सत्यमेव जयते

NATIONAL DISASTER MANAGEMENT AUTHORITY GUIDELINES

MANAGEMENT OF GLACIAL LAKE OUTBURST FLOODS (GLOFs)

October 2020

NATIONAL DISASTER MANAGEMENT AUTHORITY
* INDIA *

NATIONAL DISASTER MANAGEMENT AUTHORITY
MINISTRY OF HOME AFFAIRS
GOVERNMENT OF INDIA

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Swiss Agency for Development
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National Disaster Management Authority Guidelines

Management of Glacial Lake Outburst Floods (GLOFs)

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A publication of:

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सत्यमेव जयते

Prime Minister

MESSAGE

It is heartening to learn that National Disaster Management Authority (NDMA) has prepared national guidelines on management of Glacier Lake Outburst Floods (GLOFs).

Global warming and climate change are among the major challenges the world faces today. The hazards associated with glacial formations in the Indian Himalayan Region (IHR) require an integrated strategy to minimize disaster risks. The national guidelines will increase awareness about different aspects of GLOFs to further efficient monitoring and effective response.

The document on instructions will facilitate a holistic mechanism from local to national level while ensuring valued participation of various stakeholders in IHR. Identification and standardisation of short-term, medium-term and long-term action plans will offer active roles and responsibilities to stakeholders and help build a robust and responsive way forward to deal with glacial risks.

May the national guidelines on GLOFs, the outcome of the collaborative effort of NDMA and Swiss Agency for Development and Cooperation, Embassy of Switzerland, prove to be a valuable asset in the hands of people to efficiently deal with glacial hazards and strengthen our preparedness and resilience.

Best wishes to NDMA for its future endeavours.

(Narendra Modi)

New Delhi
आश्विन 16, शक संवत् , 1942
08th October, 2020

अमित शाह
AMIT SHAH

सत्यमेव जयते

गृह मंत्री
भारत
HOME MINISTER
INDIA

संदेश

यह प्रसन्नता का विषय है कि **राष्ट्रीय आपदा प्रबंधन प्राधिकरण (NDMA)** ने **ग्लेशियल लेक आउटबर्स्ट फ्लड्स (ग्लॉफ)** के प्रबंधन पर राष्ट्रीय दिशानिर्देश विकसित किए हैं, जिसमें ग्लेशियल जोखिमों के सभी पक्षों का सामना करने के लिए दुनिया में उपलब्ध सर्वोत्तम विधाओं को शामिल किया गया है। मेरे लिए यह हर्ष का विषय है कि एन.डी.एम.ए., स्विस एजेंसी फॉर डेवलपमेंट एण्ड कोऑपरेशन (एस.डी.सी.), स्विट्जरलैंड दूतावास के साथ साझेदारी में यह दिशानिर्देश ला रहा है।

भारत के हिमालयन क्षेत्रों में ग्लेशियल लेक आउटबर्स्ट फ्लड्स (ग्लॉफ) की संभावना अधिक है। मुझे विश्वास है कि राष्ट्रीय दिशानिर्देशों के क्रियान्वयन से यथासमय स्थानीय प्रशासन और समुदाय को प्रारम्भिक चेतावनी देने एवं आपदा जोखिम न्यूनीकरण में हमें सफलता मिलेगी।

मैं एन.डी.एम.ए. को ग्लेशियल लेक आउटबर्स्ट फ्लड्स (ग्लॉफ) के प्रबंधन के बारे में राष्ट्रीय दिशानिर्देश तैयार करने के लिए बधाई देता हूँ और प्राधिकरण को सभी भविष्य के प्रयासों में सफलता की कामना करता हूँ।

शुभकामनाओं सहित !

(अमित शाह)

PREFACE

Mountain regions are characterized by sensitive ecosystems, enhanced occurrences of extreme weather events and natural hazards; they are also regions of conflicting interests between economic development and environmental conservation. With rapid global warming, fragile mountain cryosphere and landscapes are evolving and new threats of landslides, Glacial Lake Outburst Floods (GLOFs), avalanches, cloud burst, drought and flash floods are posing serious risks to the vulnerable mountain communities.

The Indian Himalayan Region (IHR) is facing critical challenges while coping with the adverse effects of climate change. The disappearance of mountain glaciers, expansion of large glacial lakes and the formation of new glacial lakes are amongst the most recognizable impacts of global warming in this environment. IHR lies in Seismic Zones IV and V making the region highly prone to earthquakes. This combined with other disturbances such as avalanches and falling boulders is making the glacial lakes vulnerable to breaches, unleashing sudden, potentially disastrous floods in the nearby communities.

People residing at considerable distances downstream from unstable glacial lakes are facing serious threats to their lives and property. Flash floods and GLOFs have killed thousands in many parts of the world. Some of the largest events have occurred in the Indian Himalayas, such as the Kedarnath disaster in Uttarakhand (2013) and Parechu river flash floods in Himachal Pradesh (2005). Despite these losses, disaster risk management related to GLOFs has not been mainstreamed into development policies and programmes.

In this context, the National Disaster Management Agency (NDMA) has partnered with the Swiss Agency for Development and Cooperation (SDC) along with national experts from concerned Indian institutions for the development of the National Guidelines on Management of Glacial Lake Outburst Floods (GLOFs). These guidelines aim to enable concerned ministries or departments of State/UT, central governments and other stakeholders to take concerted action for preparedness, prevention, mitigation, and response to GLOFs. These Guidelines also emphasize awareness and capacity building of the relevant stakeholders.

For further study, Summary of Guidelines for Policy Makers and a detailed compendium may be referred.

Krishna S. Vatsa

Sh. Kamal Kishore	Sh. Krishna S. Vatsa	Sh. Rajendra Singh	Lt. Gen. Syed Ata Hasnain (Retd.)	Sh. G.V.V. Sarma
Member	Member	Member	Member	Member Secretary

Acknowledgement

Formulation of Guidelines for Management of Glacial Lake Outburst Floods (GLOFs) could be accomplished through constitution of Task Force of inter-disciplinary experts. The Task Force comprised of sub-groups of experts addressing different components for glacial lake disaster risk reduction. Besides members of the Task Force, experts from various National and State Government Departments/ Institutions provided useful inputs towards formulation of this document viz. the Ministry of Environment, Forest and Climate Change (MOEFCC), National Institute of Hydrology, Roorkee, Central Water Commission (CWC), Geological Survey of India (GSI), National Remote Sensing Centre (NRSC), National Institute of Disaster Management (NIDM), Snow and Avalanche Study Establishment (SASE) – DRDO, Defence Terrain Research Laboratory (DTRL) - DRDO, Indian Institute of Remote Sensing (IIRS), National Centre for Polar and Ocean Research (NCPOR), Border Roads Organisation (BRO), Wadia Institute of Himalayan Geology (WIHG), Kashmir University, Indian Institute of Technology (IIT) Bombay, Indian Institute of Technology (IIT) Mandi, G.B. Pant National Institute of Himalayan Environment (NIHE), Nehru Institute of Mountaineering (NIM) and University of Zurich, Switzerland.

NDMA acknowledges the dedication of experts of the Task Force who substantially contributed towards the formulation of this document.

The effortless contribution by Dr. Sanjay K Jain and Dr. A K Lohani Scientist–G, National Institute of Hydrology (NIH), Roorkee is much appreciated in compilation and shaping of the guidelines.

We would like to humbly thank the Government of Switzerland acting through the Swiss Agency for Development and Cooperation (SDC), especially Ms. Divya Kashyap, Senior Thematic Advisor of SDC, for partnering with NDMA and extending support throughout the process of guideline development. These guidelines have especially benefitted from the extensive technical inputs provided by Dr. Simon Allen and Dr. Holger Frey from the University of Zurich, Switzerland. Their engagement, which also brought on-board the international scientific perspective through links to the GAPHAZ working group, was possible through the support extended by the SDC.

Efforts of Mitigation Division especially Dr. Ravinder Singh, Senior Consultant (Landslide & Avalanche), NDMA and Ms. Priyanka, Junior Consultant, are highly acknowledged in bringing comprehensiveness and finalization of these guidelines.

Also, contributions of Ms. Sweksha Gupta and Shri Akshay Rai Bansal, former Junior consultants at NDMA are acknowledged in assisting during the initial stages of guidelines preparation.

It is hoped that the sincere efforts that have been put in bringing this document on the frontline will prove useful to the concerned States/ Union Territories, Departments and other stakeholders in formulating projects and plans that will lead to effective and holistic hazards and risks reduction due to GLOFs and LLOFs in future.

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Abbreviations & Acronyms

APN	Asia-Pacific Network for Global Change Research
ASTER	Advanced Space-borne Thermal Emission and Reflection Radiometer
ATIs	Administrative Training Institutes
BIS	Bureau of Indian Standards
CD	Civil Defence
CBOs	Community Based Organisations
CWC	Central Water Commission
CAPF	Central Armed Paramilitary Forces
CPF	Central Police Force
DEM	Digital Elevation Model
DEOC	District Emergency Operating Centre
DoT	Department of Telecommunication
DPDC	District Planning and Development Council
EMS	Electromagnetic Spectrum
ESCAP	Economic and Social Commission for Asia and the Pacific
ENVI	Environment for Visualizing Images
EOC	Emergency Operations Centre
EOS	Earth Observation System
ETH	Swiss Federal Institute of Technology
EWS	Early Warning System
FCC	False Colour Composite
GAPHAZ	Glacier and Permafrost Hazards in Mountains
GCP	Ground Control Point
GIS	Geographic Information System
GLIMS	Global Land Ice Measurements from Space
GLOF	Glacial Lake Outburst Flood
GoI	Government of India

GoS	Government of Sikkim
GSI	Geological Survey of India
HKH	Hindu Kush Himalaya
IAHS	International Association of Hydrologists
ICIMOD	International Centre for Integrated Mountain Development
IDRN	India Disaster Resource Network
IHR	Indian Himalayan Region
IIRS	Indian Institute of Remote Sensing
IMCT	Inter-Ministerial Central Team
IRMSS	Infrared Multi-spectral Scanner
IRS	Indian Remote Sensing
ITBP	Indo Tibetan Border Police
RS-2	ResourceSat-2
ITC	International Institute for Geo-Information Science & Earth Observation
LLOF	Landslide Lake Outburst Flood
LISS	Linear Imaging and Self Scanning Sensor
MSL	Meter above Sea Level
MoD	Ministry of Defence
MoEFCC	Ministry of Environment, Forest and Climate Change
MSS	Multi Spectral Scanner
NASA	National Aeronautics and Space Administration
NCC	National Cadet Corps
NCPOR	National Centre for Polar and Ocean Research
NDRF	National Disaster Response Force
NGO	Non-Governmental Organisation
NDMA	National Disaster Management Authority
NDSI	Normalized Difference Snow Index
NDWI	Normalized Difference Water Index

NLRTI	National Level Research and Training Institute
NIDM	National Institute of Disaster Management
NIH	National Institute of Hydrology
NIM	National Institute of Mountaineering
NIR	Near Infra-Red
NMSHE	National Mission on Sustainable Himalayan Ecosystem
NRSC	National Remote Sensing Centre
NSS	National Service Scheme
NTRO	National Technical Research Organisation
NYKS	Nehru Yuva Kendra Snagathan
PAN	Panchromatic Mode Sensor System (SPOT)
RAMMS	Rapid Mass Movement Simulation
RMS	Root Mean Square
RS	Remote Sensing
SDMA	State Disaster Management Authority
SEOC	State Emergency Operating Centre
SRSAC	State Remote Sensing Application Centre
SMPDBK	Simplified Dam-Break
SPOT	Satellite Pour l'Observation de la Terre
SoI	Survey of India
SOPs	Standard Operating Procedures
SWIR	Short Wave InfraRed
TCPO	Town and Country Planning Organization
TIR	Thermal Infrared
TIN	Triangular Irregular Network
TM	Thematic Mapper
UAVs	Unmanned Aerial Vehicles

UT	Union Territory
UNESCO	United Nation Education Scientific Cultural Organization
UNDRR	United Nations office for Disaster Risk Reduction
UNISDR	United Nations International Strategy for Disaster Reduction
VCA	Vulnerability Capacity Assessment
VIS	Visible
VNIR	Visible and Near InfraRed
WIHG	Wadia Institute of Himalayan Geology
WWF	World Wildlife Fund

Executive Summary

Glacial retreat due to climate change occurring in most parts of the Hindu Kush Himalaya has given rise to the formation of numerous new glacial lakes, which are the major cause of Glacial Lake Outburst Floods (GLOFs). A GLOF is a type of flood occurring when water dammed by a glacier or a moraine is released suddenly. When glaciers melt, the water in these glacial lakes accumulates behind loose naturally formed 'glacial/moraine dams' made of ice, sand, pebbles and ice residue. Unlike earthen dams, the weak structure of the moraine dam leads to the abrupt failure of moraine dam on top of the glacial lake, which holds large volume of water. A catastrophic failure of the dam can release the water over periods of minutes to days causing extreme downstream flooding. Such outbursts known as GLOF have the potential of releasing millions of cubic metres of water in a short period causing catastrophic flooding downstream. Peak flows as high as 15,000 cubic metre per second have been recorded in such events. As a result, the threat of GLOFs is receiving increased attention and awareness for glacial lake monitoring and hazard mitigation has increased recently.

Since glaciers in the Himalayas are in a retreating phase, glacial lakes are growing and pose a potentially large risk to downstream infrastructure and life. As glaciers retreat, the formation of glacial lakes takes place behind moraine or ice 'dam'. Different types of lakes may have different levels of hazard potential. For instance, moraine-dammed lakes located at the snout of a glacier have a high probability of breaching with high hazard potential whereas erosion lakes have little chance of breaching. These floods pose severe geomorphologic hazards and can wreak havoc on all manmade structures located along their path. Much of the damage caused during GLOF events are associated with large amounts of debris that accompany the floodwaters. GLOF events have resulted in many deaths, as well as the destruction of houses, bridges, forests, and roads. Unrecoverable damage to settlements and farmland can take place at large distances from the outburst source with longer term disturbance to the livelihoods.

The potentially dangerous lakes can be identified based on the condition of lakes, dams, associated mother glaciers, and topographic features around the lakes and glaciers. The criteria used to identify these lakes are based on field observations, processes and records of past events, geomorphologic and geotechnical characteristics of the lake/dam and surroundings, and other physical conditions.

Structure of the Guidelines

In these Guidelines, **Chapter 1** provides a general outline of glaciers and glacial lakes in the IHR including factors contributing to glacial hazards. **Chapter 2** covers the Himalayan geo-environment, topographic and geomorphological set up as well as hydrological setup. **Chapter 3** presents hazards and risk zonation mapping with details of the hazard and risk assessment. Risk reduction and mitigation measures which are an important part of the report are covered in **Chapter 4**. **Chapter 5** summarises the aspect of awareness and preparedness including community, medical preparedness. Capacity building has been described in brief in **Chapter 6**. Response such as emergency search and rescue, emergency relief, post-disaster damage, and need assessment, etc. have been given in **Chapter 7**. Research and development in the GLOF are described in **Chapter 8**. Regulation and enforcement covering planning, legal regime, and technical audits, etc. have been discussed in **Chapter 9**. Finally, **Chapter 10** enumerates the action plan and implementation of the guidelines.

Except guidelines, other main outcomes and efforts of Task Force are listed as under:-

a.) Comprehensive Mitigation Projects on Glacial Lake Outburst Flood (CMP-GLOF).

b.) Pilot Project on Reducing Glacial Outburst and Flood Risk in Lhonak Lake & Shako-Cho Lake of North District of Sikkim

Chapter 1: The Context

1.1 GLACIAL LAKE OUTBURST FLOOD (GLOF) AND LANDSLIDE LAKE OUTBURST FLOOD (LLOF) HAZARDS — AN INTRODUCTION

The climate changes, which have set in after little Ice Age, have led to regional challenges and local impact on the mountain eco-systems, including increased instances of Glacial Lake Outburst Floods (GLOFs). A GLOF is created when water dammed by a glacier or a moraine is released suddenly. Some of the glacial lakes are unstable and particularly moraine dammed lakes are potentially susceptible to sudden discharge of large volumes of water and debris which causes floods downstream i.e. GLOF (Xu Jianchu et al., 2007). The ongoing climate change is expected to alter and potentially increase the probability of lake outbursts in the future. To meet related disaster management challenges, the present document presents a framework for the management of glacial hazards and risks, especially focusing on risks of glacial lake outburst floods (GLOFs) and also landslide lake outburst floods (LLOFs) in the IHR.

1.2 FACTORS CONTRIBUTING GLACIAL HAZARDS (GLOF & LLOF)

Factors contributing to the hazards / risks of moraine-dammed glacial lakes include: (a) large lake volume; (b) narrow and high moraine dam; (c) stagnant glacier ice within the dam; and (d) limited freeboard between the lake level and the crest of the moraine ridge. Potential outburst flood triggers include avalanche displacement waves from (i) calving glaciers; (ii) hanging glaciers; (iii) rock falls; (iv) settlement and/or piping within the dam; (v) melting ice-core; and (vi) catastrophic glacial drainage into the lake from sub-glacial or englacial channels or supraglacial lakes.

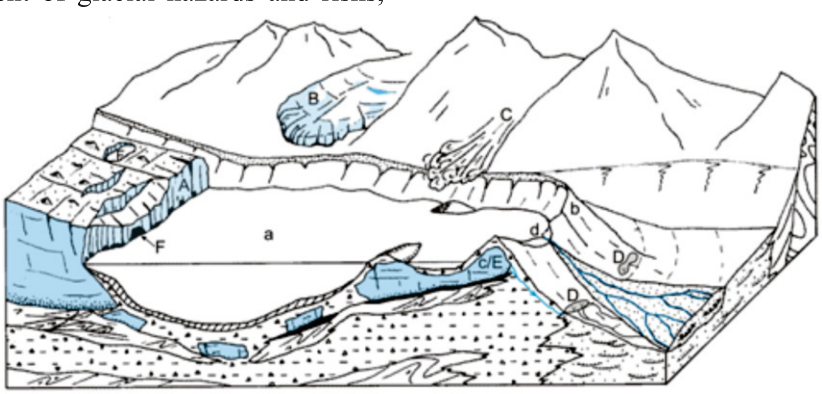


Figure 1.1: Schematic diagram of a hazardous moraine-dammed glacial lake
[**Source:** Richardson, S.D. and J.M. Reynolds (2000)]

Triggering Mechanism

Different triggering mechanisms of GLOF events depend on the nature of the damming materials, the position of the lake, the volume of the water, the nature and position of the associated mother glacier, physical and topographical conditions, and other physical conditions of the surroundings. Interaction between the above-mentioned risk factors and triggering processes like ice avalanches, debris flows, rockfall, earthquake or landslides reaching a lake strongly affect the risk of a lake outburst.

Moraine dam formation process

End and lateral moraines are created from material pushed and piled from glacier movement till released when a glacier melts and recedes and act as an unstable dam to ice melting from the glacier. End moraines are formed at the farthest limit reached by a glacier. Lateral moraines are formed along the sides of a glacier. Both terminal and lateral moraines may act as dams.

Mechanism of moraine-dammed lake failure

In addition to, earthquakes being one of the causes for moraine dam failure (Clague 2003), the frequency and magnitude of moraine dam failures and GLOFs will continue to increase with the current and continued scenario of global warming (RGSL 2003) and present one of the greatest threats to people and property in mountainous regions. The unstable nature of moraine dams greatly increases the chances of dam failure. Large lake volume above the moraine dam increases pressure against the dam. Large wave caused from calving glaciers or ice or rock avalanches into the lake may overtop the moraine dam. Melting of stagnant glacier ice in the moraine dam may also reduce the freeboard or create passageways for piping to occur. Catastrophic glacial drainage may raise the lake level quickly and overtop the dam (RGSL 2003; Hambrey and Alean 2004).

Initiation of opening within or under the ice dam (glacier) occurs in six ways:

- Floatation of the ice dam (a lake can only be drained sub-glacially if it can lift the damming ice barrier sufficiently for the water to find its way underneath);
- Pressure deformation (plastic yielding of the ice dam due to a hydrostatic pressure difference between the lake water and the adjacent less dense ice of the dam; outward progression of cracks or crevasses under shear stress due to a combination of glacier flow and high hydrostatic pressure);
- Melting of a tunnel through or under the ice;
- Drainage associated with tectonic activity; and
- Water overflowing the ice dam generally along the lower margin.

The bursting mechanism for ice-dammed lakes can be highly complex and involve some or most of the above-stated processes. A landslide adjacent to the lake and subsequent partial abrasion on the ice can cause the draining of ice core-moraine-dammed lakes by overtopping as the water flows over, the glacier retreats, and the lake fills rapidly. A mechanical failure of the ice dam can result in extreme discharge and is the most critical outburst mechanism.

1.3 PRESENT MECHANISM FOR EARLY WARNING SYSTEM

The Early warning system (EWS) is an integral component of risk management for natural disaster. It has been listed as one of the five priorities under Hyogo Framework for Action (HFA) for building disaster resilient nations and communities and is one of the seven global targets of its succeeding document, the Sendai Framework for Disaster Risk Reduction (SFDRR).

The traditional framework of early warning systems is composed of **three phases**: i) monitoring of precursors; ii) forecasting of a probable event; and iii) the notification of a warning or an alert before an event take place (see figure 1.2). Thereafter, the emergency response system becomes active. The purpose is to recognize the fact that there needs to be a response to the warning, where the initial responsibility relies on emergency response agencies. International standards set by the United Nations office for Disaster Risk Reduction (UNDRR) formerly

United Nations International Strategy for Disaster Reduction (UNISDR) encompasses the four key components of EWS. Effective early warning systems require strong technical foundations and good knowledge of the risks. At the same time, they must be embedded in an understandable manner and relevant to the communities which they serve (Villagran de León et al., 2007) with clear messages, dissemination systems that reach those at risk, and practiced and knowledgeable responses by risk managers and the public. A detailed discussion on early warning systems is covered in section 4.6 of these guidelines.

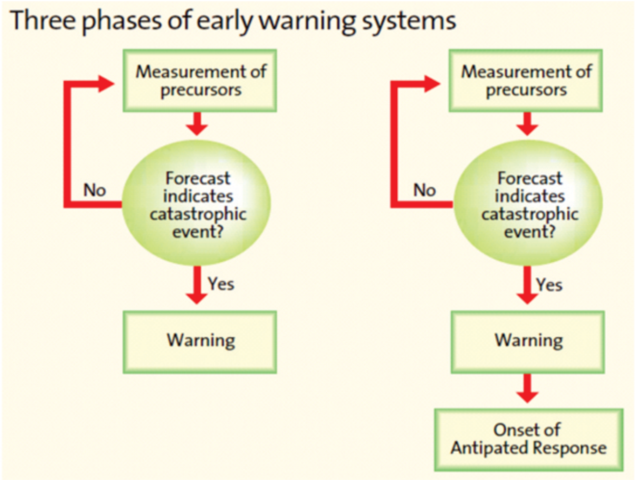


Figure 1.2: Three phase early warning system.

1.4 KEY RISK PARAMETERS

Risks are considered key when there is a high probability that the hazard will occur under circumstances where societies or social-ecological systems exposed are highly susceptible and have limited capacities to cope or adapt and as a result potential consequences are severe. Both the timing of the hazard and the dynamics of vulnerability and exposure contribute to disaster impacts. Risks that materialise in the near term may be evaluated differently than risks that materialise in the distant future, as the time available for building up adaptive capacities is different (Fig. 1.3)

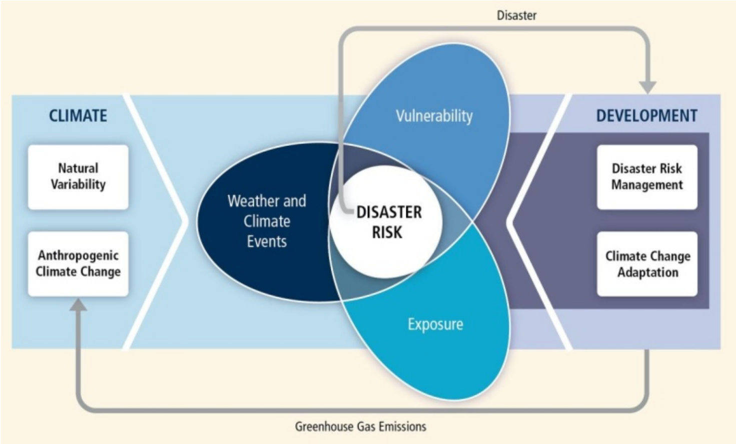


Figure 1.3: Risk Concept of IPCC (IPCC, 2012)

1.5 GLOF MANAGEMENT STRATEGIES

There are several possible methods for mitigating the impacts of GLOFs, for monitoring and for early warning systems (cf. Chapter 4). The most important structural mitigation measure for reducing GLOF risk is to reduce the volume of water in the lake in order to reduce the peak surge discharge. In general, any one or combination of the following methods may be applied for reducing the volume of water in the lake: controlled breaching, construction of an outlet control structure, pumping or siphoning out the water from the lake, and making a tunnel through the moraine barrier or under an ice dam. Careful evaluation with detailed studies of the lake, mother glaciers, damming materials, and the surrounding conditions are essential in choosing an appropriate mitigation measure. Any existing and potential source of a larger snow and ice avalanche, slide, or rock fall around the lake area, which has a direct impact on the lake and dam has to be studied in detail.

Non-structural and organizational mitigation measures can be complementary to structural measures. In particular, in remote and inaccessible regions, non-structural mitigation measures such as NGOs and other social societies in the region often provide more cost-efficient options compared to structural measures.

There should be monitoring systems prior to, during, and after construction of infrastructure and settlements in the downstream area. It will be necessary to build bridges with appropriate flow capacities and spans at elevations higher than those expected under GLOF events.

1.6 NATIONAL DISASTER MANAGEMENT POLICY AND GUIDELINES

As per Disaster Management (DM) Act 2005 and National Disaster Management Policy 2009; NDMA, as the apex body for disaster management headed by the Prime Minister, has the responsibility for laying down policies, plans and guidelines for the disaster management and coordinating their enforcement and implementation for ensuring timely and effective response to disasters in India.

The possibility of GLOF and LLOF in Indian Himalayan Region (IHR) are escalating very rapidly and pose a threat to the lives of millions of people living in this region. Preparation of these guidelines is an utmost need to mitigate the impacts of glacial hazards and risks, to develop disaster resilient communities and significantly reduce the loss of lives and assets. These guidelines will assist the Central Ministries, Departments and States to formulate their respective DM plans and extend necessary cooperation/assistance to NDMA for carrying out its mandate.

1.6.1 Approach to the Guidelines

The main objective of the guidelines is to generate awareness of various aspects of dam failure hazards in India and to implement suitable actions to reduce both the risk and costs associated with these hazards. The Guidelines envision to improve administrative response, bringing together the relevant scientific capabilities of the nation to eliminate the losses from glacial and landslide hazards.

The main aim and objectives of these Guidelines is to develop a strategy that encourages the use of scientific information, maps, methodology, guidance for early warning system, response management, development and implementation of initiatives to reduce losses from glacial hazards. These Guidelines also describes the awareness, preparedness, capacity development, research and development, regulations and enforcements and roles and responsibilities of the local, state and national ministries/ departments along with the various scientific organizations and institutions to reduce the potential risks.

CHAPTER 2: HIMALAYAN GEO-ENVIRONMENT AND CRYOSPHERE

2.1 INTRODUCTION

The Himalayan arc is young and tectonically active, formed as a result of massive collision between Eurasia and the northward-drifting Indian plate about 50 million years ago (Patriat and Achach,1984). It forms the northern limit of India. The Hindukush-Karakoram-Himalaya hosts the largest and most important glacier systems outsides the poles and is commonly referred to as **the third pole** on the earth. The changing climate associated with increased run-off and less infiltration coupled with the removal of forest cover has resulted in the depletion of the hill aquifer system in the region. Variability of monsoon rains and seasonal snow-glacier melt have often led to unpredictable flash floods, rock-falls, debris flows, avalanches, GLOFs, landslides, soil erosion resulting in the loss of human lives and property.

2.2 GEOLOGICAL SETUP

The Himalaya is a classic example of an orogenic system created by continent–continent collision (e.g., Dewey and Bird, 1970; Dewey and Burke, 1973).The Himalayan mountain range is subdivided into four principal tectonic zones, from south to north these are: the Sub-Himalaya (Shiwalik Range), the Lesser Himalaya, the Higher Himalayan Crystalline, complex and the Tethyan Himalaya (Fig. 2.1& 2.2).

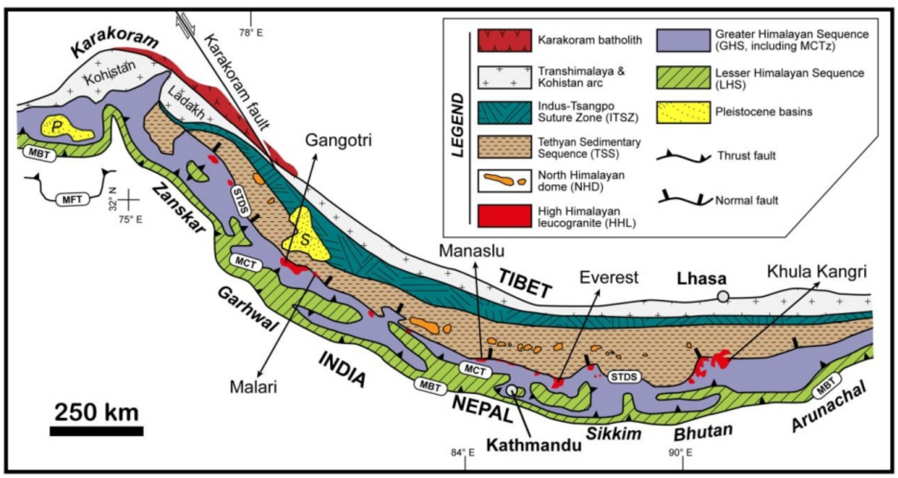


Figure 2.1: Schematic geological map of the Himalayan belt showing the main units and tectonic boundaries (modified after Law et al., 2004 and Weinberg, 2016). MFT: Main Frontal Thrust; MBT: Main Boundary Thrust; MCT: Main Central Thrust; STDS: South Tibetan Detachment System; P: Peshawar basin; S: Sutlej basin. (*Source: Carosi et al., 2018)*

2.3 TOPOGRAPHIC AND GEO-MORPHOLOGICAL SETUP

The most characteristic features of the Himalayas are their soaring height, steep-sided jagged peaks, valley and alpine glaciers, topography deeply cut by erosion, seemingly unfathomable river gorges, complex geologic structure, and series of elevation zones that display different ecological associations of flora, fauna, and climate. The regional geomorphology of the Himalaya reflects the interaction of mountain building and precipitation setup from the south. The Himalayas appear as a gigantic crescent with the main axis rising above the snow line, where snowfields, alpine glaciers, and avalanches all feed lower-valley glaciers that in turn constitute the sources of most of the Himalayan rivers. The greater part of the Himalayas, however, lies below the snow line. The mountain-building process that created the range is still active. As the bedrock is lifted, considerable stream erosion and gigantic landslides occur.

2.4 HYDROLOGICAL SETUP

The Himalaya is the water tower of the Asian continent, characterized by high precipitation and little evaporation because of lower air temperatures and longer snow coverage, resulting in large contributions of snowmelt and ice melt to the runoff of lowland areas (Viviroli et al., 2007). Himalayan glaciers are drained by 19 major rivers that form the Indus, the Ganges and the Brahmaputra river systems flowing throughout the Himalayan regions, each having a defined catchment area. These rivers rise north of the mountain ranges and flow through deep gorges that generally reflect some structural control, such as a fault line. All the major rivers like the Ganga, Indus, and Brahmaputra originate from the glacierized

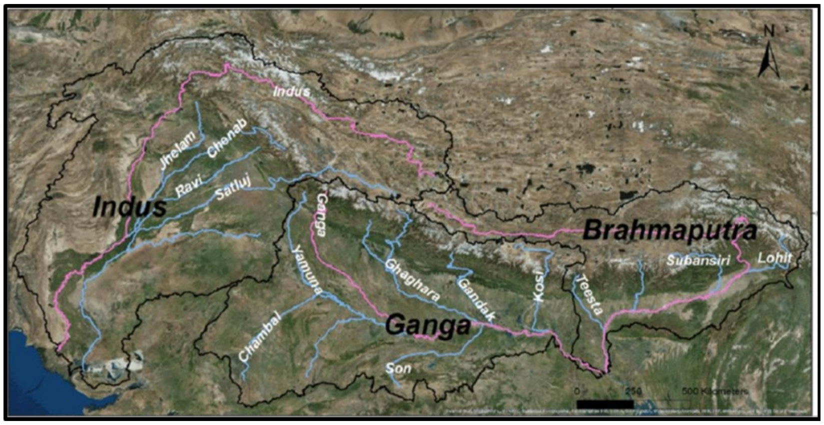


Figure 2.2: Three major river systems emerged from snow/glaciers bound area in the Himalaya.

2.5 CRYOSPHERE SYSTEM

In India 35% of the geographical area is mountainous, of which 58% is covered under the Himalayas. This area covers about 20.3% of India's total geographical area. The Himalaya consist a large area of snow/ice and snow cover after the Polar Regions, hence, studies are largely focused on snow and glaciers due to its visible impact on the environment and resources. The water flowing in the Himalayan Rivers is the combined drainage from rainfall, snowmelt and glacier-melt runoff. In the Himalayan region, several water resources projects are under operation and many more are coming up. These projects are of considerable national and local importance in terms of hydropower generation, irrigation, flood control and subsequent socio-economic development of the region. Proper planning and management of these projects depends on the correct assessment of stream flow generated from snow and glacier melt.

About 10 percent of the Himalaya is covered with glaciers and additional area of nearly 30 to 40 percent supports the snow cover. In total, there are about 9,575 glaciers (37,500 km^2) in the Indian Himalayan Region (IHR), spread across 6 states and union territories i.e., Jammu-Kashmir, Ladakh, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh (Raina and Srivastva, 2008). These glaciers form the perennial source for three great rivers: viz, the Indus, the Ganga and the Brahmaputra. The three basins (India and Environs) put together have 71182.08 km^{2}of glaciated area with 32392 glaciers. The Indus basin (including Tibet, Karakoram, Great Himalaya) has 16049 glaciers occupying 32246.43 km^{2}of glaciated area. The 18 glaciated sub-basins in Indus basin are mapped. The Ganga basin (Including Nepal) has 6237 glaciers occupying 18392.90 km^{2}of glaciated area. There are 7 glaciated sub-basins in Ganga basin. The Brahmaputra basin (including Bhutan and south Kailash range in Tibet), has 10106 glaciers occupying 20542.75 km^{2}of glaciated area. The 27 glaciated sub-basins in Brahmaputra basin are mapped. Basin wise glacier summary for Indus, Ganga and Brahmaputra basin is provided in table 2.1 and Fig. 2.3.

Table 2.1: Summary of glacier and lake inventory of Indus, Ganga and Brahmaputra basins.

Sr. No.	Basin Characteristics	Indus Area (in km^2)	Ganga Area (in Km^2)	Brahmaputra Area (in Km^2)	Total basin Area of all three (in Km^2)
1	Sub-basins (Nos.)	18	7	27	52
2	Accumulation Area	19265.98	10884.6	12126.35	42276.94
3	Ablation Area Debris	6650.95	4844.7	5264.90	16760.55
4	Ablation Ice Exposed	6310.58	2663.5	3081.48	12055.56
5	Total no. of glaciers	16049	6237	10106	32392
6	Total glaciated area	32246.43	18392.9	20542.7	71182.08
7	No. of Permanent Snow fields and Glaciers	5117	641	3651	9409
8	Area under of Permanent Snow fields and Glaciers	991.68	198.70	1282.9	2474.3
9	No. of Supra-glacier lakes	411	87	474	972
10	Area of Supra-glacier lakes	18.92	15.20	70.0	104.13
11	No. of Moraine dam /Glacial lakes	469	194	226	889
12	Area of Moraine dam /Glacial lakes	33.82	64.10	70.2	168.07

*Source: ISRO, 2010. Snow and Glaciers of the Himalayas: Inventory and Monitoring, Discussion Paper II, Space Application Centre (SAC) Ahmedabad and Ministry of Environment and Forests, New Delhi. (*http://www.moef.nic.in/downloads/public-information/Discussion_Paper%20-%2013th%20June.pdf*)*

The distribution of glaciers in the Himalayas is uneven, with higher concentration of glaciers in the North-Western part as compared to North-Eastern part. Such complexity is due to criss-cross mountain chain, altitude variation and different climatic conditions. Vohra (1996) stated that the glaciers are found in all those areas which attain or exceed the heights necessary for glacier generation. Most of the glaciers are situated on the main Himalayan range, but other ranges, such as the Pir Panjal, Dhauldhar and Ladakh ranges also support glaciers.

It has been estimated by various researchers that about 17 percent of the Himalaya and 37 percent of the Karakoram are covered by glacier ice. The major clusters of glaciers occur in and around the following ten Himalayan peaks and massifs: Nanga Parbat, the Nanda Devi group, the Dhaulagiri massif, the Everest-Makalu group, the Kanchenjunga, the Kula Kangri area, and Namche Barwa.

The principal glaciers of the Himalaya are Siachen (72 km^2), Gangotri (30 km^2), Zemu (26 km^2), Milam (19 km^2), and Bara Shigri (30.5 km^2).

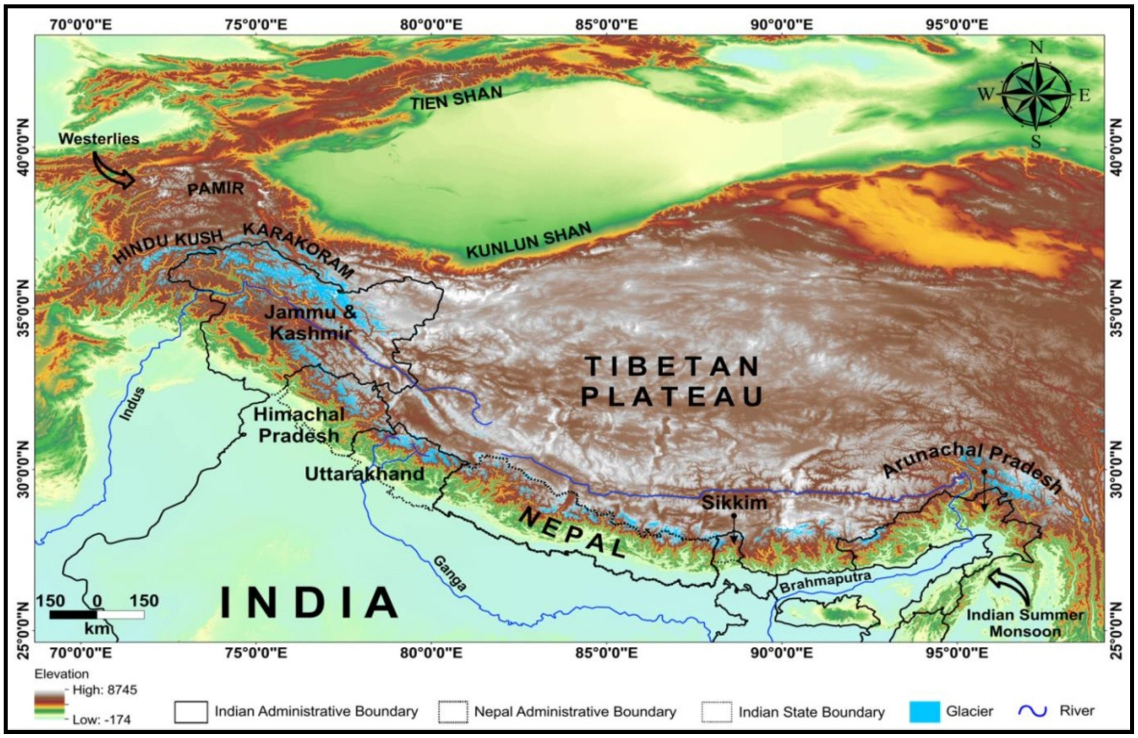


Figure 2.3: Glaciers cover and the major river systems (the Indus, the Ganga and the Brahmaputra) over the Indian Himalayan range.

2.5.1 Permafrost

Permafrost and frozen grounds are key elements of the terrestrial cryosphere that will be strongly affected by a warming climate. Permafrost is defined as sub-surface earth materials that remain continuously at or below the freezing temperature of water for at least two consecutive years (Harriset al., 1988). The permafrost evidences in the IHR was available from Tso Kar lake area way back in 1975-76 from a study conducted by the Geological Survey of India (GSI). Initial modelling assessment on a regional scale suggests that the permafrost area in the Hindu Kush Himalaya (HKH) region could extend up to 1 million km^2, which roughly translate into 14 times the area of glacier cover in the region. The permafrost covered glacial mountains in Sikkim are shown in Fig. 2.4.

Fig.: 2.4 The Permafrost covered glacial mountains in Sikkim (Eastern Himalayas, Indian Himalayan Region)

The monitoring of permafrost and surface conditions is necessary to understand the permafrost distribution in a certain area and includes, i) compilation of information from detailed field soil surveys and mapping; ii) Historical data (maps and literature), photographs and, satellite imageries; iii) spatially explicit thermal modelling of ground temperatures. This information can be used for the design of a monitoring network, and assessment of regional ecosystems.

Permafrost thaw in the high mountain areas, especially in drier climatic zones such as the Upper Indus basin (UIB) could increase the probability of GLOF and LLOF occurrences. Most of the glacial lakes in this region are formed by melting of the ground ice left by the receding glacier and surrounded by ice cored moraine. Identification of shallow permafrost in the glacier elevations of cold-arid region of Ladakh in the Upper Indus basin recently (Schmidt et al., 2016, Wani et al., 2019, Thayyen, 2020) suggests serious implications of possible permafrost thaw on glacial lakes. As warming occurs in the region, the ice core within the moraine that holds the glacial lake water can lose its strength leading to its eventual collapse leading to GLOF. A number of GLOFs are reported from the region but no study has been conducted to assess the causative factors. Furthermore, thawing of permafrost in steep mountain slopes can increase the likelihood of rockfalls and large rock avalanches that can enter a lake and trigger GLOFs.

Chapter 3: Hazard & Risk Zonation Mapping

3.1 INTRODUCTION

The hazard and risk assessment provide the basis for prioritising, designing, and implementing risk management strategies, and is therefore considered as a cornerstone of Disaster Risk Management (DRM). Given the complexity of interacting surface processes and landforms in high mountain environments, integrative, forward-looking and comprehensive system-wide approaches to hazard modelling are required, going beyond traditional modelling of single processes.

This chapter provides guidance on a systematic approach to the assessment of glacial and permafrost-related hazards and risk, and in particular Glacial Lake Outburst Floods (GLOFs), drawing upon latest international best practices (GAPHAZ, 2017). Following an introduction to the overarching hazard and risk assessment framework, the chapter focuses on two levels of assessment, firstly to identify potentially dangerous lakes, and then to undertake detailed hazard and risk assessment for such lakes, and downstream areas.

3.2 HAZARD AND RISK ASSESSMENT FRAMEWORK

The hazard and risk assessment framework follows the concept of climate risk, an integrative concept gaining increasing importance in international climate change policy (IPCC, 2014). Integrating the traditionally diverging perspectives from the disaster risk management and climate adaptation communities, climate risk is conceptualized by IPCC (Figs. 1.3 and 3.1). Figure 3.1 describes the first order risk assessment, to be applied to larger regions (e.g. national or state level) in order to identify hotspots of risk and helps prioritising sites or regions where detailed risk assessments need to be focussed. Based on the detailed risk assessment various risk management options can be effective in reducing underlying vulnerabilities, exposure, or the hazard itself as a physical event (hazard) intercepting with an exposed and vulnerable system (e.g., community, industry, or ecosystem). The assessment framework distinguishes between two primary levels of assessment: 1) First-order assessment at a national or regional scale to provide a preliminary overview of risk hot-spots where further investigation and prioritization can be focused; and 2) the detailed hazard and risk assessment for a specific location or community that then provides the basis for decision-making, design, and implementation of risk management strategies (see section 5).

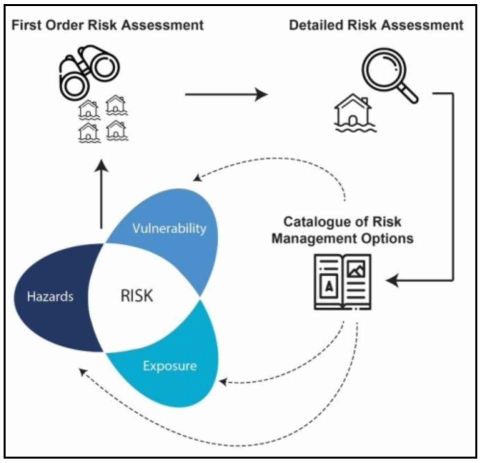


Figure 3.1: Glacial and Permafrost-related Risk Management within the broader Climate Risk framework of IPCC (2014).

3.2.1 Hazard

Hazard in the context of these guidelines refers to the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. The component of the assessment of GLOF builds on from internationally accepted best practices in hazard assessment recently published by the International Association of Cryospheric Sciences and International Permafrost Association (IACS/IPA) Standing Group on Glacier and Permafrost Hazards (GAPHAZ, 2017).

Two core components (or outcomes) of the hazard assessment process include:

1. *Susceptibility and stability assessment*: Identifying where from and how likely hazard processes are to initiate, based on an assessment of wide-ranging triggering and conditioning factors
2. *Hazard mapping:* Identifying the potential threat from the hazard for downslope and downstream areas, and providing the scientific basis for decision making and planning.

Typically, hazard is then quantified and communicated in the form of classified hazard maps, defined on the basis of the probability (or likelihood) that an event will occur and the expected intensity (or magnitude) of the given event.

3.2.2 Exposure

For glacial and permafrost related risks, exposure is typically assessed based on an inventory of anthropogenic elements that could be adversely affected by hazard (villages, habitations, roads, bridges, critical lifelines, hydropower stations, heritage sites, sacred places, schools, hospitals, military infrastructure etc.) located within the runout path of potential flood and mass movement events.

3.2.3 Vulnerability

Vulnerability is highly context specific, and can vary significantly as physical vulnerability (housing-infrastructure), social vulnerability (age, gender, education, etc.) and economic vulnerability.

3.3 DISASTER CATALOGUING AND LAKE INVENTORIES

Cataloguing of past GLOFs or other disasters is to be distinguished from a glacial lake inventory that literally maps all glacial lakes in a given region.

The cataloguing of past catastrophic mass movements is a fundamental pre-requisite for the assessment of hazards and risks. Through investigation of the distribution, type, and pattern of past hazard events, understanding of triggering and conditioning processes can be improved. When physical access or remotely sensed imagery allows detailed investigation of an outburst event, main physical parameters to be considered are:

- Lake name
- coordinates (longitude, latitude, altitude)
- location (mountain range, valley)
- lake type (supra-, pro-, peri-, sub-glacial, etc.)
- lake size (pre- and post- event)
- dam type (bedrock-dammed, moraine-dammed, ice-dammed, combined dam, landslide dammed)
- permafrost conditions (ice-cored moraine, rock glaciers, surrounding rock slopes)

- best estimate of date of lake formation (particularly for landslide-dammed lakes)
- date of outburst event
- probable trigger
- outburst mechanism(s)
- flood volume
- peak discharge at lake site
- downstream reach - the water levels and discharges along the reach at certain intervals
- flow type/sediment load
- downstream impacts

Key considerations for a glacial lake inventory concern the definition of what will be included as glacial lake, and the temporal and spatial scale at which the inventory will be undertaken. On these aspects the following factors may be considered:

- Lakes that remain in direct contact with a glacier
- Lakes which are formed within and/or dammed by glacial ice or debris (moraine)
- Lakes that are in contact with, or formed within creeping permafrost features.
- Bedrock dammed lakes occupying glaciated or former glaciated cirques.
- Other lakes that are in close proximity, and therefore directly threatened by unstable glaciers or permafrost zones.
- Have a minimum size of 1 hectare (0.01 km^2)
- Mapping all lakes within the catchment area of the district or state under consideration, including the ones whose catchment areas may extend beyond administrative boundaries.
- Undertake mapping in the post-monsoon window, when lakes will be at their largest, and conditions are most favorable for remote-sensing based analyses.

3.4 FIRST-ORDER HAZARD AND RISK ASSESSMENT

First order hazard and/or risk assessments are typically implemented at large-scale (e.g., National to State level), in order to establish an overview of potential risk hotspots and as a basis for prioritising further actions. Such assessments can extend across administrative boundaries, to consider far-reaching trans-boundary hazards and risks. For GLOFs, the starting point for any assessment is establishing a comprehensive and up-to-date lake inventory for the region of interest (Section 3.3), including existing information from studies that have assessed hazard and/or risk associated with the mapped lakes.

3.4.1 Large-Scale Assessment Methods

Large-scale assessment methods include a range of approaches that provide a first indication of the extent and threat of hazard and risk, but where hazard intensities and impacts are not physically modelled and field studies not undertaken.

At large scales, key factors that are considered in a remote-sensing based assessment of lake stability in the Himalayan context typically include as a minimum:

- The potential for ice and rock avalanche triggering of an outburst event (including the role of glacial de-buttressing and permafrost degradation)
- Climatological conditions (rainfall, snowfall, temperature)
- Lake area (as a proxy for lake volume)
- Lake watershed characteristics (e.g., favoring rainfall and snowmelt into the lake)
- Dam type (ice, rock, or debris)
- Steepness of the downstream slope of the dam

While other factors sometimes considered, depending on the availability of data and scale of the assessment include:

- Dam freeboard
- Dam width to height ratio
- Permafrost conditions – presence of an ice cored moraine

Note that a full explanation of the various predisposing and triggering factors that would be considered in a more detailed local assessment are outlined (see Section 3.5).

Available large-scale data for some or all states of the IHR that can be used to characterise exposure to GLOFs and other hazards includes:

- Population (population density grids or census data)
- Village locations (as points or outlines)
- Transport infrastructure, including strategically important roads
- Agricultural land area
- Forest areas
- Wetland areas
- Cultural heritage sites
- Tourism sites and hotels
- Hydropower stations.

Table 3.1: Indicators used in the flood vulnerability assessment for Himachal Pradesh, India. The main components of vulnerability represented by each indicator are listed, and the dependency of the relationship with vulnerability is given (after Allen et al., 2016).

S. No.	Indicator	Components represented	Dependency(1)
1.	Female population	sensitivity, capacity to prepare, respond and recover	+
2.	Population <6 years of age	sensitivity, capacity to prepare, respond and recover	+
3.	Population >60 years of age	sensitivity, capacity to prepare, respond and recover	+
4.	Literacy rate	capacity to prepare, respond and recover	-
5.	Unemployment	capacity to prepare, respond and recover	+
6.	Employment in farming	sensitivity, capacity to recover	+
7.	Disabled population	sensitivity, capacity to prepare, respond and recover	+
8.	Home renters	capacity to recover	+
9.	Derelict houses	sensitivity, capacity to respond and recover	+
10.	Water availability	capacity to prepare and respond	-
11.	Medical facilities	capacity to prepare and respond	-
12.	Education facilities	capacity to prepare, respond and recover	-
13.	Banking services	capacity to prepare and recover	-
14.	Access to radio	capacity to prepare and respond	-
15.	Access to TV	capacity to prepare and respond	-
16.	Access to internet	capacity to prepare and respond	-
17.	Access to mobile	capacity to prepare and respond	-
18.	Access to vehicle	capacity to prepare, respond and recover	-

(1) A positive (+) dependency means that an increase in the measured variable indicates an increase in vulnerability. A negative (-) dependency means that an increase in the measured variable indicates a decrease in vulnerability.

3.4.2 Potentially critical Lakes in the IHR

To identify potentially dangerous lakes, one should ideally draw upon multiple sources of information, combining large-scale first order assessment results (including trans-boundary threats), with knowledge available from previous state level investigations and studies. Such an approach is favoured because it emphasises those lakes that have been identified as critical in one or more studies, and therefore provides the most robust basis for prioritising where further local investigations, and potentially risk reduction strategies should be targeted. Importantly, the selection criteria should be based on mutually agreed and scientifically accepted criteria. A first-order assessment and listing of potentially dangerous lakes in support of this guidance document has been provided in Annex 1. It must be stressed however, that such listings of potentially dangerous lakes are merely a static snapshot, and first order hazard and risk assessments should be updated at regular intervals to keep pace with rapidly changing environmental and social landscapes.

Index-based approaches can be used by combining standardised indices (see Annex 1) for hazard, exposure, and vulnerability. Indices have the advantage that they remain objective, whereas decision-trees require a higher level of expert judgement.

Typically, first-order approaches focus on the threat to people and property, however, sector-based assessments are also recommended, as lakes that may pose a critical threat to one sector, e.g., the farming or transportation sector, may be different from those lakes that threaten populated areas, or another sector. General conclusions from the first order assessment and synthesis provided in Annex 1 include (see also Figures 3.2 and 3.3):

- Major roads and bridges across all states are threatened by potentially dangerous lakes.
- The threat to cropland is greatest in the union territory of Jammu and Kashmir & Leh-Ladakh, Sikkim, and Arunachal Pradesh.
- The threat to hydropower is the highest in Sikkim.
- GLOF risk to the population is the highest in Sikkim and Jammu and Kashmir, but a danger exists across all Himalayan states (note this does not consider seasonal variations in population as related to, e.g., tourism).

Annex -1: *Synthesis Report on current GLOF hazard and risk across IHR by University of Zurich. Available at: https://eclim-research.ch/synthesis-report-on-current-glof-hazard-and-risk-across-ihr-5/*

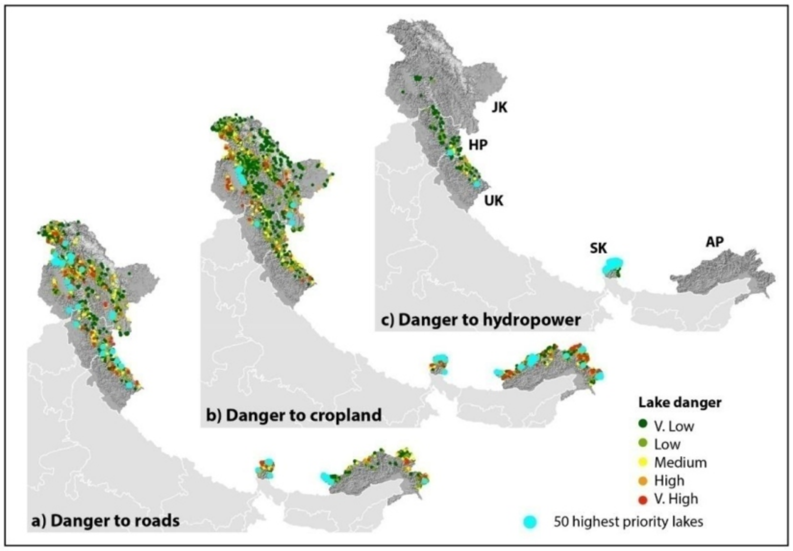


Figure 3.2: Lake danger levels assessed with a large-scale first-order approach, considering exposure of roads, crop land, and hydro-power stations.
(For full results & final listing based on comparison with other studies see Annex 1)

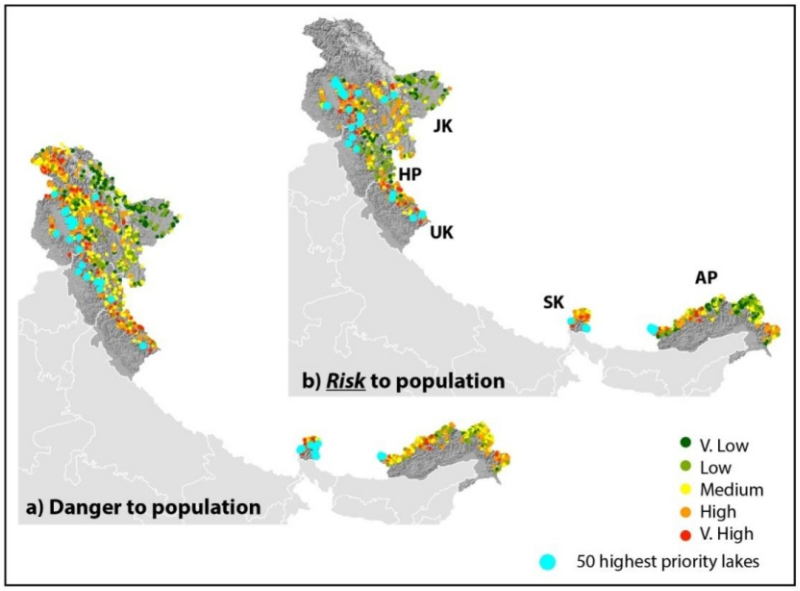


Figure 3.3 : Lake danger and risk levels assessed with a large-scale first-order approach. Danger considers lake hazard levels and population density. Lake risk includes social vulnerability (from IHCAP 2019)**, which as not available for all of J&K.**
(For full results & final listing based on comparison with other studies, see Annex 1)

Annex -1: *Synthesis Report on current GLOF hazard and risk across IHR by University of Zurich. Available at: https://eclim-research.ch/synthesis-report-on-current-glof-hazard-and-risk-across-ihr-5/*

3.5 DETAILED HAZARD AND RISK ASSESSMENT

Where critical situations are identified (e.g., where the large-scale assessment has revealed hotspots of risk), detailed hazard and risk assessments should be undertaken, combining sophisticated hazard modelling and mapping with on-ground assessment of vulnerability and exposure to generate local risk maps. A detailed risk assessment aligns to section 5.1.2 of the 2009 National Policy on Disaster Management, and institutional responsibilities for undertaking GLOF hazard and risk mapping are outlined under section 7.11.1 of the 2019 National Disaster Management Plan (NDMP). A prominent example of this level of assessment is at South Lhonak glacier lake in Sikkim, where major work was carried out by Geological Survey of India (GSI) and Defence Research & Development Organization (DRDO), including remote sensing and field observations to assess geotechnical and geomorphic factors.

3.5.1 Assessing susceptibility/stability

Wide-ranging atmospheric, cryospheric, and geotechnical factors can condition and trigger GLOFs and other glacial or permafrost-related hazards (see Appendices 1-3). The relevance of certain factors for susceptibility or stability will vary from one region to another, and expert judgement is needed to determine whether or not more emphasis (weight) should be applied to some factors. For example, in monsoon affected parts of the IHR, more emphasis might be given to the role of heavy precipitation in triggering GLOF events, while in drier permafrost-rich zones, degradation of buried ice in the moraine dam could be the most critical factor. Conditioning and triggering factors inform not only about the location and likelihood of an event, but also provide insights on the possible magnitude of the event. Appendix – 3 outlines the main factors to be considered, corresponding methodological approaches and assessment scale to be applied to assess the susceptibility and stability of a glacial lake.

3.5.2 Hazard mapping and zonation

Hazard mapping and zonation typically draws upon historical records to establish frequency – magnitude relationships that can then be used as a basis for scenario development and hazard modelling, e.g., hazard mapping for a given river floodplain might be conducted for flood event with an established peak discharge, which may vary from catchment to catchment depending upon the frequency-magnitude relationship. For hazards such as GLOFs that originate in high mountain environments, the ability to establish a reliable frequency – magnitude relationship is limited by three factors:

- Hazards originate often in remote, inaccessible locations, meaning even large events may have passed unnoticed and dates of previous events are missing or highly uncertain for the historical record.
- The cryosphere is changing rapidly and, in some cases, conditions are already beyond any historical precedence, meaning frequency – magnitude relationships are of decreasing significance.
- Many events can occur only once (e.g. complete incision of a moraine dam), and hence, frequency – magnitude relationships may not apply at all.

Given these limitations, a semi-qualitative approach to scenario development is different magnitudes (small, medium, and large) are linked to corresponding best estimates of the likely probability of occurrence (e.g., low, medium, high). The fundamental basis for the scenario development is the information gathered during the susceptibility and stability assessment, augmented where possible with the best understanding of past events occurring in the region or other areas (Figure 3.4).

3.5.2.1 Scenario development

The goal is to establish three feasible scenarios based on the underlying lakes susceptibility assessment, where the potential mass or volume initiated in a small, medium, or large event is estimated, and a corresponding best estimate of the probability of such an event occurring is assigned.

For GLOFs, the following general approaches for scenario development are foreseen:

- Probabilities are specifically assigned based on careful consideration of the underlying lake susceptibility and stability assessment. All probability – magnitude combinations are possible.

- A simple inverse frequency-magnitude relationship is applied, with the large scenario assigned the lowest probability outburst event, and the small scenario as the highest probability outburst event.

Where there is an insufficient basis or reasoning to distinguish probabilities it may be feasible to maintain the same probability level across all 3 scenarios, i.e., all three outburst scenarios are considered equally likely.

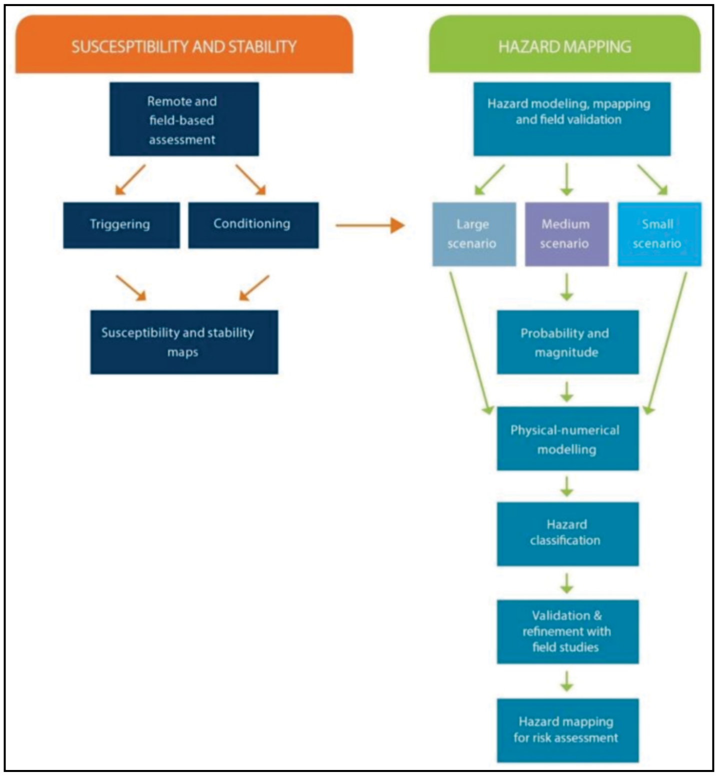


Figure 3.4: Framework for the assessment and mapping of glacial and permafrost-related hazards using a scenario-based approach (GAPHAZ 2017).

Scenarios for GLOFs are complex, owing to the various trigger mechanisms, lake types, and dam compositions. For bedrock-dammed lakes, where the only likely outburst mechanism is a mass movement triggered impact wave, a first approximation of the likely displaced water volume will be equal to the potential incoming mass. In this case, the associated probabilities will be linked to the ice and bedrock stability assessment for the surrounding slopes (see Appendices 1 and 2). For moraine-dammed lakes, the large scenario will involve complete incision of the dam and removal of the downstream slope of the dam, with steep, narrow dams most susceptible to irreversible erosion. Where the breach depth is greater than the mean depth of the lake, full release of the lake volume is possible. Due to the self-enhancing nature of dam incision, a large scenario may be considered equally probable as a small scenario for critical dam structures. For more favorable dam geometries, a reduction in outflow and cessation of erosion can occur well before the full lake volume has been emptied, making smaller scenarios more probable for impact-triggered events, and also events triggered by seepage and piping.

3.5.2.2 Hazard modelling and mapping

To link the results of scenario modelling with a corresponding hazard level, a matrix-based approach to hazard classification is typically used, for instance employed within the Swiss codes of practice. For each scenario, the 3-by-3 matrix links the modelled flood or mass movement intensities with the assigned probability level for that scenario, to establish a danger or hazard level (Figure 3.5 and 3.6). Multiple scenarios (e.g., small, medium, large scenarios) can then be overlaid and fine-tuned through field mapping to arrive at a final hazard map. This common framework can be applied for various processes occurring in glacial environments (GLOFs/debris flows, landslides, avalanches, etc.).

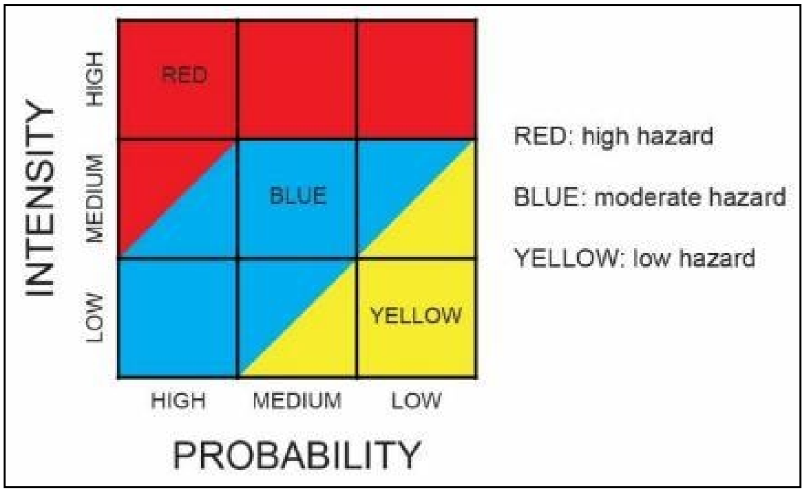


Figure 3.5: Matrix based approach for linking the susceptibility assessment (probability) with the scenario-based intensity modelling to arrive at a hazard classification.
(Colors are usually subject to nationally defined standards)

According to the Swiss practice, qualitative intensity relates to potential damage the event could cause to people and property (if they were present).

High intensity: people and animals would face the threat of injury inside buildings; heavy damage to buildings or even destruction of buildings would be possible.

Medium intensity: people and animals would face the threat of injury outside buildings, but would face low threat levels inside buildings; lighter damage to buildings should be expected.

Low intensity: people and animals would be slightly threatened, even outside buildings (except in the case of stone and block avalanches, which could harm or kill people and animals); superficial damage to buildings could be expected.

Note that for some processes not all three intensity classes are valid, e.g., in the impact zone of a rock avalanche the intensity is always considered *high*. Likewise, for debris flows, *low* intensities are not considered, according to the Swiss practice.

Table 3.2: Indicative values for the intensity classification for various high mountain hazards as used in Swiss practice *(after, Hürlimann et al., 2006; Raetzo et al., 2002)*.

Kinetic energy (E); Velocity (v); flow depth or height of the deposit (h).

Phenomena	Low intensity	Medium intensity	High intensity
Rockfall	E < 30 kJ	30 < E < 300 kJ	E > 300 kJ
Rock avalanche			E > 300 kJ
Landslide	v ≤ 2cm/year	v:dm/year (>2cm/year)	v > 0.1 m/day for shallow landslides; displacement > 1m per event
GLOF/ Debris flow (single parameter)		h < 1 m	h > 1 m
GLOF/ Debris flow (multiple parameter)		h < 1 m or v < 1m/s	h > 1 m and v > 1m/s

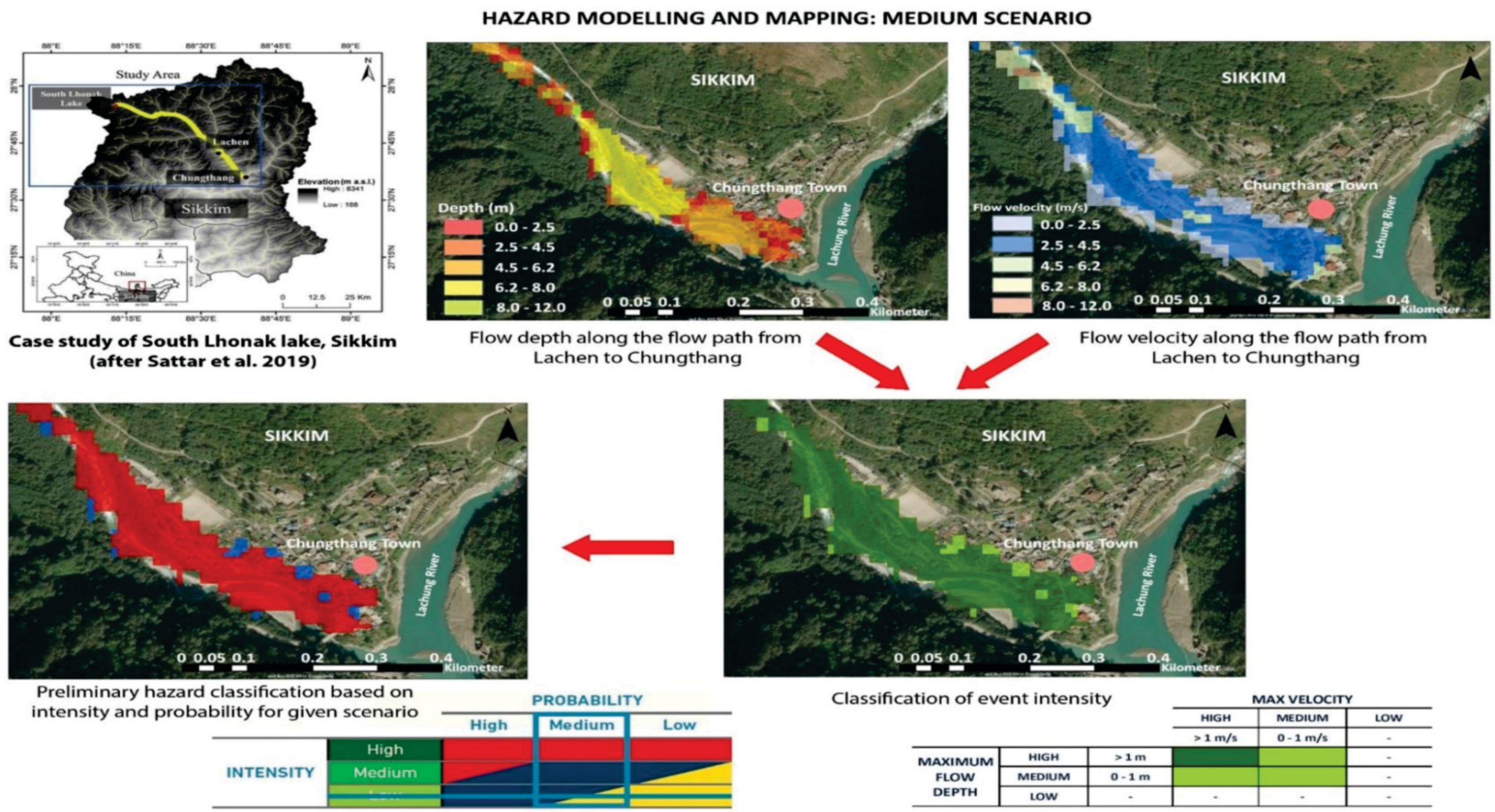


Figure 3.6: Illustrative example of GLOF hazard modelling and mapping for South Lhonak Lake, Sikkim (based on Sattar et al. 2019).

3.5.3 Risk Assessment

In order to advance from a hazard assessment to a risk assessment, results from the hazard mapping need to be combined with information on exposure (of people, assets, infrastructure and ecosystems), with information on the vulnerability.

3.5.3.1 Exposure

The most challenging aspect is to quantify the exposure of livelihoods, environmental services, and also to determine temporal dimensions of exposure. In high tourism areas, for example, many buildings located in a flood path may be unoccupied for much of the year, and in agricultural areas, families may migrate up or down the valley to different land holdings depending on the season.

3.5.3.2 Vulnerability

Community-level surveys and focus group meetings could bring together community leaders, farmer organizations, self-help groups, and other grass-roots organizations to explore local drivers of vulnerability, and undertake a qualitative Vulnerability Capacity Assessment (VCA). In particular, we highlight the importance of ensuring good representation of marginalized and disadvantaged groups in such participatory studies, including nomadic/seasonal populations, women, children, and people with disabilities. The 2009 National Policy on Disaster Management also underlines the importance of including these groups when undertaking a comprehensive assessment of vulnerability.

Important components that can be included in a VCA include: (a.) Historical timeline, (b.) Seasonal calendar, (c.) Patterns of vulnerability, (d.) Stakeholder mapping, and (e.) Coping mechanisms.

The results of participatory VCA's can be used to validate and refine large scale indicator-based assessments (see section 3.4.1), ensuring that the selected indicators adequately capture the perceived drivers and patterns of vulnerability in a community. Participatory VCA's are best led by institutions and agencies that have long-standing experience and established relationships within the communities.

3.5.3.2 Integrated Risk Mapping

Final risk maps can then be created by combining hazard mapping/zones, with vulnerability and exposure maps. Figure 3.7 provides an illustrative example of a GLOF risk assessment undertaken for the state of Himachal Pradesh, where standardised indices were multiplied to establish GLOF risk at the administration unit of a Tehsil.

As seen with the example of a local debris flow/flood risk assessment in Colombia, South America (Figure 3.8), risk assessment at this scale provides information on risk levels for specific dwellings and properties, providing a robust basis for the implementation of risk reduction strategies that aim to address those most affected by a potential event.

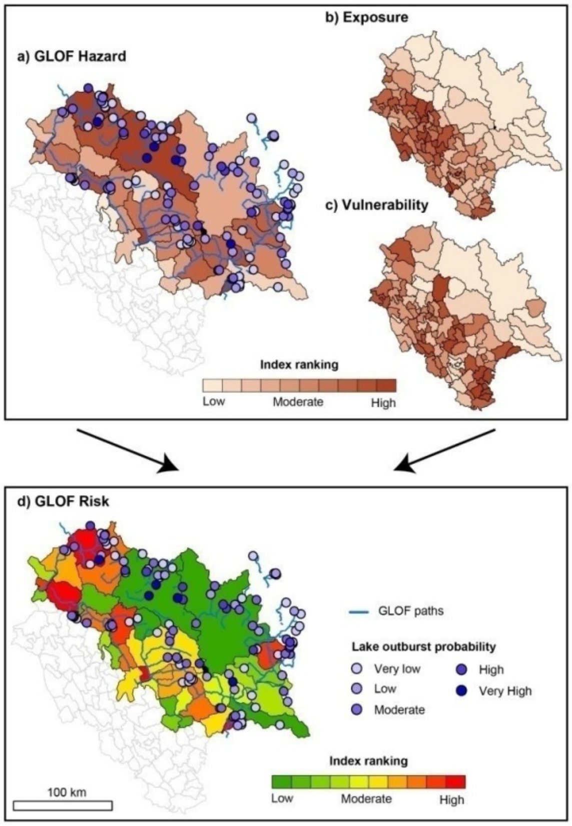


Figure 3.7: Large-scale GIS based assessment of GLOF risk, integrating mapped indices of GLOF hazard, exposure and vulnerability *(Source: Allen et al., 2016)*.

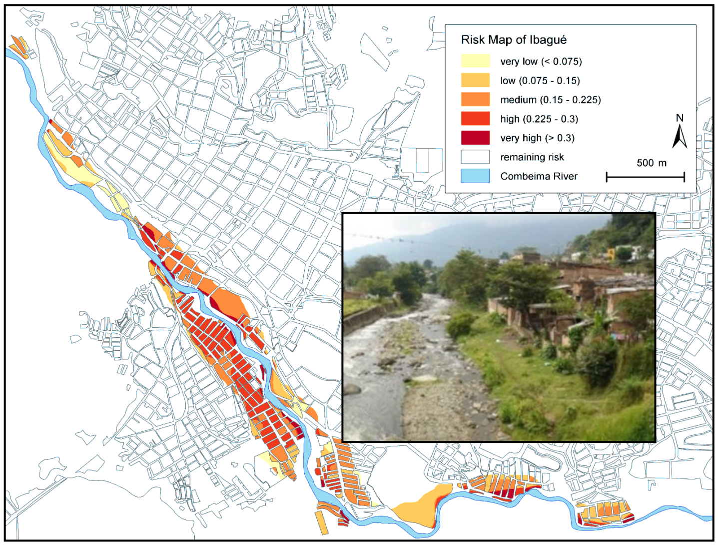


Figure 3.8: Flood and Lahar risk map for the Colombian city of Ibague, combining information on hazard, exposure and vulnerability *(Source: Künzler et al., 2012)***.**

Chapter 4: Monitoring, Risk Reduction & Mitigation Measures

4.1 INTRODUCTION

A prerequisite for successful, effective and sustainable risk management and risk reduction is a comprehensive and detailed site-specific risk assessment (cf. Chapter 3). Only the information provided by such an assessment allows the relevant authorities to take informed decisions on the most suitable measure or measures for effective and sustainable reduction of risks in a given situation. For the identification of suitable risk management options, thus, a comprehensive, multi-risk approach should be followed. This is also important in order to avoid any unintended negative effects.

The involvement of the local stake holders in the planning of risk reduction measures is essential to guarantee an effective risk reduction strategy that is also supported by the local population. Ownership of risk reduction measures by the local population furthermore is important in view of maintenance and sustainability.

Risk reduction and mitigation measures may incur huge costs and may not be feasible to implement, therefore Central/State Governments should apply a cost-benefit analysis and focus on implementing the strategy part that covers up for the major percent of the risk.

4.2 CASE STUDIES IN THE HIMALAYAN REGION

India has a remarkable history of successful warnings in relation to LLOFs, dating back to the 19th century. In 1894, a landslide in Gohna, Uttarakhand (UK), dammed the main river. On 5 July that year, the engineer in charge estimated the lake to overflow the dam in mid-August, which eventually happened. Despite the devastating impact of the flood, including washing away most of the buildings along the river and severe destruction in the town of Srinagar, no victims were reported, thanks to the precise prediction of the event and related efficient dissemination of the early warning to the population (Nature, 1894). This was made possible by the installation of a telephone line between the lake and the towns of Chamoli, Srinagar, etc., located downstream (Dimri, 2013). This can be considered as the first Early Warning System (EWS) for lake outburst floods in the Himalayas.

One of the most promising options for efficient and effective disaster risk management, is the implementation of EWS. The number of implemented and operational GLOF EWS is still very small, even at the global scale. In the Himalayan region, three cases are reported, where sensor and monitoring based technical systems for GLOF early warning have been implemented (Table 4.1). In two of the three cases, at Tsho Rolpa and Imja Lake, these EWS were complemented by structural measures for lake level lowering.

Table 4.1: Selected Cases of GLOF EWS implementations in the Himalayan region.

Lake	Region	Year	Reference
Tsho Rolpa	Rolwaling Valley, Nepal	1998	Rana et al. (2000)
Imja Lake	Everest region, Nepal	2008	Fukui et al. (2008)
Kyagar glacial lake	Shaksgam Valley, PR China	2013	Haemmig et al. (2014)

However, today none of these systems is operational, mainly due to a lack of identification and ownership by the local population (c.f. Watanabe et al., 2016, for the Imja case). This emphasizes the importance of the involvement of the local population for a successful and sustainable implementation of EWS. Another example for a GLOF EWS from the Peruvian Andes is described in more detail below (Section 5.5.5)

4.2.1 The Operation Phuktal (2015)

In cases where the dammed obstruction needs to be removed like river blockage due to landslide, explosives are sometimes used to clear the way for effective drainage. One such landslide occurred along the Phuktal River (tributary to Zanskar River) on December 31, 2014 about 90 km from Padum in Kargil district of Ladakh, which led to blockage of the river and eventually led to a potential flood situation on May 7, 2015 (Fig. 4.1).

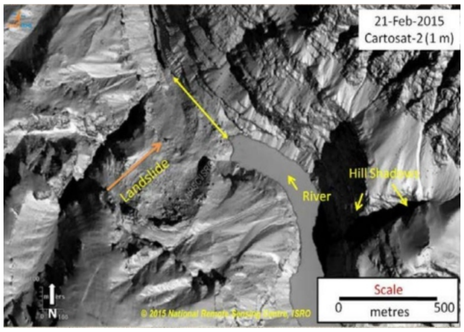


Figure 4.1: Blockage of Phuktal River due to landslide as can be seen from the image obtained through CARTOSAT- 2 *(Source: NRSC).*

It posed a major threat to life, property and infrastructure especially the Nimmo Bazgo dam.The NDMA created an Expert Task Force from various organisations. The Task force along with the Indian Army devised explosives for channelization of water from landslide dammed river through control blasting and manual excavation by clearing out the landslide debris (Fig. 4.2).

Figure 4.2: Indian Army installing a safety rope from camp base to the landslide location.

4.3 RISK REDUCTION TECHNIQUES AND MODELS

Risk reduction can be effective on each of the three components of risk (hazard, exposure, vulnerability). The selection of an adequate action depends on the urgency of the situation, the available resources as well as the specific characteristics of the site. In many cases, a combination of different measures will result in a more robust and effective reduction of disaster risk. A detailed hazard and risk assessment, according to the procedure described (Section 3.5), provides the information for a decision on (a) robust risk management option(s). Figure 4.3 gives an overview of such actions, which are further described below.

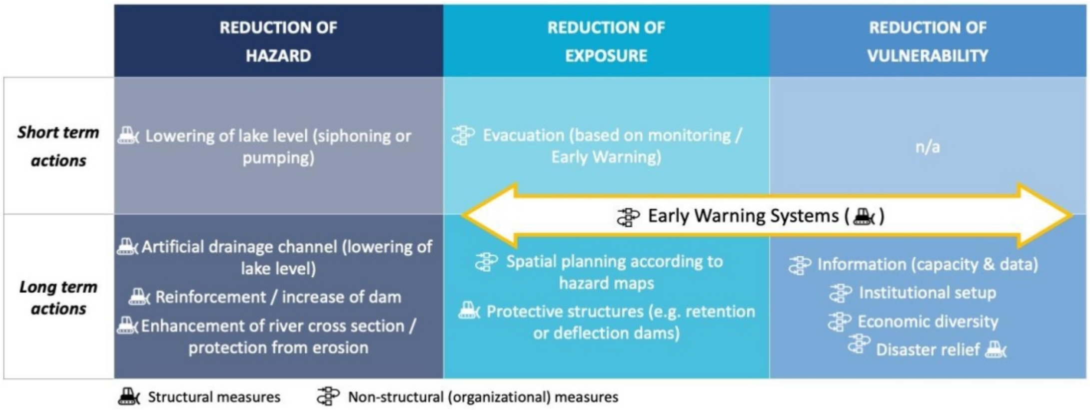


Figure 4.3: Overview of options for the risk management of glacial lakes.

These options can be discriminated by the risk element the actions are effective on (i.e. reduction of hazard, reduction of exposure or reduction of vulnerability). Also, these options can be distinguished into structural and non-structural (i.e. organizational). Structural measures (c.f. digger symbols in Figure 4.3) typically involve the construction of remediation structures, either at the lake itself, or at the settlements or infrastructure potentially affected. Such structural measures have the potential to be very effective for risk reduction, in particular when achieving a substantial reduction of the hazard. However, such actions are expensive, especially when implemented in remote regions, such as the IHR. Limited access for heavy machinery can be an impeding factor for such actions. Organizational, non-structural measures, on the other hand, in many cases can be cheaper and faster to implement. As they often aim at a reduction of exposure and/or vulnerability, they can be effective not only for GLOF and LLOF related risks, but for the reduction of multiple risks.

4.4 MANAGEMENT OPTIONS FOR GLOF & LLOF INDUCED HAZARDS AND RISKS

4.4.1 Hazard Reduction Options (Artificial Drainage System i.e., Siphoning Techniques, Control Blasting, etc.)

Actions aiming at a reduction of the hazard typically involve structural measures at the glacial lake itself and thus aiming at a reduction of the outburst susceptibility or a reduction of the magnitude of a potential event. Such measures have parallels with structural measures for floods outlined in the Section 3.3.3 of the National Disaster Management Plan (NDMA 2019), focussing on enhancing the safety of reservoirs and construction of embankments and levees.

Lowering the lake level directly influences the hazard potential of a lake, as it reduces the volume of the lake (and thus the potential flood volume and peak discharge) on the one hand, and on the other hand increases the freeboard of the dam, which is another important factor of the lake outburst susceptibility. In the short-term and in emergency situations, the level of a lake can be lowered by siphoning or pumping. The effectiveness of such efforts depends on the characteristics of the site, as well as on the access to the lake, the availability of equipment for siphoning and/or pumping and the experience of the personnel involved in such actions. Grabs and Hanisch (1993) present experiences from the Himalayas, where lake level were lowered by about 5m.

At moraine dammed and landslide dammed lakes with a low freeboard and thus in a critical situation, highly susceptible for an outburst, it is in some cases possible to lower the lake level by lowering artificially the outlet point. However, such an action is extremely risky, as it might initiate the formation of a breach, by starting a self-reinforcing process of increased discharge and increased erosion, eventually causing a GLOF or LLOF. Such measures should only be undertaken with the utmost care, and have to be accompanied by measures to prevent erosion in the artificially created outlet channel.

Figure 4.4: Artificial Channel Enlargement of Imja Lake, Nepal, 26 September 2016 *(Source: UNDP). (Artificial channel enlargement for lake level lowering is a very critical moment, as it can lead to the formation of a breach and a GLOF/LLOF)*

Culverts and open spillways are introduced in the moraine crests generally at the lowest point to keep excavation volumes to a minimum. The construction is usually carried away in a cofferdam as to isolate the site from the lake. Culverts are generally reinforced with concrete or are made up of cast sheet metal. Geo-textile liners may also be used to line channels and protect the floor from erosion. Spillways are generally left open, but it is recommended to install gateways which can control downstream erosion during the initial phase of draw down e.g. Tsho Rolpa, Nepal (Rana et. al., 2000). Strong implementation and safety measures are required when dealing with critical lakes.

Reinforcing and/or increasing the dam is a suitable option for the hazard reduction of lakes dammed by moraine and other unconsolidated material. Raising the dam crest increases the dam freeboard and decreases the potential for overtopping of a large volume of water in case of a large displacement wave in the lake. Reinforcing the dam with a stone facade provides protection against erosion and the initiation of a breach formation.

Such measures have been successfully applied to more than 35 lakes in the Cordillera Blanca, Peru over the past seven decades. Portocarreo (2014) gives an overview of the typical steps involved in such works.

1. Establish logistical access to the site.
2. Lowering of lake level by pumping or siphoning. Successful applications of siphoning have been made at lakes at altitudes up to 4,500 m a.s.l. (Reynolds GS Ltd, 2003). Applications at higher lakes remain to be tested.
3. Permanent reduction of lake level
   a. For moraine dammed lakes:
      i. Cutting the downstream face of the moraine into a V shape
      ii. Installing a reinforced concrete pipe* of appropriate diameter
      iii. Building an earth dam with a stone facade over the pipes, restoring much of the original V- shaped cut in the moraine (protection against the hydrodynamic effects of big waves). Cf. Fig. 4.5, left)
      iv. Open cuts* are also an option (Fig. 4.5, right), c.f. remediation measures at Tsho Rolpa and Imja Lake. In these cases, the floor and the sides of the drainage channel need to be protected by concrete or geo-textile liners (Reynolds GS Ltd, 2003).
   b. For bedrock dammed lakes:
      i. Drilling of one or several drainage channels/tunnels* through the bedrock dam.
      ii. Tunnels in moraine dams have only been drilled above water level in order to limit any rise in water level (e.g. Safuna Alta Lake, Peru) (Reynolds GS Ltd, 2003).

* for pipes, cuts, channels and tunnels, measures have to be taken to prevent objects (blocks of ice or snow; driftwood; etc.) from entering the structure and cause a blockage of the drainage.

Figure 4.5 : (a) Outlet channel with reinforced dam reconstruction at the moraine dammed lake Laguna Cuchillacocha, Peru *(Photo: C. Portocarrero)*, **(b) Open channel at Imja Lake, Nepal, inaugurated in October 2016** *(Photo: UNDP).*

The major disadvantages of such structural measures are the related high costs. In particular, in remote regions of the IHR, with glacial lakes often located in rough and inaccessible terrain, such works are not feasible. An alternative to this are structural works implemented at locations between the lake and the settlements/infrastructure at risk. This can include retention basins, retention and/or deflection dams.

4.4.2 Exposure Reduction Options

Exposure can be reduced either (i) on the short term in the form of an evacuation in case of an event or (ii) on the long term, by considering hazard maps of all relevant processes for spatial planning. Restricting constructions and development in GLOF/LLOF prone areas is a very efficient means to reduce risks at no cost. Roles and responsibilities concerning the regulation and enforcement around flood plain zoning and flood inundation management are outlined in Section 7.2.4 of the National Disaster Management Plan (NDMP, 2019)

For (i), information on imminent or ongoing events is needed, such as, for instance, provided by an Early Warning System (Section 5.5). Since GLOFs are very fast processes, an evacuation must be executed within a very short time, this requires an alarming infrastructure, clear protocols for all involved actors, and capacitation of the involved population and responsible authorities. Besides classical alarming infrastructure consisting of acoustic alarms by sirens, modern communication technology using cell and smart phones can complement or even replace traditional alarming infrastructure.

(ii). In contrast to other countries, there are no uniform codes for excavation, construction and grading codes in India. Nevertheless, a hazard map provides a solid basis for the consideration of hazards in the spatial planning:

In the high hazard zone, the construction of any habitation should be prohibited. Existing buildings are to be relocated to a safer nearby region and all the resources for the relocation have to be managed by Central/State governments. New infrastructuresin the medium hazard zone have to be accompanied by specific protection measures. Retrofitting techniques to strengthen the weak structures should be implemented in order to protect existing infrastructure.

Land use planning is the most effective and economical ways of reducing losses due to landslides by avoiding the hazard and minimizing the risk. There are no widely accepted procedures or regulation in India for landuse planning in the GLOF/LLOF prone areas. Such regulations need to be developed concerning the increased risk of future GLOF/LLOF events.

Figure 4.6 shows a hazard map with five levels of GLOF hazard, along with indicated evacuation routes (arrows) and safety zones (green rectangles with a white S). Such a hazard map with evacuation routes included, in combination with a spatial planning and building law, is a very effective tool for the reduction of exposure.

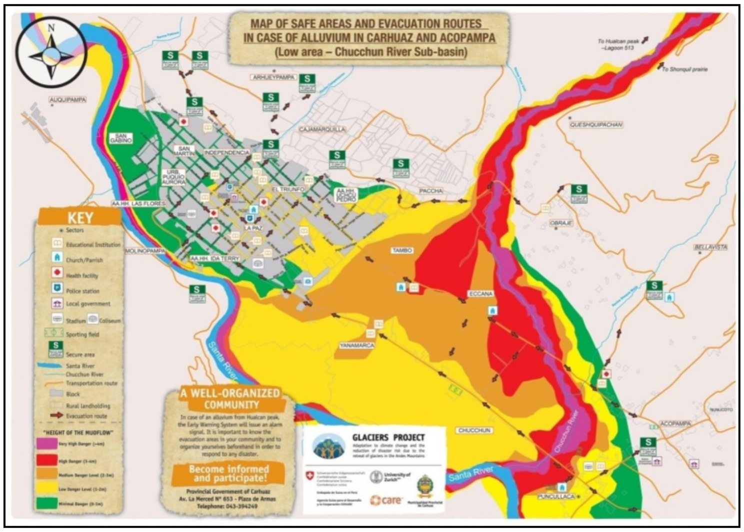


Figure 4.6: GLOF hazard map for the city of Carhuaz, Peru (Source: CARE Peru).
[Used as a tool for risk communication and reduction: Besides the hazard zones, evacuation routes (arrows) and safety zones (green rectangles with a white S) are indicated]

Locally and for particularly vulnerable infrastructures such as schools, hospitals, hydropower installations, pilgrim sites, major bridges, communication and energy lines, etc., protective structures like retention or deflection dams can significantly reduce the exposure of selected entities.

4.4.3 Vulnerability Reduction Options

Vulnerability can only be reduced in the long term. Based on the vulnerability assessment, weaknesses should be extenuated or eliminated. Capacity building with the population at risk is a crucial activity to reduce vulnerability on climate change, which also has a positive effect on most other risk management actions. Such capacity building should provide a relevant understanding of climate change and related impacts at both a regional and a local scale. Also, it should take into account cultural and traditions as well as local knowledge on experienced changes of the physical environment. Knowledge on the perception and prioritization of the different risks provides valuable information for the selection of site-specific and adequate risk management actions, which will be accepted by the local communities.

Insurances and compensation for losses are a further, efficient mean to reduce vulnerability. GLOF/LLOF insurance would be a logical means to provide compensation, and at the same time an incentive to avoid or mitigate the hazard. GLOF/LLOF insurance coverage could be made a requirement for mortgage loans. Controls on building, development, and property maintenance would need to accompany the mandatory insurance. Insurance and appropriate government intervention can work together, each complementing the other in reducing losses and compensating the victims.

Figure 4.7: Representation of a school where children were taking part in mock drill.

4.5 MONITORING TECHNIQUES

4.5.1 Introduction

Torrential rain or earthquakes may cause large-scale flank collapse damming the river channel. The collapse of such a landslide dam causes catastrophic downstream flooding. The biggest difference of such landslide-dammed lakes to glacial lakes is that glacial lakes can be identified and the risk assessed in a planned way, as the glaciers and moraines have a fixed position, unlike landslide dams which are unpredictable. Thus, more time is available to plan and implement measures to reduce the likelihood of GLOF. This can be ensured through continuous monitoring. The various means and methods which can be adopted for monitoring are discussed below.

4.5.2 Monitoring Glacial Lakes

Between early warning (hours to minutes), and long-term monitoring of dangerous lakes (annual to biannual), there is a challenge to detect new threats that may emerge over the course of days, weeks, and months. This can include rapidly expanding glacial lakes in response to prolonged heavy rainfall, new glacial lakes as a result of blockages in the glacial hydrological system or associated with surging glaciers, and newly formed landslide lakes. As many of these processes are more likely to occur during the monsoon months, cloud cover can prevent the use of optical remote sensing. There are therefore opportunities to exploit Synthetic-Aperture Radar (SAR) imagery to automatically detect changes in water bodies, including new lake formations, during the monsoon months. Methods and protocols could be developed to allow year-round remote monitoring of lake bodies from space, as a compliment and precursor to ground-based early warning systems at critical lakes.

National Remote Sensing Centre (NRSC) had completed a project during 2011-15 on "Inventory and Monitoring of Glacial Lakes / Water Bodies in the Himalayan Region of Indian River Basins", sponsored by Climate Change Directorate, Central Water Commission (CWC), New Delhi, Govt. of India. Under this project, glacial lakes and water bodies located in all three major river basins viz., Indus, Ganga, and Brahmaputra including trans-boundary region were mapped with a water spread area of size greater than 10 ha using IRS-AWiFS sensor data of 56 m spatial resolution. A total of 2,028 features were mapped consisting of both glacial lakes (503) and water bodies (1,525). It was observed that there are 352, 283 and 1,393 glacial lakes and water bodies in Indus, Ganga and Brahmaputra river basins respectively. Glacial lake extent change monitoring for lakes of size greater than 50 ha (477 glacial lakes and water bodies) has been carried out by NRSC from 2011 to 2015 during monsoon period of June to October on monthly basis. The continuation of glacial lake monitoring is being carried out by CWC for 477 lakes from 2016 onwards (every year) on monthly basis during monsoon months using IRS-AWiFS satellite data. The entire GIS database on glacial lakes and water bodies over Himalayas mentioned above is available with CWC.

In addition to or instead of remote sensing approaches, a combination of precipitation thresholds and river stage monitoring can be considered for the monitoring of landslide dammed lakes, as described below:

4.5.2.1. Object-Based Image Analysis (OBIA) technique

Traditionally, supraglacial lakes SGLs (as small as 100 sqm) were mapped through field surveys which are laborious, risky and time consuming. The location of these glacial lakes in rugged and remote terrain makes it difficult to monitor them manually. There are alternative approaches to manual mapping of SGLs, for instance by using automated or semi-automated mapping approaches. Also, there are ways of processing remote sensing data using a technique called Object-Based Image Analysis (OBIA) technique.

4.5.2.2. Field investigation of critical lakes

Field investigations including topographical and bathymetric mapping, hydro-meteorological observations, and geological, geophysical and glaciological surveys may be carried out for high priority/vulnerable lakes. Drones and other unmanned aerial vehicles (UAVs) provide powerful tools for efficiently combining on-site field work and remote sensing techniques.

The selection of critical lakes should be done based on a first-order, regional assessment of hazards and risks of glacial lakes, based on remote sensing analyses.

4.5.2.3 Monitoring by trekking guides

The guides and porters employed by private/ semi-government agencies are regular visitors to the glacial lakes. This resource can be amalgamated into the monitoring grid after suitable training and registration, for effective surveillance and reporting of the glacial lakes.

4.5.3 Precipitation threshold for landslides

Rainfall is widely recognized as an important trigger for landslides, posing an increased threat to people and economies worldwide under climate change conditions. Rainfall thresholds, defined as the best separators for triggering and non-triggering known rainfall conditions, are the most used instrument in landslide hazard assessment and early warning tools. The most common parameters used to define empirical thresholds are the combinations of rainfall intensity duration, rainfall event-duration, and antecedent rainfall conditions.

Contingent upon the kind of available rainfall data, empirical thresholds can be summarized as follows:

(1) thresholds which combine rainfall data obtained from specific rainfall events,
(2) thresholds involving antecedent parameters, and
(3) alternating thresholds, like hydrological thresholds

For setting up an early warning system using empirical rainfall thresholds, various factors need to be taken care of:

- collection of reliable and large rainfall and landslide datasets,
- selecting threshold parameters depending on landslide characteristics and precipitation data,
- defining the events and using an objective and standardized methodology,
- validation of the thresholds determined.

4.5.4 Measurement of River and Lake Water Level

Water level or stage of the River is measured as its elevation above the GTS datum. Water level measurement was conducted by reading non-recording gauges. A series of vertical staff gauges as per the specifications laid down in IS 4080-1977 have to be fixed at three sections at each site i.e. upstream, station gauge and downstream.

There exist also water level recorders for continuous or distinct, automated measurements of water levels. Two types of water level recorders exist, (i) pressure sensors, which determine changes of the water level based on changes of water pressure, and (ii) contact-less sensors, using sonic waves to determine water level. Such automated devices for water level measurements and recording as well have the potential to be incorporated into an automated monitoring or early warning system.

Water level sensors installed along the banks of the river channel, immediately downstream of the lake outlet can be used in an Early Warning System (EWS) for GLOFs to detect the onset of a breach, cf. Section 5.7.

In addition to the traditional methods of water level sensors, the satellite altimeter and LIDAR can also be used for basin level WL monitoring of glacier lakes and downstream rivers (Thakur et al., 2020; Yuan et al., 2020).

4.6 EARLY WARNING SYSTEMS

Increasing the availability of EWS for disaster risk reduction is one of the seven targets of the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015).Monitoring, Early Warning and Alarming are key elements for an effective reduction of disaster risk, and the National Policy on Disaster Management (2009) emphasises the need to establish, upgrade and modernise forecasting and early-warning systems for all types of disasters. As indicated in Fig. 4.8, Early Warning Systems (EWS) can reduce both the exposure as well as the vulnerability of the potentially affected population. EWS are complex systems, involving not only technical, but also social, political and even juristic aspects. As defined by the United Nations International Strategy for Disaster Reduction (UNISDR, 2006), EWS consist of four key elements (Fig. 4.8):

- Risk Knowledge
- Monitoring and Warning Systems
- Dissemination and Communication
- Response Capability

Figure 4.8: Key elements of Early Warning Systems *(Source: UNDP 2018)*.

Till date there are a very limited number of GLOF EWS operational globally. This is due to the extremely challenging conditions, with short warning times, limited pre-event indicators, often combined with the necessity to evacuate a large number of persons.

4.6.1 Risk Knowledge

A detailed, site-specific risk assessment is a prerequisite for an effective design and successful implementation of an EWS. This includes a detailed assessment and mapping of hazard and a detailed evaluation of the vulnerabilities. Knowledge of the different types of vulnerabilities of the potentially affected population is needed for the development of a suitable communication and warning strategy.

4.6.2 Monitoring and Warning Services

The monitoring and warning services constitute the technical core component of an EWS. This element comprises the installation of adequate measurement devices to constantly observe the critical parameters. This potentially includes sensors at the lake, in the lake surrounding, at the dam/outlet, in the stream and at other sites potentially at risk. Also, remote information from other sources can be part of the monitoring strategy of an EWS, such as satellite observations, meteorological and hydrological prediction models etc.

4.6.3 Dissemination and Communication

The dissemination and communication element comprises the distribution of understandable alerts, warnings and alarms, including also preparedness information to the population at risk. In their recommendations for building functional EWS, UNDP notes that *"Historically, most failures in EWS occurred due to miscommunication – not equipment or infrastructure failure – further underscoring the gravity of this element"* (UNDP, 2018).

4.6.4 Response Capability

Response capability, the last element of EWS, consists of the centralised knowledge, plans, protocols and other inputs needed for timely and appropriate action by affected population and involved other stakeholders and authorities. Prerequisites for a successful response to EWS warnings are that the endangered population is aware of the looming risks and perceives them as relevant, and also that they have trust in the Early Warning System.

4.6.5 General Remarks

Due to the technical complexity of some systems, it is essential to have a calibration phase after the installation of an EWS. This time is needed to refine the warning thresholds, and for the personnel operating the EWS to familiarize with the system. This calibrations phase should be used for simulations and drills.

In order to guarantee a constant availability and operationality of an EWS, maintenance of all components of the system is indispensable. Sensors and hardware have a limited lifetime, in particular under harsh high-mountain conditions. Also, the software needs to be constantly updated to new technological standards. The costs of such maintenance work need to be considered in the budget of the authority or institution responsible for the operation and maintenance of the EWS.

4.6.6. Early warning system in the Sutlej river basin, India

Some measures have been put in place in the Sutlej River basin for monitoring, forecasting, and early warning to deal with flash floods, especially from cloudbursts. As GLOFs are one of the causative factors in propagating flash floods downstream, these measures also act as an early warning system for a GLOF. Telemetry stations set up by the Snow and Hydrology Division of the Central Water Commission in Sumdo, at the confluence of the Parechu and Spiti rivers, and Khaab, at the confluence of the Spiti and Sutlej rivers, and by the Naptha-Jhakri project at Dubling, are intended to monitor any increase in the water level and to relay information. They were introduced in response to the gap in early warning that was felt after the floods in 2000, and also for the protection of hydropower projects. Similarly, a wireless network at Reckong Peo, used by security personnel with connections to border outposts, and the Doordarshan Satellite Earth Station and All India Radio Relay Centre, have been very useful in generating warnings and in communicating during emergencies (UNDP 2008).

Chapter 5: Awareness & Preparedness

5.1 AWARENESS

Given the rarity of the events like GLOFs and LLOFs, local communities are not too aware about their disastrous effects. Since outburst floods are sudden, and cause disasters that affect localised areas resulting in segregated losses, they do not receive appropriate attention due to their transitory nature, and short-lived human memory. Hence, the level of awareness about GLOFs and LLOFs has been quite low compared to other disasters like earthquakes, cyclones, cloud bursts, Tsunamis, etc. While the Kedarnath Tragedy of 2013 in the state of Uttarakhand in Western Himalayas did bring about some awareness about GLOF in the IHR, there is still a long way to go.

5.2 CREATION OF COMMUNITY AWARENESS ON GLOFs AND LLOFs RISK REDUCTION

The following are the short, medium and long term strategies which may be adopted to create community awareness on GLOFs and LLOFs risk reduction:

A. Short Term

1. **Automated Alert Services:** In collaboration with the various government and private travel agencies including Indian Airlines, Indian Railways and mobile network operators, NDMA can send automated SMS and e-mail messages on precaution to be taken while travelling in the GLOF/LLOF vulnerable areas at the time of booking of travel tickets to these areas.
2. **Toll free number or smart-phone based application for GLOFs/ LLOFs reporting**: Each state in the very high and high-risk zones can initiate a mechanism for GLOFs/LLOFs reporting upon receiving reports of early signs of GLOFs and LLOFs from people. NDMA in collaboration with the leading technical institutions of the country like Indian Institute of Technology (IIT) can design a computer/smart-phone application for disaster management. The application can be used to know about the latest information on disasters (including GLOFs/LLOFs) across the country.
3. **Creation of common signage for GLOFs/LLOFs vulnerable areas:** A common signage (aligned with International systems) for GLOFs/ LLOFs vulnerable areas can be designed and displayed in GLOFs/ LLOFs vulnerable areas across the country, advising people to be aware of rapidly rising rivers, and where to find safe ground.
4. **Use of local mass media:** A well designed mass media campaign (both print & electronic) can be undertaken in the vulnerable and affected states. The campaign must be designed in the local languages. The local community radio can broadcast programmes on awareness. It can also transmit early warning messages regarding the occurrence of GLOFs/LLOFs in the area.
5. **Use of posters, wall paintings and hoardings:** Posters and hoardings on the various aspects of awareness regarding GLOFs/LLOFs can be designed and displayed at all important public places. Wall paintings depicting GLOF and LLOF vulnerable zones can be displayed at prominent public locations in order to increase the awareness among the locals. The campaign material should be translated into local languages.

6. **Use of Global Disaster Preparedness and Response Apps**: There are a number of globally recognized disaster preparedness and response apps serving the needs of people affected by disasters. These top mobile apps could prove fruitful in providing assistance to aid workers and volunteers (Aapda Mitra) in better preparedness and response to the disaster.

B. Medium Term

1. **Awareness through documentary**: NDMA should initiate a programme using documentaries/presentations for Government organisations, schools and hospitals, soldiers, NGOs, local nodal agencies, local community organisations and youth clubs, and local people focusing on the role and responsibility before, during and after the landslide or flood disaster.
2. **Creation of village task force:** The not-for profit and/or community-based organizations should constitute a village task force in each village of the vulnerable states. The members of the task force should be made aware of the various aspects of glacial landslide mitigation and post-glacial landslide activities.
3. **Creation of a citizen science application for environmental monitoring:** NDMA in collaboration with the leading technical institutions of the country like Indian Institutes of Technology (IITs) can design an application for smart-phones, allowing citizens to record key environmental parameters, such as lake or river levels. By engaging communities in scientific monitoring, they are more likely to respond positively to any warnings or alerts.

C. Long Term

1. **Awareness programme on GLOFs/ LLOFs hazard:** There is need for emphasis on a robust awareness programme for GLOFs/LLOFs hazard. There is a need for enhancing public awareness about signs and events that manifest that a GLOFs/LLOFs is imminent so that personal safety measures may be taken in a timely manner. Some of these signs include: (a.) fragments of ice/debris from moraines in the river waters, (b.) calm waters in the river showing and unusual turbid nature, (c.) damming/ blockage of the river body by local landslide or extra-large erratic boulders which may lead to rise in the level of river water, (d) cracking sounds from the glaciers upstream, (e.) change in the colour of river water showing suspension of sediments due to landslide/collapse of moraine dam upstream, (f.) cracks in Glacier/Moraine Dammed wall along the boundary of glacier lake, etc.

2. **Use of traditional art forms/ traditional knowledge:** Due to modernization and tech savvy nature of 21st century generation, traditional disaster management practices are dying /losing relevance. Therefore, it is necessary to document and disseminate traditional best practices available in mountainous regions of India through community participation in trainings. Traditional art forms are important media of awareness generation. Traditional knowledge and modern technologies can be combined to design glacial landslide and flood Early Warning System (EWS).

3. **Awareness through Participatory Approach:** A participatory planning and implementation process is recommended in order to maintain the sustainability of the programs launched by the administration for disaster management. It is necessary that the government and the communities together evolve a joint action plan aimed at enhancing community education and development of community leadership. The Community Based Family Disaster

Preparedness and mitigation (CBFDP) is one such process to capacitate communities to prevent, mitigate and cope with disasters effectively. The elements of participatory learning can be applied at different levels such as organizational level (headquarters, branches, schools, businesses, workplaces), community level (village, town, cities) and population level (marginalized, vulnerable sections).

4. **GLOFs/LLOFs education plan:** An illustrated booklet with information on GLOFs/LLOFs awareness can be prepared in local languages. This can be circulated among the Panchayati Raj Institutions (PRIs) members, Front Line Health Workers (FLHW), School Teachers, Youth Leaders, members and other important stakeholder groups in these areas.

5. **Involvement of Not-for-Profit Organisations**: Government agencies should identify not-for-profit organisations to undertake the awareness building activities in the vulnerable States. The organisation should be asked to submit a targeted awareness generation plan.

6. **Awareness among local youth:** The not-for-profit organisations can hold regular awareness generation camps with the members of National Cadet Corps (NCC), Scouts and Guides, and National Service Scheme (NSS) volunteers. These camps should be conducted in coordination with the state and district teams of these organisations.

7. **National Data Centre on GLOF/LLOF**: It would integrate various data sources, a geo-portal to address the data needs and thus, enable an effective response. A step towards building the same has been taken by the GIS team at NDMA.

8. **Awareness among policy makers and government officials:** The policy makers are key stakeholders in disaster management. State Disaster Management Authority (SDMA) can hold workshops with policy makers and government officials of all departments to reinforce their role in ensuring that people conform to the various land use policies.

5.3 AWARENESS DRIVE FOR SPECIFIC TARGET GROUP

Awareness drive for specific target groups including **communities residing in on the downstream areas; vulnerable groups including women, children and senior citizens**; **urban planners and architects, geologists and civil engineers** should be undertaken. **Administrative integration among the government departments, public sector agencies, NGOs and civil bodies** should be given special attention in order to integrate activities related to creation of awareness and preparedness. A holistic and collaborative approach towards trainings and awareness building should be adopted in order to develop action plans to spread awareness and preparedness measures to the last mile.

5.4 PREPAREDNESS

Disaster preparedness refers to measures taken to reduce and mitigate the effects of a disaster, and forms a core component of the proactive stage of disaster risk management. Preparedness can considerably relieve the severity of impact during the scenario of a disaster. Given the rarity of GLOF and LLOF events in the IHR, not much is known to the community. While structural support (embankments, artificial drainages, etc.) may be feasible to some extent, however it cannot be widely replicated because of inadequate technology, financial and logistic constraints (inaccessibility to mountain reaches).Non-structural/institutional support is therefore, one of the key mechanisms to be strengthened in such contexts. For this Central and State Governments, in collaboration with various stakeholders and NGOs, need to work closely to implement measures of preparedness on the ground.

5.4.1 Government Agencies and other Stakeholders

SDMA/State Government is one among the early responders and must work in close cooperation with local government/non-government bodies and agencies in the region to provide aid and relief at the earliest. A network with additional responsibilities must be handed to the government officials in the region for decision and support for pre, during and post phase of the disaster. Generate awareness and provide training support on GLOF/LLOF preparedness and response to ITBP, local police and SDRF. As the community preparedness measures have been discussed in section 5.4.3. If the community at large is prepared, not only will it help reduce the impact of the disaster but will also contribute to the overall socio-economic development of the region helping the region at large to achieve resilience from GLOF and other disasters.

5.4.2 Medical Preparedness

Catastrophic natural disasters like GLOFs and LLOFs have a high potential to cause incidences of mass injuries, causalities and subsequent health outbreaks. Direct health effects of a flood may include: drowning; injuries like cuts, sprains, fractures, electric shocks; diarrhoea, vector and rodent borne diseases like malaria, lepto spirosis; skin & eye infections; and psychological stress. In order to respond to event related medical emergencies, a number of measures are required.

a) Creation of Trained Medical First Responders

The state governments/SDMAs must ensure creation of trained medical first responders for first aid and resuscitation measures for burying and drowning cases. Medical staff must know how-to pull-out water from the respiratory tract and how to carry out cardio-pulmonary resuscitation. A list of trained medical and paramedical staff must be made available to all the relevant agencies. Medical Stores and medical kits must be prepared for the management of GLOFs casualties. Intravenous (IV) fluid, ventilators, oxygen, dressing materials, tetanus toxoid, antibiotics, vaccines, anti-snake venom and anti-diarrhoea drugs will be the most commonly needed medical resources. Large-scale medical stores from where these materials can be procured in a timely manner must be identified. State governments/SDMAs must make available emergency medical equipment and drugs for resuscitation.

b) Patient Evacuation Plan

Heli-ambulances need to be deployed to aid in the evacuation of casualties from the affected region. Within identified risk hot-spots, safe zones should be established, where medical supplies can be stored, and Heli-landing sites demarcated. It is important that such safe zones are well outside the zone of residual risk, including from secondary hazards. The ambulances should have Standard Operating Procedures (SOPs) for treatment.

c) Emergency Routes and Medical Mock Drills

Since the areas vulnerable to GLOFs/LLOFs are often remote and rugged, providing immediate medical attention would be a challenge in itself. Emergency routes should be demarcated based on the results of hazard mapping (see Chapter 3) and frequent medical mock drills by the trained medical professionals must be conducted.

d) Medical Disaster Management Plans

Disaster Management Plans need to be prepared by all hospitals. Medical facilities, training of medical personnel, creating awareness about drowning and its management should be a part of the plan. Hospitals must nominate an officer for coordinating management of casualties. Contingency plans must be prepared for providing additional beds. Oxygen cylinders, Continuous Positive Air Pressure (CPAP) ventilators, dressing materials, blood and IV fluid for transfusion must be stocked. The hospital casualty room must be equipped with resuscitation equipment like suction apparatus, airways laryngoscope, pulse oximeter, defibrillator and lifesaving drugs. In addition, the aftermath of GLOFs/LLOFs, public health response is one of the prime responsibilities of medical authorities. They will ensure safe water supply and clean food availability along with the maintenance of hygiene and sanitation by proper bio-waste disposal. Water testing and food inspection is required to be carried out regularly to prevent the outbreak of any epidemic. An effective communication system is an essential requirement for prompt medical response.

5.4.3 Community Preparedness

If the community facing the disaster or vulnerable to associated hazards is well prepared, it will greatly reduce the impact of the disaster. Simulation exercises, mock drills and awareness programmes for the GLOF/LLOF prone district need to be developed and made an essential part of the preparedness programme. The entire cycle of an exercise programme from orientation seminar to full scale exercise takes about 6 to 12 months. Complete exercises in disaster prone districts of the Himalayan states vulnerable to GLOF and LLOF events must be conducted at least once in three years after careful planning so that grey areas in the preparedness programme are identified and efforts are made to make the necessary modifications.

Chapter 6: Capacity Development

6.1 INTRODUCTION

A successful and sustainable implementation of this framework for GLOF and LLOF risk assessment and management require different kinds of capacities, including engineering, scientific, socio-economic, organisational, and institutional in various forms. The complexity of task requires an interdisciplinary approach with a collaboration of engineers, hydrologists, geo-morphologists, modelling experts, remote sensing specialists, infrastructure planners and builders, environmentalists and sociologists, and authorities at local, state and national level. In addition, it is essential to develop experiences from events and situations and to document and analyse cases and extract lessons learnt to develop best practices.

In this section, aspects of education and capacity building at the university level, training of professionals involved in the assessment and management of GLOF and LLOF risks, and capacity building within local, potentially affected communities is discussed.

6.2 GLOFs AND LLOFs EDUCATION

University education is the foundation for the basic training of the different types of experts involved in GLOFs and LLOFs risk assessment and management.

For the assessment of GLOFs and LLOFs hazards and risks, a thorough understanding of natural processes and their complex interactions in glaciated high-mountain regions is required, including knowledge of the past and future developments at different spatio-temporal scales. This understanding needs to be complemented with technical skills, such as remote sensing, cartography, and development and application of numerical models for the simulation of these processes (Figure 6.1).

For the evaluation of the vulnerability, specialists from social sciences are needed to assess and understand the social, cultural and economic background of the potentially affected population.

In case of an emergency situation, engineering skills are needed for design and implementation of short, medium and long-term hazard and risk reduction. For the implementation of Early Warning Systems (EWS, cf. Section 5.5), electronic and communications engineers, and programming experts are required.

For response in case of catastrophic events, efficient relief capacities and resources are needed which requires managerial and response implementation capacities.

6.2.1. Education of Professionals

All glaciated regions and mountain/hill ranges are likely to be affected by GLOFs and LLOFs risks. Knowledge exchange and experience sharing with scientists and practitioners working on GLOFs and LLOFs issues across different mountain ranges and hilly regions of the world is, therefore, an important part of the continuous further education of professionals and experts. Organizing and participating at workshops and conferences, bringing together GLOFs and LLOFs risk assessment and management experts is a key means to benefit from experiences gained in other regions. Online resources like the Training modules relating to glacier hazards and disaster risk management developed under the Indo-Swiss Capacity Building Programme on Himalayan Glaciology can also support education of professional.

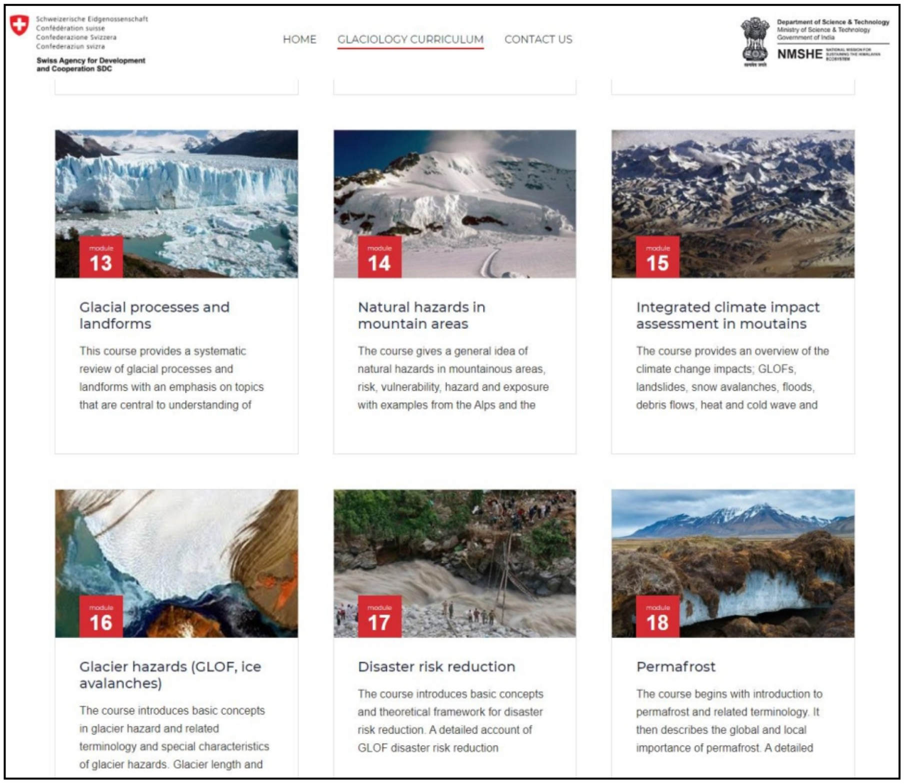


Figure 6. 1: Training modules relating to glacier hazards and disaster risk management.

(Produced under the Indo-Swiss Capacity Building Programme on Himalayan Glaciology, organised by The Department of Science and Technology (DST), Government of India and the Swiss Agency for Development and Cooperation in 2019- http://glaciology.in/curriculum/*)*

Further, to strengthen the education of professionals, there is a need for the documentation of past and recent events (cf. Section 7.5) and development of best practices. Such a database allows for constant development of expertise, based on the lessons learnt from past events.

6.2.2. Community Education

Building capacities in communities potentially threatened by GLOFs and LLOFs is important in order to improve response capacities in case of a catastrophic event. Such capacity development activities should involve the following aspects:

- Information of the reasons and causes of a potential risk, including changes in the environmental and climatic conditions over the past years.
- Current risk situation and potential scenarios of outburst events, including expected impacts at different sites relevant for the community.
- Development and implementation of a risk reduction strategy, including warning and alarming procedures, if available.
- Individual risk reduction measures (avoid unnecessary presence in the riverbed, location of immobile assets outside the hazard zone, etc.).
- Behaviour in case of an event, potentially involving drills and simulations of early warning and alarming systems.

Community education efforts should be embedded in a set of activities with the potentially affected communities, involving the evaluation of local knowledge and risk perceptions related to past and current GLOFs and LLOFs risk, surveys and interviews for the vulnerability assessment (cf. Section 3.5), the planning of risk management options (cf. Section 5.4.2 and 5.5.4), etc.

Education and awareness raising also needs to extend to reach transient populations, such as recreational and religious tourists (pilgrims) exposed to GLOFs and other associated hazards. This could be achieved, for instance, through information signs, infographics, and brochures.

6.3 TRAININGS

6.3.1. Training of Professionals

Regular workshops for professionals of institutions involved in the assessment and management of GLOFs and LLOFs risks should be held once the present guidelines are implemented. Such workshops will foster cross-organisational collaborations that are required for a comprehensive and strategic management of related risks.

Pilot studies developed to demonstrate the risk assessment and management strategies of these guidelines can be used to illustrate the approaches as practical examples. Over time, these pilot studies can be replaced by real cases that will emerge according to the present guidelines.

The mapping, monitoring and modelling of potential glacier or landslide lakes is usually done by various Earth Observation (EO) system such as polar orbiting satellites, aerial and UAV based platforms. Therefore, specialized training modules or online webinar for such basic and advanced topics can be organized for professionals/users working in this area, by the concerned institutes in India (IIRS, NIH, NRSC, SASE, WIHG, IITs), in collaboration with NDMA and NIDM. Such trainings can be used to get inputs from international experts and specialists for providing updated knowledge to the students and practitioners.

6.3.2. Training of Decision makers

As the policy and decision makers regulate and manage the disaster preparedness and response system, it is necessary that they are aware of the gaps in the disaster preparedness and what communities face during such disasters. For that, trainings and workshops for policy and decision makers should also be conducted periodically. This will enhance the efficiency and regularity in the system to mitigate the GLOF/ LLOF disaster risks and hazards.

6.4 CAPACITY UPGRADATION

6.4.1 Documentation

It is recommended to establish a systematic database of past GLOFs and LLOFs disasters and emergency situations developed according to the approaches presented in these guidelines. Such a database is important in order to extract best practices and lessons learnt from past events, which will contribute to further refining of these guidelines according to newer insights gained over time. NDMA is well placed to develop and host such a database, and moderate related educational efforts.

The GLOF and LLOF events database should include the following aspects for each case or lake:

- Observed environmental conditions, if available before, during and after an outburst, should be described
- Consequences of event.
- Assessment of outburst susceptibility and scenarios of possible future developments
- Institutional roles and responsibilities, as well as communications between institutions
- Risk reduction and mitigation measures taken
- Critical reflection and lessons learnt
- Actions to be taken further

Chapter 7: Response

7.1 INTRODUCTION

Magnitude of disasters like GLOFs and LLOFs can vary from small to large scale and the response measures are required to be taken at the appropriate levels. Under response measures, there is an utmost need to provide immediate assistance to maintain life, improve health, provide initial repair to infrastructure and support the morale of the affected population.

7.2 EMERGENCY SEARCH AND RESCUE OPERATION

7.2.1 Local Community

Experience has shown that over 80 per-cent of search and rescue is carried out by the local community before the intervention of the state machinery and specialised search and rescue teams. Thus, trained and equipped teams consisting of local people must be set up in GLOF and LLOF vulnerable and prone areas to ensure immediate and effective response. Regular updating/revision of the training, and participation in mock drills will be important to ensure readiness to respond.

7.2.2 Search and Rescue Teams

On the ground, besides others, the NDRF battalions will assist the state government/district authorities in training the local communities. They will be further assisted by the ATIs, CD, Home Guards and NGOs. The state governments, through the ATIs, will develop procedures for formally recognizing and certifying such trained search and rescue team members; they will also provide suitable indemnity to community level team members for their actions in the course of emergency response following a flood. Youth organisations such as the NCC, NSS and NYKS will provide support services to the response teams at the local level, under the overall guidance and supervision of the local administration.

7.3 EMERGENCY RELIEF

Trained community level teams will assist in planning and setting up emergency shelters, distributing relief packages among the affected people, identifying missing people, and addressing the needs for food, health care, water supply and sanitation, education, etc. of the affected community. These teams will also assist the government in identifying the most vulnerable people who may need special assistance following the disaster. Emergency relief can only be effective if it is underpinned by effective disaster preparation (see chapter 6), and these components need to be closely linked.

7.3.1 Emergency Medical Response

7.3.1.1 Emergency Treatment at Site

Prompt and efficient emergency medical response will be provided by Quick Reaction Medical Teams (QRMTs), mobile field hospitals, Accident Relief Medical Vans (ARMVs) and heli-ambulances in areas inaccessible by roads . They will be activated to reach the affected areas immediately, along with dressing material, splints, portable X-ray machines, mobile operation theatres, resuscitation equipment and life-saving drugs, etc. Resuscitation, triage and medical evacuation of victims who require hospitalization will be done in accordance with SOPs. Heli access may be critical in remote mountain regions, and road access can be destroyed by the event itself. However, weather conditions, particularly during monsoon, can prevent safe helicopter access, and hence, alternative routes into affected areas should be identified in advance.

7.3.1.2 Medical Facilities and Medical Treatment at Hospital

A well-rehearsed medical preparedness plan is required to provide intensive care to cases rescued from drowning and those buried under the debris. An emergency medical plan will be triggered immediately on receiving information about imminent threat of GLOF/LLOF. The action will be immediately initiated for crisis expansion of required number of beds. The medical superintendent should be able to forecast the requirement of enhanced manpower and medical stores after knowing the number of causalities likely to be received at the hospital. Special efforts will be made for the availability of IV fluid, antibiotics vaccines etc. Children, women, elders and other vulnerable casualties will be attended on priority basis.

7.3.1.3 Mortuary Facilities and disposal of Dead Bodies

The state will develop contingency plans to have sufficient mortuaries to preserve the dead bodies. After proper identification, dead bodies will be immediately disposed of through district authorities, to prevent the outbreak of an epidemic and environmental pollution.

7.3.1.4 Public Health Issues in Aftermath

Safe and sufficient drinking water will be ensured. Protecting existing water sources from contamination, adding chlorine tablets in the water for residual disinfection effect and provision of latrine and proper waste disposal to avoid contamination through flies and other insects are important steps required immediately in the aftermath of a GLOF/LLOF. Vector control will be done by spraying of shelters with residual insecticides. Provision of insecticide treated mosquito nets is recommended.

7.3.1.5 Psychosocial Aspects

A large number of victims will suffer from psycho-social effects in the aftermath of the disaster event. The psycho-social impact of floods could manifest as a reaction in the form of post-traumatic stress disorders (PTSD) and other psychosocial ailments among the displaced populations. A team comprising of a social worker, a psychologist and a psychiatrist will provide counselling to such people.

7.3.1.6 Documentation of Medical Response

Documentation of the medical response provided after a GLOF/LLOF event will be done by a medical administrator. This documentation will be used as feedback for future improvement of the response strategies.

7.4 INCIDENT RESPONSE SYSTEM

All response activities will be undertaken at the local level through a suitably devised Incident Response System (IRS) coordinated by the local administration through the Emergency Operations Centers (EOCs). State governments will commission and maintain EOCs at appropriate levels for the coordination of human resources, relief supplies and equipment. Standard Operating Procedures (SOPs) for the EOCs will be developed by state governments and integrated within the framework of the IRS, which will take advantage of modern technologies and tools, such as GIS maps, scenarios and simulation models for effectively responding to disasters. GIS maps available from other sources, such as the city planning departments will be compiled considering their potential application after a disaster. The state governments/SDMAs will undertake the training of personnel involved in the IRS. Some of the state governments have already adopted this system.

7.5 COMMUNITY-BASED DISASTER RESPONSE

7.5.1 Institutionalizing the Role of Community Based Organisations, Non-governmental Organisations etc. in Incident Response System

A number of organisations, like NGOs, self- help groups, CBOs, youth organisations such as NCC, NYKS, NSS etc., women's groups, volunteer agencies, CD, Home Guards, etc. normally volunteer their services in the aftermath of any disaster. Village level task forces will also be constituted on a voluntary basis for better preparedness of the community including shepherds/Himalayan nomads. The state governments/ SDMAs and DDMAs will coordinate the allocation of these human resources for performing various response activities. State governments will work with these agencies to understand and plan their roles in the command chain of the IRS, and incorporate them in the DM plans.

7.5.2 Dissemination of Information

Soon after the disaster, accurate information will need to be provided on the extent of the damage and other details of the response activities through electronic and print media. The state governments will utilise different types of media, especially print, radio, television and internet, to disseminate timely and accurate information.

7.6 LOGISTICS

7.6.1 Emergency Logistics/Equipment:

Specialized heavy earthmoving and search and rescue equipment are required immediately after a GLOF/LLOF to help clear debris and carry out search and rescue operations of trapped people under huge masses of debris. Also, Motor launches, country boats, inflatable rubber boats, life jackets, lifebuoys and other equipment will be required immediately after floods to carry out search and rescue of trapped people. State governments will compile a list of such equipment, identify suppliers thereof and enter into a long-term agreement for their quick mobilization and deployment in the event of floods and a landslide disaster.

The IDRN, which is a web-based inventory of information on emergency equipment and response personnel available in every district, will be revised and updated every three months.

7.6.2 Relief Camps

The setting up of relief camps (Rahat Ghar) for the people whose houses have been damaged by floods/landslides and the provision of basic amenities in such camps involves complex logistics of mobilizing relief supplies, tents, water supply and sanitation systems, transport and communication systems, and medical supplies. Most importantly, site selection for relief camps based on best available scientific information (hazard mapping etc.) should be part of the disaster preparedness phase. Relief camps, and access corridors to these camps, should be outside of zones of residual risk, and safe from any potential secondary hazards.

A temporary shelter building, where the locals can find shelter during the times of disaster should be erected/ built in a raised location to ensure resilience to landslides and floods. The building will include a raised plinth which will safeguard it from flood waters and needs to be built with landslide resistance standards of the highest orders.

7.6.3 Establishing the Accessibility

The primary challenge in the response to natural calamity in the Himalayas is ensuring accessibility to the affected areas, due to likelihood of choking of the limited communication lines. In case of the Himalayas,

c) Preparation of Hazard Zonation Maps and mapping of unsafe areas for human settlements that are likely to be at risk from a susceptible GLOF/LLOF.

d) Ensure continuous monitoring of highly susceptible lakes followed by field survey in terms of change in the area of the lake, change in water level, position of a lake in relation to moraines and associated glaciers, the activity of lakes and condition of the dam.

e) Involvement of the shepherds/ guides/porters and local communities in monitoring of glacial/landslide lakes with high risk boundary conditions and discernible terrain changes.

f) Seek inputs from Indian Meteorological Division (IMD) and Snow & Avalanche Study Establishment (SASE), CWC, Survey of India (SOI) to ensure continuous weather monitoring and to facilitate decision making in case of emergency. **[Action:** State/UT Admin**]**

g) In case of abrupt expansion of the lake, ascertain the cause at the earliest through satellite/aerial and physical means. **[Action:** State/UT Admin/NRSC**]**

h) Ensure availability of satellite communications (SAT Comms.). **[Action:** State/UT Admin/DoT**]**

i) Convene a meeting at District/State level to tackle the issue. Inform NDMA and provide regular updates.**[Action:** State/UT Admin**]**

j) Refer the situation to the National Disaster Management Authority (NDMA) if it is beyond the capability/resources of State Govt. **[Action:** State/UT Admin/ NDMA**]**

k) National Crisis Management Committee (NCMC) to convene a meeting at the earliest depending upon the severity of the situation. Simultaneously, the Defence Crisis Management Group (DCMG) meeting may also be held, if required. **[Action:** Cabinet Secretariat/ NDMA/MoD**]**

l) NDMA / SDMA to activate the Control Rooms and update all records. Establish telephonic and video contact with all concerned officials including officials of the concerned State Control Room, IMD, CWC, NRSC and National Technical Research Organization (NTRO) obtain satellite images of the affected area. NDRF / SDRF alerted to be on standby. **[Action:** NDMA/ SDMA (State/UT Admin)/NDRF/SDRF/NRSC/ NTRO/ IMD/ CWC**]**

m) Based on the lessons learnt, the affected State to organize a Team of Experts from those agencies which are likely to be involved. These could be some or all of the following suggestive list of institutions:- **[Action:** State/UT Admin/NDMA**]**

(i) Central Water Commission (CWC)
(ii) India Meterological Department (IMD)
(iii) Survey of India (SOI)
(iv) Geological Survey of India (GSI)
(v) Central Institute of Mining & Fuel Research (CIMFR)
(vi) National Mission for Sustainable Himalayan Ecosystem (NMSHE)
(vi) National Institute of Hydrology (NIH)
(vii) Snow & Avalanche Study Establishment (SASE)
(viii) Border Roads Organization (BRO)
(ix) MoD / Integrated Defence Staff (IDS)
(x) Hydro Power Developers
(xi) Dept of Science & Technology (Suitable representative from State Govt.)
(xii) Official media personnel.
(xiii) Other Departments.

the heavy earth moving machinery might not be useful and relevant in the immediate response stage. Hence, innovative methods using locally available natural resources will have to be used and local agencies and population will have to be trained for the same. It is important to innovate and design lighter machinery, which are more suitable to be carried in the mountains in a disassembled form.

7.7 POST DISASTER DAMAGE AND NEED ASSESSMENT

Assessment of the damage, both direct and indirect, due to GLOF/LLOF as wells as secondary physical effects, such as landslide-caused flooding, is very important to understand whether it will be possible to treat it economically or not. While direct losses include the impact on infrastructure, vehicles, life loss, etc., indirect landslide losses could include:

i) The loss of industrial, agricultural, and forest productivity; and tourism sector revenues as a result of damage to land or facilities, or interruption of transportation systems.
ii) Reduced real estate values in areas threatened by GLOFs/LLOFs.
iii) The loss of tax revenues on properties devalued as the result of GLOFs/ LLOFs.
iv) Measures that are required to be taken to prevent or mitigate additional landslide damage.
v) Adverse effects on water quality in streams and irrigation facilities at and near the GLOFs/LLOFs affected region.
vi) The loss of human or animal productivity because of injury, death, or psychological trauma.

Indirect losses many a times exceed direct losses. Unfortunately, most indirect losses are difficult to evaluate and are therefore either ignored or estimated rather conservatively. Also, usually people and entities prefer to keep their financial losses discrete and not disclose these publicly. Restoration of direct assets will also lead to improvement in the indirect losses but much effort is required to be made by all the local organisations/ NGOs/ Communities to regain the indirect assets.

Physical damage assessment is done through airborne videography/ imagery, satellite data and field surveys. Much of the work on damage assessment nowadays is based on the Earth observation data i.e. optical and SAR satellite data. It is highly useful to identify places clogged with water and those hit by landslides. Precise measurements can give results of movement at millimeter (mm) scale.

7.8 STANDARD OPERATING PROCEDURE (SOP)

STANDARD OPERATING PROCEDURE (SOP) ON AVERTING THREATS EMANATING FROM GLACIAL LAKE OUTBURST FLOODS (GLOFs) AND LANDSLIDE LAKE OUTBURST FLOODS (LLOFs) IN HIMALAYAN REGION

The SOP lays down the guidelines and actions to be taken by the various agencies during the disaster event /crises. The standardized Incident Response System (IRS) for managing the GLOFs and LLOFs will be incorporated in line with these procedures. The SOP is implemented three stages as outlined below.

Pre-Operational Phase (Stage I)

a) Preparation of an inventory of the glacial/landslide lakes through remote sensing and GIS and prioritisation of the lakes according to the GLOF/LLOF risk assessment framework. **[Action:** State/UT Admin/District Admin/ NRSC/NTRO/ CWC/ National Mission for Sustaining the Himalayan Ecosystem (NMSHE)-DST**]**

b) Mapping of glacial/landslide lakes and relevant water bodies in IHR as well as classification of lakes based on the susceptibility as Highly Susceptible, Moderately Susceptible and Low susceptibility. **[Action:** NRSC/NTRO/ CWC/ NMSHE/ MOJS/ NLRTI**]**

n) State/ UT Admininstration to take immediate precautionary and preventive measures to ensure safety to life and property. These include: -

(i) Informing the populace living both down/upstream of the impending danger.

(ii) Installing water level monitoring gauges at suitable locations.

(iii) Preparing (rehabilitation) relocation plans.

(iv) Establishing communication facilities at the likely affected areas.

(v) Alerting and preventing locals/ tourists from venturing into affected areas by establishing check posts/ check points.

(vi) Erecting banners/ boards with warning signs.

(vii) Taking immediate steps to relocate personnel from high risk zones.

o) The Expert Team / essential members to conduct an on the spot assessment of the GLOF/LLOF and carry out recce to ascertain: -

(i) Free board available i.e. difference between current water level and dam height.

(ii) Type and texture of the dam.

(iii) Possible time available before a sudden dam break.

(iv) Seepage towards downstream if any.

(v) Any threat likely to develop due to impounded water.

(vi) If physical intervention to drain the lake is required, then alignment and dimension of channel required to be created.

(vii) How the channel is to be created, i.e. by using earth movers or manual clearing of debris (where earth movers cannot be deployed).

(viii) Whether explosives can be used for creating a channel? If so, resources required i.e. manpower, equipment, explosives, etc.

(ix) Any site-specific requirements.

(x) Photography and videography of the site and surrounding areas.

p) Set up of Expert team by NDMA / SDMA to assist State in preparing a detailed action plan giving out: -

(i) Transportation

(ii) Communication

(iii) Medical

(iv) Safety

(v) Logistics stocking, replenishment and reserves

(vi) Induction, execution and de-induction phases

(vii) Media plan, photography & videography of events

<u>Operational Phase (Stage II)</u>

a) Installation of Automatic Water Level Recorders (AWLR) and Water Gauges at the susceptible lakes for continuous monitoring of water level in the lake.

b) Ensuring controlled breaching of the dam by reducing the volume of the water in the lake via construction of an outlet control structure, pumping or siphoning of the water from lake and tunneling through the moraine barrier or under an ice dam. **[Action:** State/UT Admin**]**

c) CWC to prepare pre-run scenarios and generate flood inundation/DEM Chart to indicate level of potential threat in the event of the dam break/overflow scenario.

d) Planning of evacuation strategies on the basis of results from flood inundation modelling. **[Action:** State/UT Admin/CWC/CAPF/Local Police**]**

e) Ensure installation of Early Warning Systems (EWS) involving threshold based automatic alarm system monitored on a daily or weekly basis by State Emergency Operating Centre (SEOC) and managed by State Disaster Management Authority. **[Action:** SEOC-SDMA/DEOC-DDMA**]**

f) Securing and establishment of shelter homes, camp site and forward staging areas. **[Action:** State / UT Admin/ Army/ ITBP/ CAPF]

g) Establishing communication facilities (including HF/ VHF/ HAM/ satellite phones) at the site, staging areas and District Control Room. **[Action:** State/UT Admin/CAPF/ITBP/Army**]**

h) Installing safety devices like anchors, ropes, harnesses etc. where required.**[Action:** NDRF/ SDRF/ CAPF/ ITBP/Army/NIM**]**

i) Stocking of logistics like ration, equipment and machines, fuel, medicines, explosives and accessories, lighting arrangements. **[Action:** State/UT Admin/CAPF/ITBP/BRO/ Army**]**

j) Relocating the likely affected people from low lying areas at least 48 hours before actual commencement of work at the site. **[Action:** State/UT Admin/District Admin**]**

k) Detail a lookout team to alert members at the work site from falling stones, loose land mass etc. **[Action:** Expert team leader**]**

i) Marking the alignment of the channel to be created at the blockage site.**[Action:** Expert team leader**]**

m) Controlled use of explosives to break boulders/ dislodge compacted earthmass. Expertise of CIMFR, BRO & Army Engineers and others may be sought for use of explosives. **[Action:** Explosive Experts in State/UT Admin/ Army/ BRO**]**

n) Manual clearing of debris along the marked alignment. **[Action:** Expert team leader/CAPF/Army**]**

o) Manual clearing of debris and use of explosives can be alternately followed until the desired width, depth and length of channel is created for free flow of impounded water. **[Action:** Expert team leader/CAPF/Army**]**

p) Use of earth movers (JCB) if it is possible to reach them at the site. These can even be dismantled in parts, carried by helicopters under slung and assembled at the site (As done during River Sunkoshi blockage in 2014, Nepal). **[Action:** State/UT Admin/Airforce/ Army Engineers**]**

q) Loose debris can even be washed away using high pressure water jets at places subject to deployment of heavy-duty compressors. **[Action:** State/UT Admin/ Army**]**

r) Photography and videography of events for future reference. Representatives of media should be associated. **[Action:** State/UT Admin/ Expert Team Leader**]**

s) Heli-Ambulance/ air support to be requisitioned to National Emergency Response Centre (NERC) / Joint Secretary (Air). **[Action:** State / UT Admin/ MHA/MoD**]**

t) Bill for such air support to be raised against SDRF allocation**. [Action:** Air Force/ MHA**]**

u) Obtain daily weather reports to the plan for next day's activity. **[Action:** Team leader/Air Force/IMD**]**

v) Media briefing and press release at the end of the day's activity by the designated representative of State associated with the team. **[Action:** State/ UT Admin / District Admin/ NDMA/ Army PRO**]**

w) Ensure effective coordination and seamless communication among central and state agencies for quick, clear, effective dissemination of warnings, information and data. **[Action:** State / UT Admin/ District Admin**]**

Post Operational Phase (Stage III)

a) Round the clock monitoring from the Lookout Post till the situation normalises. **[Action:** State/UT Admin/ Army**]**

b) Obtain satellite imageries, from NRSC & NTRO to compare pre and post activity changes in volume of impounded water upstream, status of flow of water through channel and flow of water downstream. **[Action:** State/UT Admin/CWC/NRSC/ NTRO/NDMA**]**

c) Periodical aerial recee and videography of the sites without connectivity to know the latest status. **[Action:** State/UT Admin/ Army/ Air Force/ Expert Team**]**

d) Sectoral assessment of the damage such as infrastructure damage, livestock damage, agriculture damage. **[Action:** State / UT Admin/ IMCT**]**

e) Ensure calculation of the compensation required to be provided to the population exposed to the hazard. **[Action:** State / UT Admin**]**

f) Decide on rehabilitation of population once impounded water has drained out. CWC can assist in advising the safe levels. **[Action:** State/ UT Admin/ CWC/NRSC/NTRO**]**.

g) In cases where the dam has breached, Post Breach Analysis and Assessment by team of experts shall be carried out and further course of action recommended. **[Action:** State / UT Admin**]**

h) All concerned / involved Ministries and Govt. organizations must ensure they have adequate well-trained experts so that they can be speedily moved to the disaster site. **[Action:** State / UT Admin/ CWC/SASE/SOI/BRO/CIMFR/ ITBP**]**

i) Compendium of recommendations and lessons learnt shall be drawn and shared with all concerned agencies / Depts. **[Action:** State/ UT Admin/ Expert Team Leader**]**

Conclusion

The SOP on "Averting Threats Emanating from Glacial Lake Outburst Floods (GLOF) and Landslide Lake Outburst Flood (LLOFs) in Himalayan Region" gives out detailed actions /steps to be taken by respective authorities in the event of GLOF/LLOF. It is, by no means, exhaustive but a referral document which needs periodical modification with sharing of experiences and best practices across the country.

CHAPTER 8: RESEARCH AND DEVELOPMENT

8.1 INTRODUCTION

Typically, GLOFs increase to peak flow then gradually or abruptly decrease to normal levels once the water source is exhausted. Therefore, outburst flood peak flow is directly related to lake volume, dam height and width, dam material composition, failure mechanism, downstream topography, and sediment availability. In order to get the maximum GLOF peak at any location, the breaching of moraine dams of above glacial lakes have to be considered along with channel routing. GLOFs tend to entrain large amounts of sediment, with the potential to transport massive boulders, particularly in the upper reaches where channel gradients in high mountain catchments are often steep. This is particularly true for floods from moraine dammed lakes, which frequently transform into debris or hyper concentrated flows following the entrainment of material from the moraine and immediate downstream channel. Due primarily to their large flow depths and locally high energy gradients, GLOFs produce erosive forces far greater than typical meteorological floods would for the same stream conditions.

In long stream channels such as in the Himalayas and the Andes, dynamic flow transitions are often observed for GLOFs, from initial debris flow types to hyper concentrated flows and possibly back to debris flows depending on channel slope and availability of erodible material. Flood paths extending up to 100 km and even more have been observed (Carey et al., 2012; Cenderelli and Wohl, 2003; Schwanghart et al., 2016). A time series water sampling of trans-boundary fluvial systems and their hydro-geochemical analyses has been done to trace the origin of the flash floods in the headwaters of Himalayan Rivers (Rai and Singh, 2007).Towards this, the collected discharge data of CWC may be used for the validation. Further, atmospheric phenomenon like cloud bursts and intense rainfall may be studied by establishing advanced instrumentation like Doppler RADAR systems and Automatic Weather Stations (AWS) at high altitudes.

8.2 RESEARCH ISSUES & CHALLENGES

The purpose of the modelling is to reconstruct a historical GLOF, or to investigate the impact of a potential future GLOF. The models are required to give the user an estimated peak breach discharge, and time to peak discharge, and require prior knowledge of the moraine geometry (e.g. its height, width, length) and/or the glacial lake (e.g. it's volume, depth, and surface area), which can be plugged into a simple equation.

Key challenges that modelers face here stem in large part from the incredible complexity of these flows. Assessment of the accuracy of such models also requires the availability of pre and post-flood DEMs, which allow the modeler to see whether the modelled patterns of erosion and deposition match those observed in reality for documented GLOFs. However, these data are rarely available due to the logistical (and financial) challenges associated with producing repeat topographic surveys of often remote and largely inaccessible valleys, as well as predicting if and when a given moraine will fail. Further, for most glacial lakes, a hazard assessment cannot rely on information from past GLOF events (such as observed erosion patterns, for instance), as lake outbursts often are single events, without historical precedence. Nevertheless, current scientific state-of-the-art techniques for GLOF hazard modelling relies on scenario-based, future-oriented numerical models, that are coupled according to the chain of processes involved in a GLOF (cf. Chapter 3, as well as GAPHAZ 2017, Jain et al., 2012, Schneider et al. 2014, Frey et al. 2018, Mir et al., 2018). Recent efforts include modeling approaches that are able to simulate entire chains of mass movement processes within a single modeling framework (Mergili et al. 2017, 2020). There is still a large research potential both in the development of hazard scenarios and the estimation of related uncertainties, as well as the numerical modeling of mass movements involved in a GLOF.

A wider area of research is related to the use of local knowledge for disaster risk management. Local population in the IHR has a long-standing experience in dealing with hazards and risks from glacial lakes. In particular when considering the common lack of observational data in remote mountain regions, local knowledge can indeed provide valuable information on past conditions and events. Further, involvement of the local population in disaster risk reduction efforts is indispensable (cf. Chapter 4). Another area with research potential include the integration of socio-economic assessments and developments in risk assessments and management strategies, which requires the involvement of and collaboration with social scientists.

8.3 EFFECT OF FUTURE CLIMATE CHANGE

In relation to climate warming and cryospheric changes, a primary challenge concerns the anticipation and assessment of hazards resulting from a fundamental change from glacial to periglacial landscapes (Haeberli et al., 2016). Disappearance of glaciers, permafrost degradation, landscape evolution and corresponding changes in inter-connected surface processes are cumulative developments that lead far beyond historical precedence. Future conditions will in many places be far removed from the past and present and therefore limit the value of historical event inventories. Quantitative, future-oriented and scenario-based system approaches must therefore be applied (see Chapter 3). However, modelling future high-mountain landscapes with their complex systems of interacting surface processes and landforms is a young, emerging research field, and uncertainties are inherently large. Individual components within the complex system have strongly diverging characteristics in their response to climate change. By comparison, due to slow heat diffusion and retarding effects from latent heat exchange in subsurface ice, permafrost degradation is a slow process with long-term commitments. Corresponding deglaciated landscapes can therefore be expected to turn into periglacial landscapes characterised by slowly degrading permafrost, numerous new lakes and pronounced disequilibrium in conditions concerning vegetation cover, slope stability and sediment cascades.

In view of the large uncertainties involved with anticipating such conditions, focused monitoring using advanced space-borne and terrestrial technology is required in case of high hazard or risk levels, coupled with regular re-assessment of the general conditions and specific hazard situations. The formation of new lakes located within increasingly close proximity to steep and destabilizing mountain headwalls has the potential to greatly enhance regional risks from far-reaching flood waves. Corresponding hazard and risk management relating to low-probability events with extreme damage potential is especially difficult for planning, policymaking and decision taking. Furthermore, the expected penetration of humans with their infrastructure for tourism, traffic or hydropower, etc., into previously un-accessible or even avoided high mountain areas must be taken into account.

Chapter 9: Regulation and Enforcement

9.1 INTRODUCTION

The widespread loss of property and life during the recent GLOF events (such as the Kedarnath disaster) have shown that most construction plans are ill conceived and do not follow the building standards or design codes. Climate change is expected to alter and potentially increase the probability for lake outbursts in the future posing potential threats in the downstream settlements. Urban centers, towns and some villages in mountain areas are being burdened beyond their capacity by tourism and rural-to-urban migration while the loss of large areas of farmland has ruined livelihoods of rural communities and affected the food security in the mountains. New regulations need to be framed for the Himalaya keeping in mind the hazards due to GLOF/LLOF and the causative factors of cloud burst, flash flood, earthquakes. In the case of existing structures, as it is difficult or impossible to alter land use, specific construction codes are required to reach the desired protection level. Regulations and enforcement are required on two fronts - namely, (i) a no habitation/ construction zone in the GLOF hazard area as determined from flood plain zoning studies; and (ii) the strict enforcement of the existing building standards/regulations which have been derived from various laws pertaining to planning and development. Subsequently, it is necessary for their implementation by the multiple agencies in a holistic manner.

9.2 IDENTIFIED GAPS

There is a need for a Himalaya GLOF Mitigation Policy and a Himalaya GLOF/LLOF Mitigation Strategy. The following needs are identified for the Himalaya: -

(1) Himalaya GLOF/ LLOF Mitigation Policy (HGLMP) which is a must for Himalaya GLOF/ LLOF Mitigation Strategy (HGLMS) should be common all over the Indian Himalaya States. HGLMS must be developed by the States and be area/problem specific but must reflect the HGLMP. Emphasis must be given to prevention/ preparedness in HGLMP/HGLMS.

(2) The existing bye laws/regulations at the local body or state/central level should be incorporated in the HGLMP and HGLMS. They should not contradict each other. The HGLMS must focus on implementation and enforcement of laws/ regulations and accountability.

(3) Necessity of flood hazard zonation, slope and land-use maps to guide urban planners for clearing constructions. For this, cloud burst forecasting, flash flood modelling and slope instability analysis reflecting the potential for extreme rainfall, flooding, landslides representing the ongoing event/process are required and should be two separate components of HGLMS.

(4) HGLMP and HGLMS should not contradict National Environment Policy and therefore, they should be validated by the MoEFCC.

(5) Best practices which are used to mitigate floods and landslides at the local level and activities which can be

held responsible for the GLOF/ LLOF hazard should be documented in the HGLMP.

(6) There is a need to have specific land use policy for the Indian Himalaya Region for the regions facing GLOF/ LLOF hazard, especially at the micro-level under the jurisdiction of the local bodies. Coordination among the panchayats, line departments, forest department and municipal authorities for management of water bodies and drainage outside municipal limits is also required.

(7) State specific GLOF/ LLOF mitigation strategies to be formulated to address specific issues of each mountain state.

(8) The municipal bye-laws must provide for regulating construction activities in areas that fall in hazard zones or areas close to rivers, springs and watersheds of the towns. In many cases these provisions exist in the bye-laws but need to be strictly enforced.

(9) As there is no specific standards/ code(s) are available with respect to GLOF/LLOF hazards, the same must be developed by BIS.

9.3 TECHNO-LEGAL REGIME

To address the special problems of towns and villages located in GLOF/ LLOF susceptible areas, necessary modifications must be made to the Model Town and Country Planning Legislations (2016), Zoning Regulations, Development Control, Building Regulations/Bye-laws taking into consideration the special conditions of the Indian Himalaya Region. Such laws are mainly state legislations as the state is competent to legislate and make laws on such subjects. The Environmental Regulations and Environment Impact Assessment (EIA) according to the notifications of the MoEFCC must also be included in the techno-legal regime.

9.3.1 Model Building bye-laws 2016

Building bye-laws are legal tools used to regulate coverage, height, building bulk, and architectural design and construction aspects of buildings to achieve orderly development of an area. The Town and Country Planning Organization under the Ministry of Housing and Urban Affairs has recently prepared the "Model Building Bye-laws -2016" for the guidance of the State Governments, Urban Local Bodies, Urban Development Authorities, etc. Under the natural hazards, the committee has included the hazards due to earthquakes, cyclones, floods, and landslides. However, no specific mention of GLOF/ LLOF events is given in the bye-laws.

9.3.2 Regulations for Land Use Zoning for Natural Hazard Prone Areas

Zoning regulations are legal tools for guiding the use of land and protection of public health, welfare and safety. The regulations for land use zoning for natural hazard prone areas are notified under Town and Country Planning Act as applicable in the respective States as and when Master Plan/ Development Plan of different cities/towns/areas are formulated. These zoning regulations are implemented through the provisions of Development Control Regulation/Building Bye-laws, wherever the Master Plan are not in existence or not formulated.

A detailed guideline for land use zoning has been prepared with an objective to regulate land use in hazard prone areas to minimize the damage caused to the habitat, as a result of natural hazards viz. earthquakes, cyclonic storms, landslides and floods. These include prioritization of types of buildings for land use zoning.

9.3.3 Indian Standard Codes

The National Building Code published by the Bureau of Indian Standards in 2016 and subsequent revisions are advisory in nature and not mandatory. The code also covers aspects of administrative requirements and bye-laws including building services.

As landslides and GLOF are closely interrelated, for protection of landslide hazard, two IS codes are mentioned for ready reference- (i) IS 14458 (Part 1): 1998 Guidelines for retaining wall for hill area: Part 1 Selection of type of wall; and (ii) IS 14458 (Part 2): 1997 Guidelines for retaining wall for hill area: Part 2 Design of retaining/breast walls. (iii) IS 14458 (Part 3): 1998 Guidelines for retaining wall for hill area: Part 3 Construction of dry-stone walls, (iv) IS 14496 (Part 2): 1998 Guidelines for preparation of landslide – Hazard zonation maps in mountainous terrains: Part 2 Macro-zonation

9.3.4 Related NDMA Guidelines

The NDMA has also issued guidelines on landslides, floods and urban flooding and a National Landslide Risk Management Strategy (2019) which are relevant to GLOF/ LLOF. However, considering the special characteristics of the GLOF events, there is a need for special regulations for areas situated downstream of GLOF/ LLOF hazard areas.

9.3.5 Initiatives of the Ministry of Environment, Forest and Climate Change (MoEFCC)

The Ministry of Environment, Forest and Climate Change (MoEFCC) is the nodal agency in the administrative structure of the central government for planning, promotion, co-ordination and overseeing the implementation of environmental and forestry programs. Certain initiatives of MoEFCC are relevant in the context of flooding in hilly areas. The Environmental Impact Assessment (EIA) is one of the proven management tools for incorporating environmental concerns in development process and in improved decision-making. The EIAs were initiated with the appraisal of river valley projects and now includes other sectors like industrial projects, thermal power plants, mining schemes and infrastructure projects, etc. Guidelines will be issued to State EIA Authorities to subject even smaller projects to meet EIA norms.

9.3.6 State Level Legislation

The planning and development are state subjects and therefore, the development in the states is based on the legislative support as applicable in that state. The legislative support in the state is applicable to formulate Master Plans, Zonal Development Plans and Area Planning layouts for their implementation and enforcement.

9.3.7 Legislative Support at the Local/ Municipal Level

At the local level, the Municipal Authorities and Panchayats regulate the development/construction of buildings through the building bye-laws as followed in their respective areas. The State Governments/UTs from time to time issue directions/guidelines for safety against natural hazards, which are followed by local bodies while granting permission for construction of buildings/ structures.

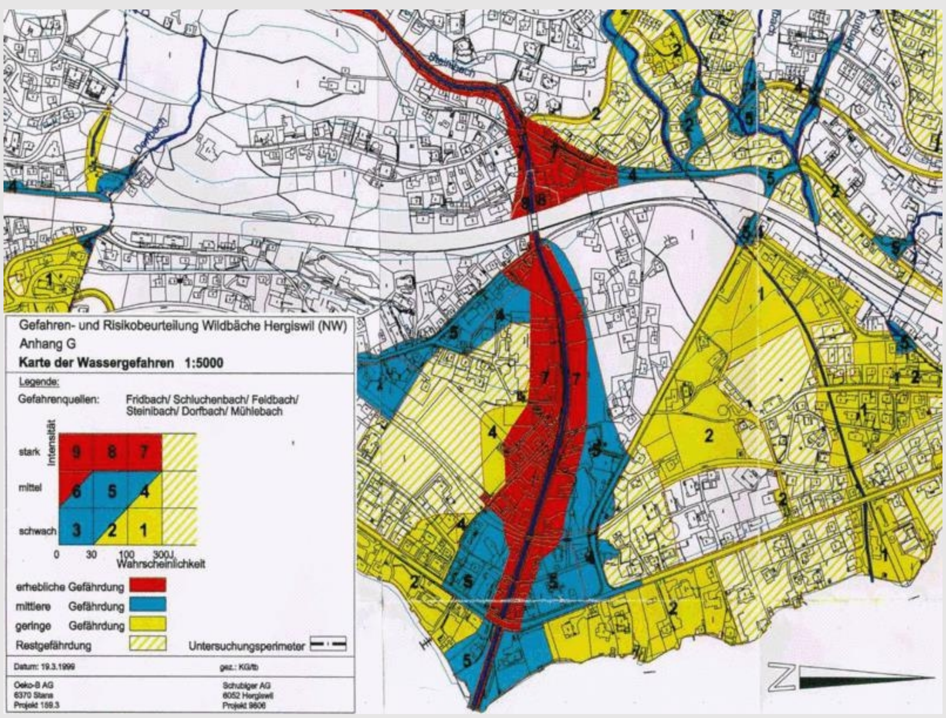
9.4 TECHNO-LEGAL REGIME AND RISK MANAGEMENT IN SWITZERLAND

Box 1: Example of Zoning Regulations and Hazard Assessment in Switzerland

Switzerland is a mountainous country that has a long history of living and responding to natural hazards, including GLOFs. The Federal Flood Protection Law and the Federal Forest Law came into force in 1991. The purpose of these laws is to protect the environment, human lives and property from the damage caused by water, mass movements, snow avalanches and forest fires. As a result of these regulations, greater emphasis has been placed on preventative measures, and cantons are legally required to establish registers and maps denoting areas of hazards and to take them into account in their guidelines for landuse planning.

Hazard maps, according to the federal guidelines express three degrees of danger, represented by corresponding colours: red, blue and yellow. This ensures homogeneous and uniform means of assessment of the different kinds of natural hazards affecting Switzerland. Within the **red** zone (high hazard), development is generally prohibited. In the **blue** zone (moderate hazard), development is strongly regulated, while in the yellow zone (low hazard), people need to be notified and alerted of possible hazards.

Importantly, hazard maps are compiled for all the different processes that are relevant for a specific site or settlement. This has important implications for spatial planning, since being outside the GLOF hazard zone, for example, does not necessarily imply to be safe from avalanches or other flood hazards. Hence, risk management follows a multi-risk approach.



Box 1: Example of a flood hazard map for the village of Hergiswil, central Switzerland (http://www.planat.ch/en/authorities/hazard-maps)

9.5 RECOMMENDATIONS

There are no widely accepted procedures or regulation in India for land use planning in the GLOF/LLOF prone areas. Therefore, a committee should be constituted to formulate specific land use zoning, development control and building construction regulations need to be developed concerning the increased risk of future GLOF/LLOF events and give its recommendations within a year. The following actions are recommended for preparing techno-legal regime for cities, towns and villages in GLOF hazard areas also considering the associated hazards of cloudburst, flashflood, earthquakes and landslides.

9.5.1 Policy Level Recommendations

The State Governments / Sanctioning authorities should have a panel of reputed and technical personnel including SDMA, who can assist the building sanctioning authority in formulating GLOF specific regulations. They should take into consideration the Government Orders issued by the various State Governments which contain a number of provisions to be followed while sanctioning the building plans by the Development Authority, Special Area Development Authority, Corporation, Municipal Board and also by the concerned government department while formulating the regulations. At present there are several Acts/Rules/ Regulations applicable in the states. There should be single legislation to control development and building activity which could be formed taking into consideration present legislative framework and incorporating the suggestions made and should follow strictly the provisions suggested for safety against natural hazards e.g. the provision of Indian Standards. EIA should also consider the expected GLOF event(s) for future projects in GLOF hazard areas.

9.5.2 Technical Level Recommendations

The regulations should make it mandatory for all buildings, especially hospitals, schools, community halls to be designed according to the latest specifications and codes, for example the National Building Code of India, 2016. The special technical committee should recommend additional measures to be included in GLOF hazard areas.

9.5.3 Community Level Recommendations

There is a need to bring awareness at all levels of society starting with a high-level awareness program for decision makers regarding safety against natural hazards and the techno-legal regime. Awareness/ training program is required for engineers/ officials working with local authorities regarding bye-laws, regulations, codes and manuals for disaster resistant construction.

9.5.4 Tourism Level Recommendations

The regulations should be made to create the buffer zone to restrict the tourism in GLOFs prone areas and nearby region to reduce the impact of pollution in those areas. This should be monitored by state tourism committee to reduce the frequency of GLOF occurrences and recommend additional measures to be included in GLOF hazard areas. Awareness programmes/ notices should be disseminated for instructions, in collaboration with local authorities for disaster resistant tourism services.

Chapter 10: Implementation of The Guidelines— Preparation of GLOF & LLOF Management Plans

10.1 PLAN OF ACTION

Comprehensive DM plans will be prepared at the National, State and District levels. At the National level, the DM plan will focus on various aspects of DM including preparedness, mitigation and response. These plans will clearly identify the roles of key stakeholders for each disaster level and also include assessments of their own response capacities.

There is no Nodal Ministry and Agency identified for the subject on glacial studies including Glacial Lake Outburst Flood (GLOF) and Landslide Lake Outburst Flood (LLOF). Although, Central Water Commission (CWC) was monitoring the glacial lakes including water bodies from the year 2009 onwards and also identified to provide mitigation measures for landslide dams in the NDMA Guidelines on Management of Landslides and Snow Avalanches (June, 2009). Therefore, it is proposed to identify the Ministry of Jal Shakti (MoJS) as Nodal Ministry and CWC as Nodal agency for the glacial studies including GLOF and LLOF.

[**Action:** The MoJS/CWC]

These plans will be subjected to approval from NDMA, will include various aspects of glacial and landslide hazard management especially GLOF and LLOF. The main features to be included in the plan are as follows:

i) Preparation of state and district level DM plans with the aim of managing GLOF and LLOF hazard events.

ii) Revision of town planning bye-laws and adaptation of model land use bye-laws in hilly areas.

iii) Wide dissemination of model land use planning practices in hilly areas.

iv) Establishing appropriate mechanisms for compliance review of all land use planning and building bye-laws in hilly areas.

v) Enforcing and monitoring the compliance of land use and town planning bye laws, and other safety regulation in areas vulnerable to GLOF/LLOF.

vi) Training of trainers in professional and technical institutions.

vii) Training of professionals like engineers and geologists for hazard assessment and mapping, investigation techniques, analysis and observational practices

viii) Launching Public awareness campaigns on GLOF & LLOF hazard and risk reduction, and sensitizing all stakeholders on hazard mitigation.

ix) Preparing an inventory of past and recent GLOF and LLOF events.

x) Developing an inventory of critical lakes including attributes based on Geospatial and on field analysis like topography, rock type etc.

xi) Assessing the status of risk (exposure and vulnerability) of the existing built environment.

xii) Preparation of the DM plans by educational and health institutes/ organisations, government offices, etc., and carrying out mock drills for enhancing preparedness in vulnerable areas.

xiii) Strengthening the EOC network.

xiv) Streamlining the mobilization of communities, government agencies, the corporate sector, and other stakeholders.

xv) Preparing community and village level DM plans, with specific reference to the management of GLOFs and LLOFs.

xvi) Developing simple and effective information and warning dissemination systems that can reach affected communities in far flung areas clearly and in time.

xvii) Introducing GLOF and LLOF safety education (as a sub-group to Landslide and Flood education) in schools, colleges and universities.

xviii) Strengthening hazard safety R&D in professional technical institutions.

xix) Preparing document on the lessons learnt from previous GLOF and LLOF incidents, and their wide dissemination.

xx) Preparing an action plan for upgrading the capabilities of organisations and institutions involved in Glacial, Landslide and Flood disaster management studies with clear roadmap and milestones.

xxi) Developing appropriate risk transfer instruments by collaborating with insurance companies and financial institutions.

The proposed timeline for the implementation of the various activities in Guidelines are both important and very necessary especially in case of the non-structural measures for which no clearance is required from central and other agencies. Structural measures will be dealt with precise schedules evolved in the GLOF/LLOF management plans that will be followed at the central/state ministries, duly taking into account the availability of financial, technical and managerial resources. A strategy plan of implementation of various activities in the guidelines needs to be devised at the state and central level.

10.1.1 Short Term (1-2 years)

i) Formation of Specialized Committee under MoJS/CWC in consultation with NDMA involving expert agencies/institutes dealing with research and development on Glacial, Landslide and Flood Hazards to formulate specific land use zoning, development control, building construction regulations etc.

[**Action:** The MoJS/CWC in consultation with NDMA]

ii) Taking up pilot projects at least at 10 sites in the next two years to strengthen up the existing methodology right up to hazard and risk level.

[**Action:** The MoJS/CWC in consultation with concerned State/UT Disaster Management Authorities and other stakeholders]

iii) Hiring group of expert agencies to identify susceptible sites through Remote Sensing and GIS. Also, create a priority list by examining the vulnerability and associated risk for which immediate attention is required.

[**Action:** The MoJS/CWC in collaboration with NRSC and other stakeholders in consultation with NDMA]

iv) Development of Early Warning System (EWS) based on Ground Instrument, Water level sensors and Seismicity in consultation with Expert Institutes (such as NIH-Roorkee, C-DAC) and other nodal agencies.

[**Action:** The MoJS/CWC in consultation with concerned State/UT Disaster Management Authorities and other stakeholders]

v) Set up a regular monitoring system using remote sensing satellites and GIS.

[**Action:** The MoJS/CWC in collaboration with NRSC and other stakeholders]

10.1.2 Medium Term (3-4 years)

i) Already available BIS codes with respect to water projects are not sufficient for GLOF/LLOF; therefore, BIS needs to developed the same on different aspects of GLOF/LLOF in coordination/ collaboration with Nodal Ministry/ Agency.

[**Action:** The BIS in coordination with MoJS/CWC and other stakeholders in consultation with NDMA]

ii) **Improve and upgrade the current Early Warning System** keeping in view the validity and benefits of the results that were acquired during its active session.

[**Action:** The MoJS/CWC in consultation with concerned State/UT Disaster Management Authorities and other stakeholders]

iii) **Enhancing the mitigation measures by implementing the Risk Reductions Techniques namely:** Water lowering by Tunnel/ spillway and Hazard Reduction by Dam Construction.

[**Action:** The MoJS/CWC in consultation with concerned State/UT Disaster Management Authorities and other stakeholders]

iv) **Design of animated character for spreading awareness on disaster management (including GLOF/LLOF):** An animated character can be designed in partnership with computer animators.

[**Action:** The MoJS/CWC]

v) **Creation of a disaster management application:** NDMA in collaboration with the Indian Institute of Technology (IIT) can design a computer application for disaster management. The application can be used to know about the latest information on disasters (including GLOF/LLOF) across the country.

[**Action:**The NDMA in collaboration with MoJS/CWC and other Expert Institutions]

vi) **Awareness through documentary:** The National Disaster Management Authority (NDMA) should initiate a programme on power point documentary/presentation for Government organisation, School and Hospital organisation, Soldiers, NGOs, Local nodal agencies, Local club, and local people focusing on the role and responsibility before, during and after the GLOF/LLOF disaster.

[**Action:** The NDMA in collaboration with MoJS/CWC and concerned State/UT Disaster Management Authorities and other stakeholders]

vii) **Creation of village task force and volunteers:** The not-for-profit organizations should constitute a village task force and volunteers (Aapda Mitra) in each village of these states. The members of the task force should be made aware of the various aspects of GLOF/LLOF mitigation and post-disaster activities.

[**Action:** State/UT Disaster Management Authorities in consultation with NDMA]

10.1.3 Long Term (5-8 years)

i) **Use of web-based and app-based dissemination tools** for the preparation of maps for common use not only by the administrators but also by the community, tourists etc.

[**Action:** The MoJS/CWC in collaboration with Expert Institutions]

ii) **Wireless sensor network (WSN)** based ground instrumentation and real time monitoring of GLOF/LLOF.

[**Action:** The MoJS/CWC in collaboration with Expert Institutions and consultation with State/UT Disaster Management Authorities]

iii) **Incorporation of latest and advanced mitigation measures** to reduce the risk.

[**Action:** The MoJS/CWC in collaboration with Expert Institutions and consultation with State/UT Disaster Management Authorities]

iv) Incorporation of the advanced Evacuation and Emergency planning measures.

[**Action:** The MoJS/CWC in collaboration with Expert Institutions and consultation with State/UT Disaster Management Authorities]

v) **Awareness programme on GLOF/LLOF hazard:** Government (National/ State) has also emphasized on a robust awareness programme for GLOF/LLOF hazard. Public awareness is being enhanced about signs and events that manifests that a GLOF/LLOF is imminent so that personal safety measures may be taken.

[**Action:** The MoJS/CWC, NDMA and State/UT Disaster Management Authorities in consultation with Expert Institutions]

vi) **Use of traditional art forms/ traditional knowledge:** Due to modernization and tech savvy nature of 21stcentury generation, old traditions disaster management practices are dying up. Therefore, it is necessary to document and disseminate old traditional best practices available in mountain regions of India through community participation in trainings. Traditional art forms are important mediums of awareness generation. Traditional knowledge and modern technologies are also useful in designing Early Warning System (EWS).

[**Action:** The MoJS/CWC, NDMA and State/UT Disaster Management Authorities in consultation with Expert Institutions]

vii) **Awareness through Participatory Approach:** The planning and implementation process is recommended in order to maintain sustainability of the programs launched by the administration for disaster management. It is necessary that the government and the communities together evolve a joint action plan aimed at enhancing community education and the development of community leadership. The elements of participatory learning can be applied at different levels such as organizational level (headquarters, branches, schools, businesses, work places), community level (village, town, cities) and population level (marginalized, vulnerable sections).

[**Action:** The MoJS/CWC, NDMA and State/UT Disaster Management Authorities in consultation with Expert Institutions]

viii) **Involvement of Not-for-Profit Organisations:** NDMA should identify not-for-profit organisations to undertake the awareness building activities in these States. The organisation should be asked to submit a targeted awareness generation plan.

[**Action:** The MoJS/CWC, NDMA and State/UT Disaster Management Authorities in consultation with Expert Institutions]

ix) **Awareness among school children, their parents and teachers:** The not-for-profit organisations can organise sessions for school children, their parents and teachers from Class IX onwards on various aspects of GLOF/LLOF occurrence and their mitigation. A one-day training module can be designed for the participants.

[**Action:** The MoJS/CWC, NDMA and State/UT Disaster Management Authorities in consultation with Expert Institutions]

x) **Awareness among local youth:** The not-for-profit organisation can hold a day long awareness generation camp with the members of the National Cadet Corps (NCC), Scouts and Guides, and National Service Scheme (NSS) volunteers. These camps should be conducted in coordination with the state and district teams of these organisations.

[**Action:** The MoJS/CWC, NDMA and State/UT Disaster Management Authorities in consultation with Expert Institutions]

xi) **Awareness among members of Panchayati Raj Institutions:** On similar lines; the not-for-profit organizations can also hold a one-day awareness generation workshop for the Panchyati Raj Institution (PRI) members of the various panchayats in the district in the district headquarter. The Community Based Family Disaster Preparedness and mitigation (CBFDP) is a process to capacitate communities to prevent, mitigate and cope with disasters effectively.

[**Action:** The MoRD and State/UT Disaster Management Authorities in consultation with Expert Institutions]

xii) **Awareness among policy makers and government officials:** The policy makers are key stakeholders in disaster management. State Disaster Management Authority (SDMA) can hold workshops with policy makers and government officials of all departments to reinforce their role in ensuring that people conform to the various land use policies.

[**Action:** The MoJS/CWC, NDMA and State/UT Disaster Management Authorities in consultation with Expert Institutions]

xiii) **National Data Centre on GLOF/LLOF:** It would integrate various data sources, a geo-portal to address the data needs and thus, enable an effective response.

[**Action:** The MoJS/CWC in consultation with NRSC-ISRO]

xiv) **Climate Change related GLOF/LLOF risk management:** The past incidences clearly indicate the high frequency as well as intensity of the hydro-meteorological hazards in the mountain region such as heavy rainfall, landslides, riverine floods, cloud burst, Glacial Lake Outburst Floods (GLOFs), droughts etc. Therefore, local communities require awareness, specialized training and right information to cope up with disasters in the mountains.

[**Action:** The MoJS/CWC, NDMA, NIDM and State/UT Disaster Management Authorities in consultation with Expert Institutions]

Section 7.11 of NDMP (2019) may also be referred for any other specific responsibilities of Central/ State agencies related to GLOF.

10.2 IMPLEMENTATION AND MONITORING

10.2.1 Institutional Mechanisms

The National Disaster Response Force (NDRF)/SDRF mandated by the DM Act, 2005, will address, in close collaboration with all other field level agencies, all concerns regarding the response to the threat of GLOF/LLOF disaster or other disasters if and when these arise or occur.

The NDRF/SDRF personnel will be equipped with the most modern search and rescue equipment and will undergo GLOF/LLOF specific training to be able to effectively deal with diverse types of GLOF/LLOF and other mass movements and familiarise themselves with the case records of some of the major GLOF/LLOF events.

The projects prepared by the central ministries, departments, state governments, district authorities, rural bodies, urban local bodies, and other stakeholders in accordance with these Guidelines will be implemented by them in accordance with in-built schedules. These plans will indicate clearly the structure of the monitoring as per Govt. of India norms and the reports to be generated at various levels together with the agency to which the report is to be sent, its format and the frequency/timing.

10.3 FINANCIAL ARRANGEMENTS

10.3.1 Mainstreaming of Disaster Management in Developmental Plans

The central and state ministries/ departments will mainstream disaster management efforts in their developmental plans. In the annual expenditure plans, specific allocations will be made for carrying out disaster awareness programmes, maintaining preparedness and for undertaking mitigation efforts. Wherever necessary and feasible, the corporate sector should also be involved in supporting risk management efforts as part of Corporate Social Responsibility (CSR).

10.3.2 Plans of Central Ministries/ Departments

The various measurement for GLOF management recommended in the Guidelines will be funded by the central ministries/ departments and state governments concerned by making provisions in their Five-Year and annual plans. Additional funds will also be made available through special mitigation projects to be formulated and implemented by the state governments/SDMAs under the overall guidance and supervision of the NDMA. Besides this, 10 per cent of the Calamity Relief Fund (CRF) could also be utilized for the purchase of equipment for GLOF preparedness and mitigation, and for rescue and relief operations.

[**Action:** SDMAs in collaborations with Central Ministries]

10.3.3 State Plans

GLOF management schemes would be

planned, funded, executed and maintained by the state government themselves as per their own priorities. Central plan assistance would be in the form of block loans and grants and would not be tied to any sector or project. Allocations for the GLOF sector within the overall plan outlay would have to be made by the state government themselves. The various measures for GLOF management recommended in these Guidelines will be included by the respective state government in their own plans.

[**Action:** State governments/SDMAs]

10.3.4 Centre for Glacial Research, Studies & Management (CGRSM)

A national level ***Centre for Glacial Research, Studies and Management (CGRSM)*** will be established by the MoJS under the umbrella of the National Institute of Hydrology (NIH), Roorkee as a premier centre with state-of-the art facilities, which would eventually grow into a national centre of excellence. It will be fully autonomous in its functioning, similar to that of the national laboratory of the Council of Scientific and Industrial Research with full operational freedom and an independent budget. It will operate within a framework of specified rules. The CGRSM will be headed by an eminent expert with a proven track record.

This initiative will help in ensuring a wider view of glacial studies as a component of the environment/climate change and bringing the existing pool of expertise in earth sciences including hydrology, geomorphology, seismology, meteorology, landslide, IT etc. to bear upon this new initiative.

The national centre will be serviced by a nation-wide chain of actual as well as virtual sub-centres (field offices) in high-altitude to ensure adequate national coverage, information flow, community participation, networking, feedback etc. It will also foster, promote and sustain a scientific culture in the glacial studies including GLOF/LLOF aiming for a paradigm shift in the culture of prevention and safety. It will aim to galvanise the existing scattered pool of scientific and technological expertise especially in subjects such as geomorphology, earth sciences, meteorology, seismology, space research, IT and communication technology, urban development, remote sensing etc. Other areas of concern to be addressed by the centre will be to learn lessons from past incidences and arranging for high quality education, research, training and documentation. To begin with sub-centres (field offices) will as far as possible, be located in one of the existing knowledge institutions to be identified in consultation with the State Government. The network could be gradually expanded in tune with the dynamics of felt needs. The establishment of virtual sub-centres will be encouraged to serve as clearing houses of information. The national capacity building initiative of the central and state governments would make adequate funding provisions to ensure a critical mass of staffing and infrastructure in the field offices, The CGRSM will nurture the field offices, eventually making them financially self-supporting within the time frame of one decade.

In the field of geotechnical investigation and research, the CGRSM will coordinate and collaborate with the national and international Institutions such as Wadia Institute of Himalayan Geology (WIHG), NCPOR-Goa, NRSC-ISRO, IIRS-ISRO, SASE-DRDO, Zurich University, SLF DAVOS, NGI etc, as well as scientific organizations such as the Standing Group on Glacier and Permafrost Hazards in Mountains (GAPHAZ) of the International Association of Cryospheric Sciences (IACS) and the International Permafrost Association (IPA).

[**Action:** The MoJS in consultation with NDMA]

10.3.5 Centrally Sponsored/Central Sector Schemes

The role of the central government is advisory, promotional and facilitative in nature. On specific requests from the state governments, the MoJS/CWC will include some of the works / schemes in consultation with NDMA and Technical Advisory Committee (TAC) as recommended in the Guidelines for funding under these schemes, provided that sufficient funds are available. A high level scientific and TAC which will be chaired by the Secretary, MoJS will be constituted by the MoJS in consultation with the NDMA to serve as a think tank to nurse the glacial studies with cutting edge science and technology, fresh ideas and stimulus.

TAC will also make recommendations to the GoI on various aspects of the CGRSM including its formation, aims and objectives, funding, functioning and autonomy.

The Joint Secretary, NDMA; Joint Secretary, MoEFCC; Joint Secretary, MoES; Joint Secretary, MoJS; Joint Secretary, DST and Executive Director of the NIDM will be ex-officio members of both CGRSM and TAC.

[**Action:** The MoJS-CWC]

The TAC will comprise top professionals (either national or international) drawn from multi-specialty streams of Government, Private, Independent researchers connected with glacial studies including GLOF/LLOF and it will address research, human resource and capacity development, glacial mapping, investigation, mitigation, control, preservation and protection of glacier as a component of the environment.

It will also provide full support to the human resource development and training functions delegated to the NIDM and other national institutions.

[**Action:** The MoJS in consultation with the NDMA and MoEFCC]

10.3.6 District Planning and Development Council Funds

From the funds available with the District Planning and Development Council in GLOF prone areas, a part will be allocated for the implementation of GLOF management schemes in the districts.

[**Action:** State/UT Admin]

10.3.7 Comprehensive and Pilot National GLOF Mitigation Projects

The NDMA has proposed to take up a pilot and Comprehensive Mitigation Project on GLOF (CMP-GLOF) whose aims and objectives will be developed and finalized in due course. In a broader sense, it will consider the following issues:

i) Assessment of the risk and vulnerabilities associated with GLOF disasters.
ii) Reduction in the degree of the risk, severity or consequences of GLOF and improving their mitigation.
iii) Setting pace setter examples for geological and geotechnical investigations of GLOF and also for efficacy of GLOF treatment measures.
iv) Establishment of monitoring and early warning systems for susceptible glacial lakes.
v) Capacity development of institutes/ organizations enhancing the capabilities of communities and training of functionaries.
vi) Identification of institutes/ organizations and entrusting them with the implementation of R&D programs.
vii) Enhancing the promptness and efficacy of response to impeding threats of GLOF or their actual occurrence.
viii) Ensuring that proper arrangements are made for organizing rescue, relief and rehabilitation works.
ix) Improving the quality and increasing the speed of rehabilitation and reconstruction process.
x) Spreading awareness with a stress on preparedness and providing advice and training to the agencies involved in the management of GLOF.

[**Action:** The NDMA in collaboration with MoJS/CWC]

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Appendix 1

Factors to be considered under an assessment of ice avalanche susceptibility/stability (from GAPHAZ 2017)

Susceptibility factors for Ice Avalanches	Relevance			Key Attributes	Susceptibility		Assessment methods	Assessment scale
	Con.	Trig.	Mag.		Lower	Higher		
Atmospheric								
Temperature	+	+		Mean temperature	No trend	Strong trend	Station-based or gridded climate analyses	Basin
				Intensity and frequency of extreme temperatures	Low	High	Station-based or gridded climate analyses	Basin
Precipitation		+		Intensity and frequency of extreme precipitation events.	Low	High	Station-based or gridded climate analyses	Basin
Cryospheric								
Thermal conditions	+			Cold, polythermal or temperate glacier. Distribution and persistence of permafrost. Thermal anomalies due to hanging glaciers.	Expert judgement of implications for failure mechanisms and processes.		Model-based (indirect) Geophysical (semi-direct) Boreholes (direct)	Regional to basin. Site specific.
Glacier type	+		+	Cliff or ramp type situation.	Expert judgement of		Remote sensing	Regional

					implications for frequency/magnitude.			to basin
Crevasse density and orientation	+		+	Formation of cracks across glacier. Size and depth of crevasses.	Not evident	Large and widespread	Remote sensing	Basin to site specific
Bed topography	+			Steep slope angle and sudden breaks in topography. Convex slopes. Lack of frontal abutment.	Favorable	Unfavorable	Inferred or modelled from surface topography. Geophysical survey.	Regional to basin. Site specific.
Glacial hydrology	+	+		Distributed subglacial drainage system for ramp-type failures. Evidence of increased water pressure and or blockages (critical for polythermal glaciers), such as pooling at surface or sudden changes in discharge for large catastrophic failures.	Favorable	Unfavorable	Remote sensing, hydrological modelling, and field studies.	Basin to site specific.
Glacier velocity	+			Increase in surface velocity, particularly below crevasse zones.	No change	Rapid increase	Remote sensing, field studies	Basin to site specific
Glacier geometric change	+			Thickening towards base of hanging glacier. Thickening of valley glacier tongue as evidence for surging.	No change	Large thickening	Remote sensing	Basin to site specific
Glacier length change	+			Retreating or advancing towards steeper topography, and/or new thermal regimes.	Favorable	Unfavorable	Remote sensing, field studies, anecdotal evidence	Regional to basin
Ice avalanches	+	+	+	Frequency and magnitude of instabilities, including serac fall.	Not evident	Frequent and increasing	Remote sensing, field studies, anecdotal	Basin to site specific

evident						activity	evidence.	
Geotechnical and geomorphic								
Underlying bedrock stability	+	+	+	SEE ROCK AVALANCHE SUSCEPTIBILITY ASSESSMENT (Appendix 2)	Unstable	Stable	SEE ROCK AVALANCHE SUSCEPTIBILITY ASSESSMENT	Basin to site specific
Seismicity	+	+		Potential magnitude & frequency, ground acceleration	Low potential	High potential	Geological mapping & modelling.	Regional

Appendix 2

Factors to be considered under an assessment of rock avalanche susceptibility/stability (from GAPHAZ 2017)

Susceptibility factors for Rock Avalanches	Relevance			Key Attributes	Susceptibility		Assessment methods	Assessment scale
	Con.	Trig.	Mag.		Lower	Higher		
Atmospheric								
Temperature	+	+		Mean temperature	No trend	Strong trend	Station-based or gridded climate analyses	Basin
				Intensity and frequency of extreme temperatures	Low	High	Station-based or gridded climate analyses	Basin
Precipitation		+		Intensity and frequency of extreme precipitation events.	Low	High	Station-based or gridded climate analyses	Basin
Cryospheric								
Permafrost conditions	+		+	State of permafrost, distribution and persistence within bedrock slopes. Depth of active layer and unstable mass.	No permafrost or cold permafrost	Warm (melting) permafrost	Model-based (indirect) Geophysical (semi-direct)	Regional to basin. Site specific.
Glacier conditions	+		+	Retreat (thinning) from within or below rock slope.	No retreat	Significant retreat	Remote sensing, field studies, anecdotal	Regional to basin

							evidence	
Geotechnical and geomorphic								
Rock mass quality	+		+	Lithological characteristics Degree of weathering	Favorable	Unfavorable	Geological mapping (remote sensing or field)	Basin to site specific
Condition of Discontinuities	+			Degree of weathering, aperture, filling (e.g. breccia or gouge), seepage	Favorable	Unfavorable	Geological mapping (remote sensing or field)	Basin to site specific
Geometry of Discontinuities	+		+	Dip, orientation, spacing, persistence	Favorable	Unfavorable	Geological mapping (remote sensing or field)	Basin to site specific
Condition of slope	+			Overhanging, convexities, irregularities	Favorable	Unfavorable	Geological mapping (remote sensing or field)	Basin to site specific
Slope angle	+			Topographic slope angle. Critical range or threshold angle established from local inventories.	Low slope angle	Steep slope angle	Geological mapping (remote sensing or field)	Basin to site specific
Slope height	+		+	Relative relief of the face or slope	Small	Large	Geological mapping (remote sensing or field)	Basin to site specific
Seismicity	+	+		Potential magnitude & frequency, ground acceleration	Low potential	High potential	Geological mapping &modelling.	Regional
Rockfall evident	+	+	+	Frequency and magnitude of past activity	Not evident	Frequent and increasing activity	Geological mapping (remote sensing or field)	Basin to site specific

Appendix 3

Factors to be considered under an assessment of GLOF susceptibility (from GAPHAZ 2017). Factors may be relevant for conditioning (Con.), triggering (Trig.), and/or the magnitude (Mag.) of any GLOF. For many factors, relationships with suscep tibility or stability are not straightforward, and the expert must apply judgement across a range of attributes to determine whether conditions are favourable (low susceptibility) or unfavourable (high susceptibility)

Susceptibility factors for GLOFS	Relevance			Key Attributes	Susceptibility		Assessment methods	Assessment Scale
	Con.	Trig.	Mag.		Lower	Higher		
Atmospheric								
Temperature	+	+		Mean temperature	No trend	Strong trend	Station-based or gridded climate analyses (e.g. IMD)	Basin
				Intensity and frequency of extreme temperatures	Low	High		
Precipitation	+	+		Intensity and frequency of extreme precipitation events (inc. snowfall).	Low	High	Station-based or gridded climate analyses (e.g. IMD or GPM-IMERG)	Basin
Cryospheric								
Permafrost conditions	+			State of permafrost, distribution and persistence within lake dam area and bedrock surrounding slopes	No permafrost or cold permafrost	Warm (melting) permafrost in dam area and/or surrounding	Model-based (indirect) Geophysical (semi-direct)	Regional to basin. Site specific.

						debris or bedrock slopes		
Glacier retreat and downwasting	+		+	Enlargement of proglacial lakes, enhanced supraglacial lake formation, dam removal or subsidence	No retreat, lake expansion, or dam subsidence	Significant retreat, lake expansion, or dam subsidence	Remote sensing	Regional to basin
Advancing glacier(incl. surging)	+			Formation of ice-dammed lakes	No change evident	Advance and damming evident	Remote sensing	Regional to basin
Ice avalanche potential	+		+	SEE ICE AVALANCHE SUSCEPTIBILITY ASSESSMENT (Appendix 1)	Lower	Higher	SEE ICE AVALANCHE SUSCEPTIBILITY ASSESSMENT	Basin to site specific
Calving potential	+		+	Width of glacier calving front, activity, crevasse density	Not evident	Large and frequent	Remote sensing and field studies.	Basin to site specific
Lake size	+		+	Area or volume	Smaller	Larger	Remote sensing, modelling of bed topography, field studies	Regional to site specific
Lake bathymetry	+		+	Influence on dam hydraulics, influence on displacement wave propagation and run-up	Favorable	Unfavorable	field studies (sonar measurements)	Site specific
Sub- Supra- or englacial drainage	+	+		Connectivity of the lake to the glacial hydrological system	Not connected	Well connected	Field studies and modelling	Site specific

Geotechnical and geomorphic								
a) Dam characteristics								
Type	+		+	Bedrock, moraine, ice	Bedrock	Ice, (ice-cored moraine)	Remote sensing	Regional to basin
Ice-cored moraine	+			Thickness, persistence, and condition (linked to permafrost)	Absent	Large and thawing	Geophysical field studies	Site specific
Dam width to height ratio	+		+	Width across the dam crest relative to the dam height	Larger	Smaller	DTM analysis, field studies	Basin to site specific
Freeboard to dam height ratio	+		+	Elevation difference between lake surface and lowest point of moraine.	Larger	Smaller	Remote sensing, DTM analysis, field studies	Basin to site specific
Lithology	+		+	Coarseness of moraine material, presence of fine-grained material, volcanic material etc.	Coarse material predominant	Fine-grained or volcanic material predominant	Field studies	Site specific
Downstream slope	+			Mean slope on downstream side of lake dam.	More gentle	Steeper	DTM analysis, field studies	Basin to site specific
Vegetation and anthropogenic disturbance	+			Density and type of vegetation (grass, shrubs, trees). Destabilizing effects of anthropogenic activities.	Widespread	Absent	Remote sensing, field studies	Basin to site specific
b) Catchment topography and hydrology								
Catchment area	+			Total size of drainage area upstream of catchment, proportion	Smaller	Larger	DTM analysis	Regional to basin

				glaciated/non-glaciated				
Mean slope	+			Steepness of catchment area	More gentle	Steeper	DTM analysis	Regional to basin
Drainage density	+			Density of the stream network in catchment area	Lower	Higher	DTM analysis	Regional to basin
Stream order	+			Presence of large fluvial streams, facilitating rapid drainage into lake	No or low order only	Large high order streams evident	Remote sensing, DTM analysis	Regional to basin
Upstream lakes	+			Presence and susceptibility of upstream lakes.	Absent	Several lakes	Remote sensing	Regional to basin
c) Geotechnical stability								
Rock avalanche potential	+		+	SEE ROCK AVALANCHE SUSCEPTIBILITY ASSESSMENT (Appendix 2)	Lower	Higher	SEE ROCK AVALANCHE SUSCEPTIBILITY ASSESSMENT	Basin to site specific
Moraine instabilities	+		+	Potential for landslides from moraine slopes into the lake	No steep moraine slopes adjacent to lake	Steep, unstable moraine slopes adjacent to lake.	DTM analysis, remote sensing, field work, geophysical investigations	Basin to site specific
Seismicity	+			Potential magnitude & frequency, ground acceleration	Lower	Higher	Geological mapping & modelling (e.g. GSHAP)	Regional

Composition of Task Force

	Shri. Sandeep Poundrik IAS	**Joint Secretary (Mitigation Division), NDMA**	**Chairman**
1.	Dr. Ravinder Singh	Senior Consultant (Landslide and Avalanche), NDMA, New Delhi	Convener
2.	Dr. Sanjay K. Jain	Scientist - G, National Institute of Hydrology, Roorkee	Member
3.	Dr. A. K. Lohani	Scientist - SG, National Institute of Hydrology, Roorkee	Member
4.	Dr. D. P. Dhobal	Scientist - F, Wadia Institute of Himalayan Geology, Dehradun	Member
5.	Dr. Kapil Gupta	Professor, Deptartment of Civil Engineering, Indian Institute of Technology, Mumbai	Member
6.	Dr. Simon Allen	Department of Geography, University of Zurich, Switzerland	Member
7.	Dr. Holger Frey	Department of Geography, University of Zurich, Switzerland	Member
8.	Dr. Surya Prakash	Head - Geo-metrological Risk Management Division, National Institute of Disaster Management, New Delhi	Member
9.	Dr. Praveen Thakur	Sc./ Er. - SF, Indian Institute of Remote Sensing - Indian Space Research Organisation, Dehradun	Member
10.	Dr. Irfan Rashid	Asstistant Professor, Kashmir University, Kashmir	Member
11.	Sh. B. G. Prusty	Scientist - G, Defence Terrain Research Laboratory - DRDO, New Delhi	Member
12.	Sh. Rakesh Mishra	Suptd. Geologist, Geological Survey of India, Lucknow	Member
13.	Dr. Parmanand Sharma	Scientist- E, National Centre for Polar and Ocean Research -Goa	Member

14.	Dr. B. Simhadri Rao	Scientist - SG, National Remote Sensing Centre, Hyderabad	Member
15.	Dr. S. S. Randhawa	Principal Scientist,Himachal Pradesh Council for Science, Technology, and Environment, Himachal Pradesh	Member
16.	Dr. Dericks P. Shukla	Asstistant Professor, School of Engineering, Indian Institute of Technology -Mandi	Member
17.	Dr. Gaurav Bhutani	Asstistant Professor, School of Engineering, Indian Institute of Technology -Mandi	Member
18.	Sh. K. K. Joadder	Former Chief Planner (Retd.), Town and Country Planning Organisation, Delhi	Member
19.	Sh. Ajay Kumar Sinha,	Director, Morphology & Climate Change Directorate, Central Water Commission, New Delhi	Member
20.	Er. Kireet Kumar	Scientist - G, G.B. Pant National Institute of Himalayan Environment-Almora	Member
21.	Dr. Harendra Singh Negi	Scientist - F, Snow and Avalanache Study Establishment - DRDO, Chandigarh	Member
22.	Ms. Lalthanpari	Scientist - E, Bureau of Indian Standards	Member

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Contact Us

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