a forecasting system and make a scientific assessment of flash flood hazards in the West River basin; and
- produce an atlas of the study area containing baseline maps and thematic maps including risk assessment maps.

Methodology

Various forms of data, including spatial data, thematic data, socioeconomic data, attribute data, and statistics, were collected for the study, and a review of the relevant literature conducted. Spatial data were collected (and purchased) from many sources including national centres for basic geo-information, relevant databases and websites, the national science data library, and by digitalizing existing maps. Field investigations, interviews, and consultations (via regular correspondence and email), as well as survey questionnaires, were conducted to collect thematic data on flash floods, socioeconomic data on the study area, and attribute data on geographic entities. Internet searches of government websites, government yearbooks and communiqués, and various literature and reports revealed relevant statistics.

In addition to these secondary sources of data, firsthand data on flash flood forecasting and risk cartography were collected through field surveys, observation, experiments, and by inviting manuscripts from peer experts. Local knowledge and practices, and the outcomes and findings of such practices, were documented from interviews with locals.

Thematic data on flash floods and land use were used for flash flood forecasting, risk assessment, and cartography. Regional flash floods and land coverage were surveyed using remote sensing interpretation with high-resolution and multi-periodical images. Loss and damage caused by particular flash flood events was determined through field investigations, interviews, visits, and a literature review.

Outcomes

The study piloted and set up 24 mathematic models including five data processing models, three flash flood forecasting models, and 16 flash risk assessment models. Seventeen methods were studied and improved, mainly including data encoding, transforming and standardizing methods, and flash flood risk mapping methods.

The project had five major outcomes:

- databases and basic information management system
- flash flood forecasting and risk assessment
- flash flood risk maps
- capability building
- tool kits

Databases and information management system

A number of comprehensive databases (including a spatial database, attribute database, thematic database, meta database, model database, and multi-media database) were piloted and scaled up in the study area (as well as in the Wenchuan earthquake-affected areas and Hunan Province). Nine kinds of databases were established with more than 800 data tables for storing and managing various and massive data and materials. For this, data were collected, compiled, processed, standardized, and encoded.

Using these databases and WebGIS technology, a basic information management system for data sharing and knowledge dissemination was developed and applied. This system has eight main functions: basic science education, data gathering, data access, data management, data querying, statistical analysis, thematic mapping, and information dissemination. The basic information management system made the other activities of the project easier and more effective, and enabled information sharing and knowledge dissemination to take place.

Flash flood forecasting

Forecasting is an effective non-structural way to prevent and mitigate flash floods, but its feasibility and effectiveness depend on data integrity and precision, the forecasting model used, and the technique and methods adopted. In this study, flash flood forecasting was carried out through the following activities:

Forecasting data: Forecasting requires real-time data and precise meteorology and hydrology data. This data must be processed quickly and the successive information fed back into the forecasting model and system. In this study, real-time forecasting data were gathered from a numerical meteorological Doppler radar set up just in the study area. The accepted radar data were transformed into a '*.txt' format through a system developed for the study and then stored in a database.

In the remote and isolated mountain areas of the study area, the high precision and integrity of radar data were poor. In order to resolve this problem and provide integrated and precise data, seven field meteorological and hydrological observation stations were set up in the study area with the capacity to gather meteorological data once every 1.5 minutes and transmit the data wirelessly to the data centre. In addition, the internal interpolation model for meteorological data were researched and established using the Kriging technique according to topographic conditions and meteorological variation with altitude.

Forecasting model: A scientific and feasible model is the key to flash flood forecasting. A new matrix formula was developed to assess the probability of flash flood in the study area. The model consisted of three steps to determine the matter-element assemblage for the grade of flash flood probability.

Forecasting technique: On the basis of forecasting data collection and processing and using the established forecasting model, a real-time flash flood forecasting system was developed and applied to the project through GIS, the database, remote sensing, programming, and communication technologies. This warning system consisted of infrared cameras, vibration sensors, a wireless signal projector, and solar cells. The system can gather the motion parameters and wirelessly transmit warning signals to local residents.

Flash flood risk assessment

The flash flood risk assessment consisted of a hazard assessment, vulnerability assessment, and loss and damage evaluation (Figure 29). The flash flood hazard and vulnerability assessments were briefly expounded as follows:

Flash flood hazard assessment: A flash flood hazard assessment was conducted to calculate the range, depth, duration, and degree of flash flood inundation by simulating the hydrological processes of a given frequency flash flood. Using a GIS technique and hydrological and topographic data, a back-propagation (BP) neural network time-sequence model was set up and applied in the study (Formulas 1 to 3).

Step 1: The stream network was extracted and created using GIS-based hydrological analysis. The process included processing DEM (digital elevation model) in a grid format/small geo-cell, determining the flow direction of each geo-cell, calculating the flow accumulation, identifying the corresponding sink, filling up the relevant sink, delineating the watershed, and creating stream networks at various levels.

Figure 29: **Procedure used for flash flood risk assessment**

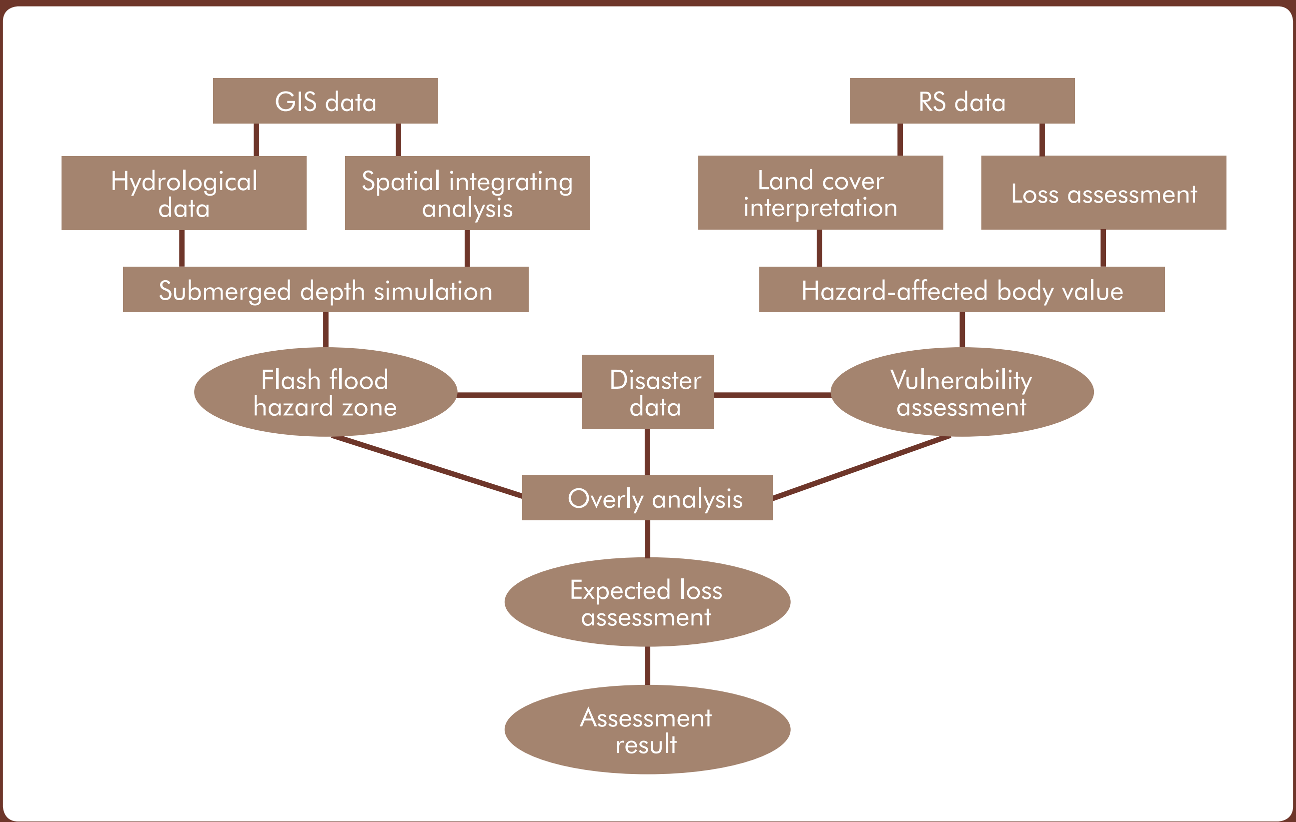
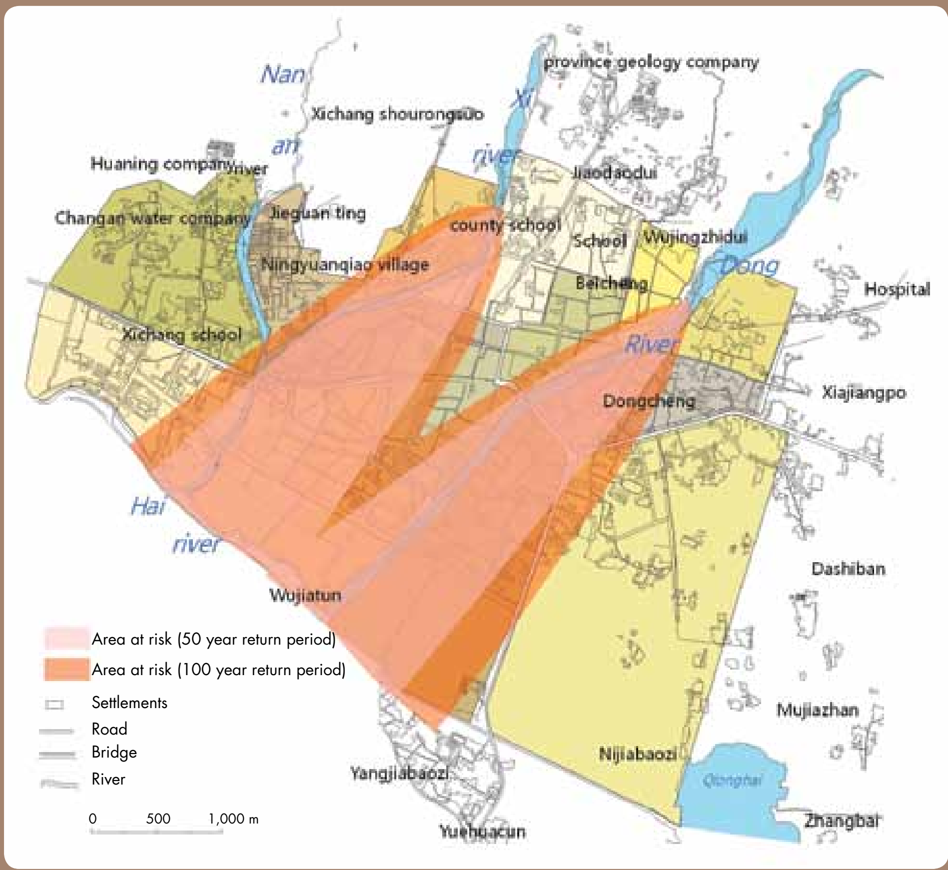


Figure 30: **Simulation and hazard assessment of flash flood of different frequencies**



Step 2: The maximum design discharge of each drainage outlet was calculated using the formula

$$Q = 0.278\psi iF = 0.278\psi \frac{S}{\tau^n} F$$

where Q is the maximum design discharge of a drainage outlet, ψ is the runoff coefficient of the flood peak, i is the maximum rainfall intensity, F is the drainage area, S is the rainstorm parameter from the Department of Water and Resources, and τ is the concentration time of drainage.

Step 3: The water level of the relevant geo-cell was calculated using the formula

$$H(x,y) = h_w(x,y) - h_g(x,y) \quad [h_w(x,y) > h_g(x,y)]$$

where (x,y) are the geographic coordinates, $H(x,y)$ is the inundated depth at coordinates (x,y), $h_w(x,y)$ is the water level at coordinates (x,y), and $h_g(x,y)$ is the elevation at coordinates (x,y).

Step 4: The inundated range/area was calculated using the formula

$$Q = \sum_{i=1}^{n} H(x,y) \times A_i$$

where Q is the maximum design discharge of drainage outlet, $H(x,y)$ is the inundated depth at coordinates (x,y), A_i is the corresponding range/area inundated, and n is the number of assessing units.

Step 5: A simulation and hazard assessment of flash flood was conducted through the BP neural network time-sequence model (Figure 30).

Flash flood vulnerability assessment: The vulnerability assessment focused on the socioeconomic attributes of flash floods, with population, estate cost, resource value, environmental value, and production value as the basic risk elements.

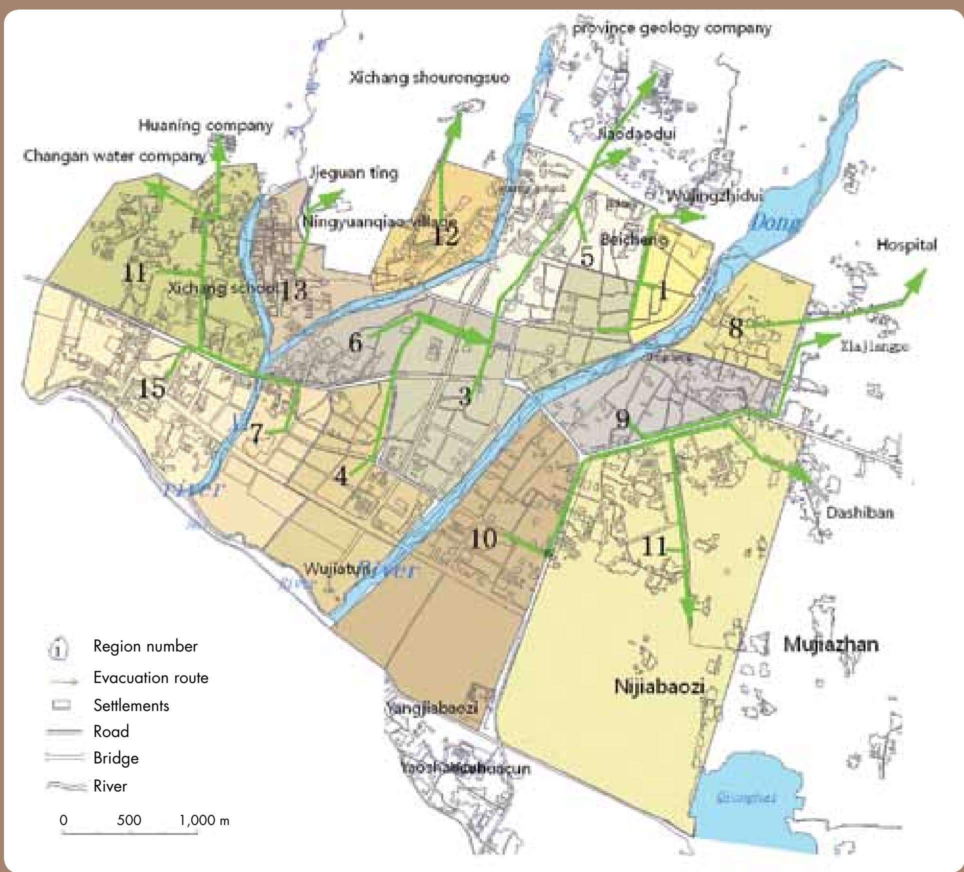
Flash flood risk mapping

In order to summarize the findings of the flash flood risk assessment and contribute to flash flood risk management, the procedures and standards, including map design and compilation, data format and processing, and thematic expression, of flash flood risk mapping were set up and formulated. Consequently, a series of practical flash flood risk maps (51 sheets in

Table 11: **Flash flood risk maps produced by the study**

Map group	Sheets	Main maps	Remarks
Flash flood-inducing environment	14	Topography, slope, altitude, aspect, geo-structure, stratum, lithology, temperature, rainfall, land use, water system, residential areas, roads, administrative divisions, etc.	These maps give information on the natural background to flash-flood formation and provide fundamental data support for the layout of control stations and networks, flash flood monitoring, forecasting, warning, risk assessment and management, and capacity building, among other things.
Flash flood investigation	12	Remote sensing images, flash flood, disaster loss and damage, population, economy, etc.	These maps focus on the danger posed by flash floods including potential socioeconomic loss and risk to resources, assets and other hazard-affected entities and provide fundamental data support for vulnerability assessment and flash flood risk management.
Flash flood prevention and control measures	7	Flash flood control engineering, soil and water conservation engineering	These maps contain information on structural and non-structural measures for flash flood prevention and control.
Monitoring and forecasting	4	Meteorological monitoring, hydrologic monitoring, flash flood monitoring, warning system, forecasting system	These maps focus on the principles, content, methodology, and technology involved in comprehensive flash flood monitoring and forecasting and reflect the achievements of the project.
Risk management	8	Framework of flash-flood risk management, flash-flood risk assessment	These maps establish the framework for flash flood risk management; they contain the flash flood risk assessments and mapping.
Capacity building	3	Flash flood awareness raising, education, training, drills, emergency response, health prevention, etc.	These maps look at the impact of capacity building on flash floods in the study area.
Information-sharing and knowledge-dissemination	3	Comprehensive databases, information-sharing and knowledge-dissemination platform, online release and interaction	These maps are designed for regional information sharing and knowledge dissemination on flash floods; they show the application and impact of the project on flash flood prevention and mitigation.

Figure 31: **The evacuation map for 50-year frequency flash flood in Xichang**



seven map groups) were made using GIS, CorelDraw, and PhotoShop (Table 11; Figure 31).

Capacity building and tool kits

Flash flood capacity building training was conducted for more than 3,700 stakeholders in the study area. Stakeholders include communities, residents, students, volunteers, and representatives of local governments, enterprises, organizations (commercial and non-governmental), and the armed forces. Capacity building activities included the distribution of booklets and posters; lectures; expert consultations; knowledge contests; curriculum teaching; workshops; local TV promotions; slide shows; programmes for students; and training and drills. These activities raised flood risk awareness and strengthened the response capacity of communities and stakeholders in the study area. Community-based preparedness and people's participation in flash flood prevention and mitigation was promoted and the risk management of flash floods in Xichang was improved with the participation of stakeholders and volunteers. In addition to this, tool kits were compiled and distributed among communities in the study area containing more than 4,000 popular science booklets and many emergency bags.

Results

In addition to the five outcomes, the project contributed to:

- **Community resilience:** The project contributed to community resilience for flash floods by using learning from past flash flood experiences and reducing vulnerability through flood forecasting, risk assessment and risk mapping. Risk assessment and mapping were also used to inform industrial arrangements and land use planning. The project also helped encouraged special agricultural practice such as changes to cropping patterns and stall-feeding of livestock to discourage pasture degradation; improved forest areas and developed commercial forestry; encouraged the exporting of services; used local labour for local construction; made proper use of local resources; and strengthened linkages and partnerships for external support and relief.
- **Reducing vulnerabilities:** By complementing existing structural measures with non-structural measures such as flash flood forecasting, risk assessment, and awareness raising, and by building response capacity at the community level, the project reduced vulnerability to flash floods in the study area.
- **Flash flood risk management:** The project raised the capacity of stakeholders in flash flood risk management in the study area through capacity building activities; by piloting and using relevant models, methods, and information systems for flash flood forecasting; and through risk assessment and the maps produced by the study.

Lessons Learnt

- **Language and cultural differences must be considered in project activities or they can become obstacles to effective flash flood risk management**. The Yi people in the study area do not readily learn other cultures and languages, posing a significant obstacle to communication, education, and training, and making it difficult to implement capacity building and flash flood risk management in some Yi areas.
- **Monitoring instruments and effective processing methods for hydrological and meteorological data are essential preliminary steps in flash flood risk management**. Only one Doppler radar and seven field observation stations were established in the study area meaning that some areas are not covered. Meteorological data for some blind areas were interpolated using only linear function and according to experience and the relationship of precipitation to topography and climate. This affects the precision of flash flood forecasting and risk assessment models.
- **Structural measures should not be overlooked and are necessary to support non-structural measures.** Structural engineering measures for flash floods were lacking and most of existing structural engineering measures in the study area were in disrepair. Unfortunately, there are no structural engineering measures in most of the remote and isolated mountain zones in the study area.

Recommendations

- Combine indigenous knowledge and local practices with up-to-date science and techniques for more effective flash flood risk management and to build resilience at the community level.
- Implement structural measures in key units and zones.
- Implement effective and feasible flash flood forecasting and risk assessment systems; this requires reinforcing not only meteorological and hydrological observations at national and local levels, but developing or improving relevant flash flood forecasting and assessment models.
- Enhance the participatory and positive scope of minority groups in flash flood risk management through training, by expanding employment, and by harmonizing them with other groups in all respects.

References

Ageta, Y; Kadota, T (1992) 'Predictions of changes of glacier mass balance in the Nepal Himalaya and Tibetan Plateau: A case study of air temperature increase for three glaciers.' *Annals of Glaciology* 16: 89–94

Bajracharya, SR; Mool, PK; Shrestha, BR (2007) *Impact of climate change on Himalayan glaciers and glacial lakes: Case studies on GLOF and associated hazard in Nepal and Bhutan*. Kathmandu, Nepal: ICIMOD in cooperation with UNEP Regional Office Asia and the Pacific (UNEP/ROAP)

Brahmaputra Board (1985) *Master plan of Brahmaputra basin*, Part I, Main Stem, Volume I. New Delhi, India: Brahmaputra Board, Ministry of Water Resources, Government of India

Central Bureau of Statistics (2001) *National Population Census 2001, Nepal*. Kathmandu, Nepal: National Planning Commission, Central Bureau of Statistics, Government of Nepal

Deka, CR (2008) Land degradation by Jiadhal River of Dhemaji District: A study using remote sensing and GIS technique. *ENVIS Assam Newsletter* (October-December 2008): 2, 8. www.envisassam.nic.in/newsletter/08%20 4oct-dec.pdf (accessed 1 December 2011)

Goswami, DC (1998) 'Fluvial regime and flood hydrology of the Brahmaputra River, Assam.' *Memoir Geological Society of India* 41: 53–75

Hazarika, UM (2003) *Problems of flood, erosion and sedimentation in the Jiadhal River basin, Dhemaji District, Assam: A geo-environmental study*. PhD thesis, Gauhati University, Guwahati, Assam, India

Hazarika, UM (2010) 'Fluvial environment of Jiadhal River basin, Dhemaji District, Assam.' *International Journal of Ecology and Environmental Sciences* 36(4): 271–275

ICIMOD (2011) *Glacial lakes and glacial lake outburst floods in Nepal*. Kathmandu, Nepal: ICIMOD

Ives, J; Shrestha, R; Mool, P (2010) *Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment*. Kathmandu, Nepal: ICIMOD

Kadota, T; Ageta, Y (1992) 'On the relation between climate and retreat of Glacier AX010 in the Nepal Himalaya from 1978 to 1989.' *Bulletin of Glacier Research* 10: 1–10

Kadota, T; Fujita, K; Seko, K; Kayastha, RB; Ageta, Y (1997) 'Monitoring and prediction of shrinkage of a small glacier in the Nepal Himalaya.' *Annals of Glaciology* 24: 90–94

Mishra, DK (2008) *Trapped between the devil and deep waters: The story of Bihar's Kosi River*. New Delhi,India: Peoples' Science Institute, Dehradun and South Asia Network on Dams, Rivers and People

Mool, PK; Che, T; Bajracharya, SR; Shrestha, BR (2005) *Monitoring of glaciers and glacial lakes from 1970s to 2000 in Poiqu basin, Tibet Autonomous Region, PR China*. Kathmandu, Nepal: ICIMOD; Lanzhou, China: Cold Arid Environmental and Engineering Research Institute (CAREERI)

NDMA (2008) *National disaster management guidelines: Management of floods*. Delhi, India: National Disaster Management Authority, Government of India

Shrestha, AB (2008) *Resource manual on flash flood risk management: Module 2 – Non- structural measures*. Kathmandu, Nepal: ICIMOD

Shrestha, AB; GC, E; Adhikary, RP; Rai, SK (2012) *Resource manual on flash flood risk management – Module 3: Structural measures*. Kathmandu, Nepal: ICIMOD

Shrestha, AB; Shah, SH; Karim, R (2008) *Resource manual on flash flood risk management: Module 1 – Community-based management*. Kathmandu, Nepal: ICIMOD

WECS (1987) Preliminary study of glacier lake outburst floods (GLOFs) in the Nepal Himalaya: Phase I Interim Report No. 4/1/200587/1/1. Kathmandu, Nepal: Water and Energy Commission Secretariat, Ministry of Water Resources, His Majesty's Government of Nepal

World Bank (2011) *World Development Indicators database*. http://data.worldbank.org/data-catalog/world-development-indicators

Xu, D (1985) *Characteristics of debris flow caused by outburst of glacial lake in Boqu River in Xizang, China, 1981*. Proceedings of Debris Flow Symposium, Japan. Attached as Appendix 5-3 in WECS (1987)

International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Nepal
Tel +977-1-5003222 **Fax** +977-1-5003299
Email info@icimod.org **Web** www.icimod.org

ISBN 978 92 9115 269 8