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Summary for Policy Makers

on

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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Executive Summary

Glacial retreat due to global warming occurring in most parts of the Hindu Kush Himalaya, has given rise to the formation of numerous new glacial lakes which bear the potential for disastrous glacial lake outburst floods (GLOFs). Since glaciers in the Himalayas, as in all mountain ranges of the world, are retreating, new glacial lakes are forming and existing lakes are growing, posing a potentially large risk to downstream infrastructure and life. As glaciers retreat, the formation of glacial lakes takes place behind moraine, rock or ice dam. In particular moraine dams, which is the most common dam type in the Himalayan region, are potentially weak and can breach suddenly, leading to a discharge up to millions of cubic meters of water and debris. Such outbursts, known as GLOFs, have the potential for causing catastrophic flooding downstream.

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 and thus may have high hazard potential, whereas rock dam's lakes have little chances of breaching and thus have a lower hazard potential. These floods pose severe geomorphological hazards and risks and can wreak havoc on all man-made structures located along their path. Much of the damage caused during GLOF events are associated with large amounts of debris / boulders that accompany the floodwaters. GLOF events have resulted in many deaths, as well as the destruction of houses, bridges, forests, and roads as experienced in the Kedarnath tragedy (June, 2013). Unrecoverable damage to settlements and farmland can take place at large distances from the outburst source. In most of the events livelihoods are disturbed for long periods.

As a result, the threat of glacial lake outburst flood (GLOF) in particular is receiving increased attention and awareness for glacial lake monitoring and hazard mitigation has increased recently. In this regard, National Disaster Management Authority (NDMA) in collaboration with Swiss Agency for Development and Cooperation (SDC), Embassy of Switzerland India prepared a guideline document on the Management of Glacial Lake Outburst Floods (GLOFs) to take appropriate actions and measures by the concerned Ministries / Departments and other stakeholders.

Here, a concise summary of the guidelines document is provided, highlighting key messages and recommendations for decision and policy-makers. For further details the full NDMA Guidelines may be referred. This document in summarized form provides a general outline of glaciers and glacial lakes including factors contributing to glacial hazards. It covers the hazards and risk zonation mapping, risk reduction and mitigation measures which are an important part of the disaster management are. In brief, this document summaries the aspect of awareness and preparedness including community and medical preparedness, along with capacity building. Disaster response such as emergency search and rescue, emergency relief, post-disaster damage, and need assessment, etc. have been covered. Research & development, regulation and its enforcement covering planning, techno-legal regime, and technical audits, etc. on the GLOFs has been captured as a progressing element here. Finally, this summary enumerates the action plan and implementation of the guidelines.

CONTENTS

1. INTRODUCTION

In the Himalayas, just as in other mountain ranges of the World, climate change is leading to melting of glaciers among other impacts. Melting of glaciers often leads to the formation and growth of new glacial lakes. Outbursts of such glacial lakes have caused devastation in mountain regions all over the world, including within the Indian Himalayan Region (IHR). Continued climate change is expected to alter and potentially increase the likelihood of lake outbursts in the future, as glacial lakes grow in size and number, stability of steep slopes is weakened due to changes in thermal and mechanical conditions, and heavy rainfall increases landslide activity. All these impacts could result in historically unprecedented hazard and risk situations for human life and property. This requires development of future oriented process and modeling based assessment strategies and implementation of fail-safe solutions. To meet related disaster management challenges, NDMA has prepared a guideline document that provides a framework for the management of glacial hazards and risks, with a particular focus on glacial lake outburst floods (GLOF).

GLOF is a term used to describe a sudden release of water retained in a glacial lake that can be located in front, at the side, underneath, within, or on top of a glacier. Large lakes located in front of the glacier are mainly dammed by loose moraine (glacial debris left behind after the ice has retreated), and these lakes are generally considered to be potential flood sources. 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 of three great rivers, 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 numbers of 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 1.

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[1] *Lake outburst can be triggered by several factors such as ice or rock avalanches, the collapse of the moraine dams due to the melting of ice buried within, earthquakes or sudden inputs of water into the lake e.g. through heavy rains or drainage from lakes further up the glacier. Lake outbursts lead to sudden release of large volumes of water in very short interval of time resulting in flooding in the downstream areas.*

[2] *Raina,V.K. and Srivastava D. 2008: Glacier atlas of India. Bangalore, Geological Society of India. 315pp. ISBN -13: 978-8-185-86780-9.*

Table 1: Summary of Glacier Inventory of the Himalayan Regions (India and Environs) and their distribution in the Indus, the Ganga and the 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, 2011.*[3]

GLOFs are recognized in the National Disaster Management Plan (NDMP) 2019 of India as a potential climatological disaster, however there is a wide variation in the extent to which glacial hazards and risks are addressed in the disaster management plans of the Himalayan states. Recognizing the growing threat across the Himalaya, the main objectives of the NDMA guidelines is to generate awareness on various aspect of glacial hazards in India, and to outline suitable actions to reduce the associated risks. Accordingly, the guidelines aim to improve administrative responses, drawing on international best practices and bringing together the relevant scientific capabilities of the nation to eliminate potential losses from glacial hazards.

[3] *ISRO, 2011. 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. (available at: http://www.moef.nic.in/downloads/public-information/Discussion_Paper%20-%2013th%20June.pdf.)*

2. HAZARD AND RISK MAPPING

Due to rapid environmental changes, the assessment of glacial hazards and risks can no longer only rely on experiences from the past. Particularly for GLOFs, with potentially far-reaching downstream impacts, ***district to state level regular monitoring and assessment*** *of hazard and risk is required to keep pace with* ***rapidly changing*** *environmental conditions. For critical situations,* ***scenario-based, future-oriented hazard and risk mapping*** *is required, considering the full range of environmental and socio-economic conditions and their dynamics. {Chapter 3}*

A robust hazard and risk assessment provide the basis for prioritising, designing, and implementing risk management strategies, and is therefore considered to be a **cornerstone of Disaster Risk Management (DRM)**. Today, under the influence of global warming and rapidly changing environmental conditions, there is an urgent need for up-to-date information to define the possible size and frequency of hazards in mountain regions, and identify vulnerable and exposed communities and infrastructure.

A comprehensive framework guides the risk assessment process, distinguishing between two primary levels (**Fig. 1**): (1) **First-order assessment at a national, state, or district scale** provides a preliminary overview of risk hotspots where further investigation and prioritization can be focused;(2) **the detailed risk assessment for a specific location or community** provides the basis for the design and implementation of diverse risk management options.

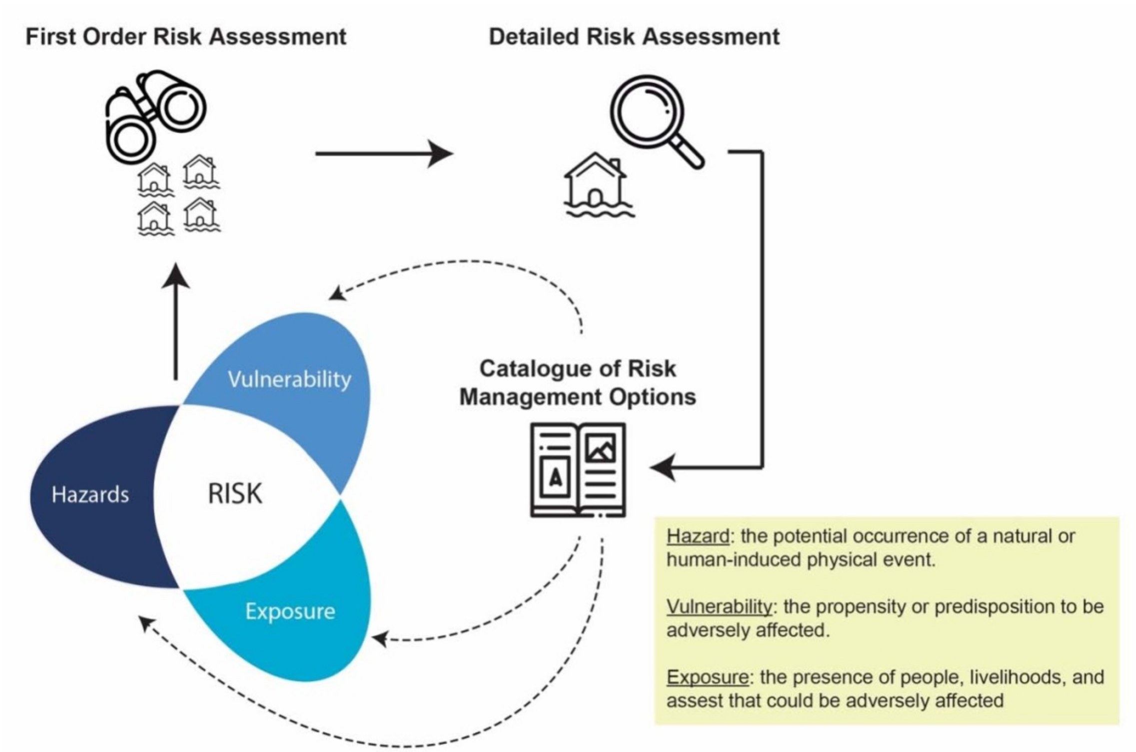

Fig. 1*: Framework for glacial-related risk management recognizing hazards, vulnerability and exposure as the key drivers of risk.*

Regular monitoring of glacial lakes using satellite observations is crucial for maintaining an up-to-date lake inventory for first-order GLOF risk assessment. Ideally, annual updating of lake inventories should be undertaken, particularly in monsoon affected areas where landslide dammed lakes are also a primary concern, while the length of time between comprehensive mapping efforts should not exceed 5 years. In rapidly melting glacial environments, **new lakes can emerge very quickly**.

A key challenge facing decision-makers is that various GLOF studies and reports can provide inconsistent findings. **A standardized approach to monitoring**, categorizing and prioritizing potentially dangerous lakes at national, state and district level is required to **support decision-making**. The Kedarnath tragedy of 2013 highlighted that **even very small lakes can be extremely dangerous**. In fact, the size of a lake is only one of several factors (atmospheric, cryospheric, and geotechnical) that need to be considered in a comprehensive assessment of lake stability and susceptibility.

Multiple lines of evidence (including both scientific publications and detailed field studies by local authorities) show a number of potentially critical, high priority lakes located across the IHR that threaten people and their communities (**Fig. 2**). Out of 25 such lakes, 13 are located in Sikkim, 5 in Himachal Pradesh, 4 in Ladakh and Jammu-Kashmir, 2 in Uttarakhand and 1 in Arunachal Pradesh. Besides human settlements, also cropland, roads and hydropower installations are also threatened across all states.

Regional cooperative initiatives should be considered regarding **lakes located upstream in Tibet**, and to a lesser extent in Nepal, as these lakes can threaten the IHR. **Early identification of such transboundary threats is important**, to enable timely communication and exchange of information between neighboring countries.

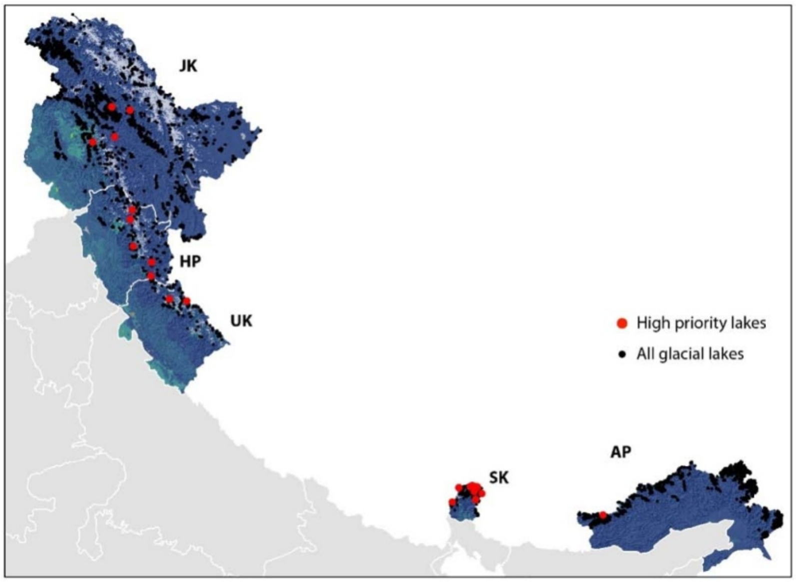

***Fig. 2**: Overview of glacial lake distribution and lakes considered by multiple studies and investigations to be of high priority*[4]

[4] *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/*

Where potentially critical, high priority lakes are identified, detailed hazard and risk assessments should be undertaken, combining sophisticated hazard modelling and mapping with anon-ground assessment of vulnerability and exposure to generate local hazard and risk maps. **Field studies are crucial to establish conditions of the lake** (depth, volume), the dam characteristics (composition, geometry, stability, etc.), and to engage with potentially affected downstream communities.

For hazards such as GLOFs originating in high mountain environments, **it can be difficult to determine the possible size and likelihood of an outburst occurring**, not least because glacial environments are changing rapidly and observations from the past may not hold true for the future. Hence, **a semi-qualitative approach is recommended** whereby **scenarios of three different event magnitudes** (e.g., small, medium, and large) are linked to corresponding **best estimates of the likely probability** of these events occurring (**Fig. 3**).For example, in the case of a moraine-dammed lake, a large scenario could involve the release of the entire lake volume in a case where the dam is completely eroded. Outburst scenarios are developed based on expert analyses of the susceptibility and stability of the lake.

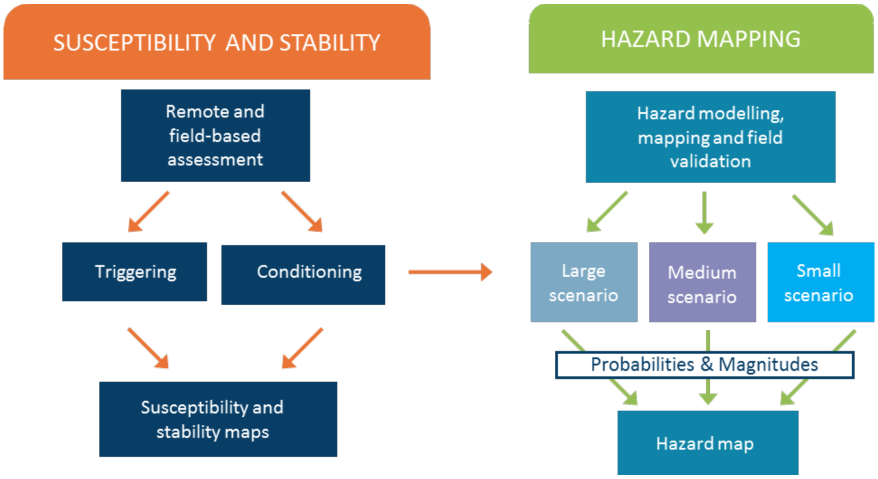

***Fig. 3**: Framework for the assessment and mapping of glacial hazards, drawing on international best practices.*

Various **numerical modelling tools are available for simulating the flow of the GLOF downstream**, where hazard levels can be categorised based on simulated flow heights and velocities. There is no best-approach, and **selected models should align with the local requirements, capacities, resources, and data availability**. Likewise, the implications of the final classified hazard zones and appropriate management responses, including land-use regulations will vary based on the local societal, governance, and legal context.

In view of **possible extreme outburst events** characterized by very low probabilities but very large potential societal impacts, the inclusion of **a "worst-case" scenario is recommended**. This could be appropriate, for example, for a very large volume lake that is considered to be relatively stable. Included under this scenario could also be outbursts from anticipated new lakes that may develop in the future. The potential land area affected by such a worst-case event could be **marked as an area of residual danger** in the final hazard map.

3. Monitoring, Risk Reduction and Mitigation Measures

*A **catalogue of risk reduction measures**, both **structural** or **non-structural,** are available and can be implemented as short-term or long-term solutions to reduce the under lying drivers of risk. A pre-requisite for the selection of adequate risk management options is a detailed risk assessment, and knowledge of the socio-economic and cultural situation of the potentially affected population. **Early Warning Systems** are highlighted as a complex, yet very effective cross-cutting strategy to reduce exposure and vulnerability, requiring strong technical and social components.{Chapter 4}*

Risk reduction and mitigation measures can be **effective on each of the three components of risk**, i.e. reduction of hazard, exposure or vulnerability, respectively (**Fig. 4**), and on **different time scales** (short- and long-term measures). A distinction is made between structural measures, consisting of physical remediation structures; and ii) organizational, non-structural measures.

Risk reduction measures, can be **effective on multiple risks**, however they must be carefully implemented in order to **avoid unintended negative effects**. Decision-making on risk reduction measures should involve **cost-benefit evaluations**, i.e. contrasting the costs of a measure (implementation costs plus maintenance costs during the planned lifetime) with the value of the prevented damages.

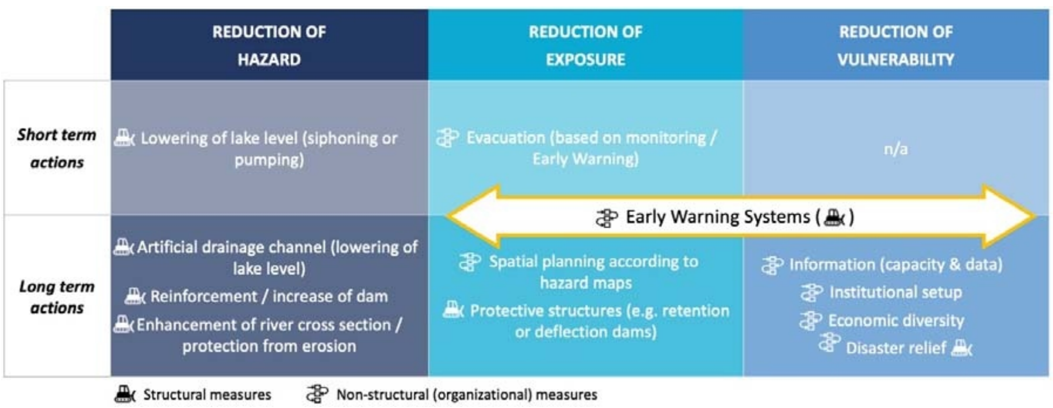

***Fig. 4** : Overview of options for the management of risks related to glacial lakes.*

Spatial planning is among the most efficient and sustainable disaster prevention measures in the long term. Hazard maps provide important tools for such land use planning by preventing (new) constructions in high hazard zones and allowing for the implementation of specific structural risk reduction measures for infrastructure in the medium hazard zones (**Fig. 5**). For spatial planning, all relevant hazardous processes (including those other than GLOF) at the site must be considered.

Experiences and lessons learnt from disaster risk reduction implementation in mountain ranges throughout the World show that the **local population must be closely involved from the beginning in the design, planning and implementation of risk reduction and management strategies** in a transparent collaboration mechanism, building on mutual trust. **Risk perceptions and local knowledge must be respected** and reflected in the risk reduction strategy in order to avoid its ineffectiveness and possible failure.

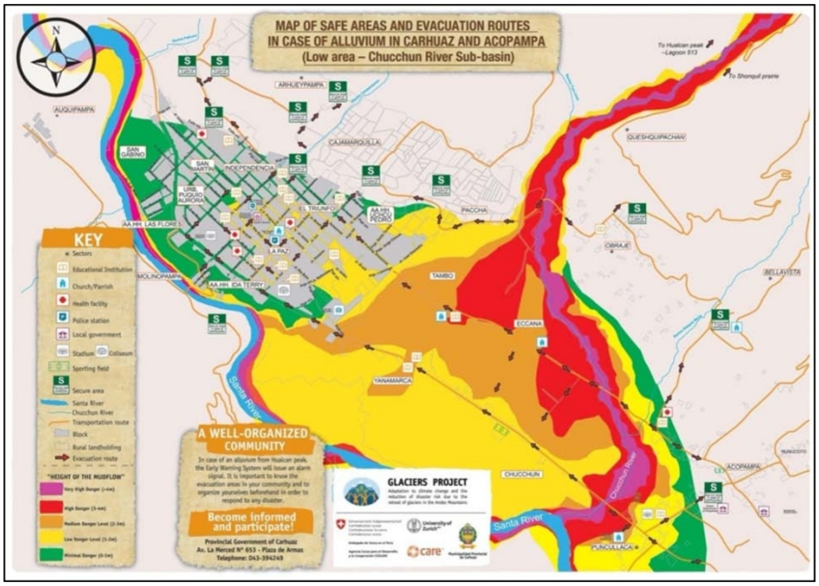

Fig. 5: GLOF hazard map for the city of Carhuaz, Peru, used as a tool for hazard communication. Besides the hazard zones, evacuation routes (arrows) and safety zones (green rectangles with a white S) are indicated (source: CARE Peru).

Early Warning Systems (EWS) are commonly agreed upon as the **most effective approach** to disaster risk reduction in communities that are exposed to climate-related disasters. In fact, early warning has a **prominent role in the international policy agenda** and is aligned directly with Priority 4 of the Sendai Framework on Disaster Risk Reduction (DRR), and UN Sustainable Development Goal (SDG) 13 on Climate Action (target 13.3). According to the international standards on early warning, an EWS consists of the **four key elements** (**Fig. 6**):i) Risk Knowledge; ii) Monitoring and Warning Service; iii) Dissemination and Communication; and iv) Response Capability.

This EWS approach strengthens the entire risk reduction strategy designed around the technical aspects of an EWS, significantly improves its robustness and provides a basis for integrating other critical lakes in the area into the system and allows for the development of a comprehensive multi-risk warning and prevention framework.

***Fig. 6**: Four key elements of Early Warning Systems, according to the UNISDR.*

4. Awareness and Preparedness

***Awareness of GLOFs is typically low** in comparison to other higher frequency, but potentially lower impact hazards. Approaches to building awareness and strengthening preparedness can be **effective on short, mid, and longer time horizons**, and should be tailored to the needs and priorities of different target groups. In particular, attention should be given to **the most vulnerable members of society**, including women, children, disabled, elderly, and marginalised communities. If the potentially affected population is well prepared, this will reduce disaster risk, build resilience, and enhance sustainable development.{Chapter 5}*

Fig. 7: *Mock-drill during disaster management awareness and preparedness at School in Sikkim.*

The main stakeholder is the community in regions vulnerable to GLOFs as they are the first and the last responders to the disaster, as they will witness it firsthand and are the ones who have to deal with its long-term consequences. In addition, travelers, tourists and pilgrims are **target groups for awareness raising campaigns** and initiatives, as they are potentially at risk without local knowledge of historic events and the actual local situation.

- **Short term public awareness strategies** for GLOF risks include initiatives in the areas at risk, such as posters, wall paintings and hoardings, possibly using a common signage across the country. Toll free phone numbers, along with web platforms and apps can be activated in urgent situations for reporting, information, and response. SMS and email-based alerts can be used to make travelers aware of potentially critical situations.
- **Medium term strategies** involve **mainstreaming of GLOF** risks via traditional and online mass media across IHR states. **Databases** of information material can provide a valuable basis for the creation of awareness campaigns, apps, and further activities for increasing preparedness and response capacity. Information and **capacity development** for local Emergency Operation Centers (EOCs) and village task forces for GLOF issues can significantly increase local awareness and preparedness.
- In the **long term**, national awareness campaigns, a **national data center on GLOF** with a related database and platform should be envisaged. **Schools** play a crucial role for long-term awareness improvement, by including climate change impacts and related hazards and risk in their curricula, if possible, also involving the parents. Such school activities should be complemented by awareness campaigns for the local youth, non-profit organizations and special campaigns for women, children, elderly and disabled and marginalized persons, as they are most vulnerable to GLOF disasters.

Frequent workshops with the potentially affected communities, including simulations and mock drills are recommended to increase preparedness. Further, disaster management plans should include overviews of people and assets at risk, access options, safe zones, medical facilities and other rescue and emergency materials, including documentation of hierarchies, responsibilities, deputies and contacts.

5. Capacity Development

A successful and sustainable implementation of the framework for GLOF risk assessment and management requires scientific, management, engineering and institutional capacities, it is essential to develop experiences from events and situations, document and analyse cases, extract lessons learnt and develop best practices. Efforts to develop capacities should focus both on ***training of professionals*** *and practitioners, and* ***strengthening academic education*** *in relevant disciplines from* ***natural and social sciences****.{Chapter 6}*

Tackling the challenges of climate change impacts on natural hazards and risks is a complex challenge, requiring expertise from and collaboration between a large variety of disciplines. **Mainstreaming the topic of GLOFs** and other natural hazards and risks and their management into the education system should be envisaged, in order to develop the required capacity, expertise and **multi-disciplinary skills** within the next generation of experts.

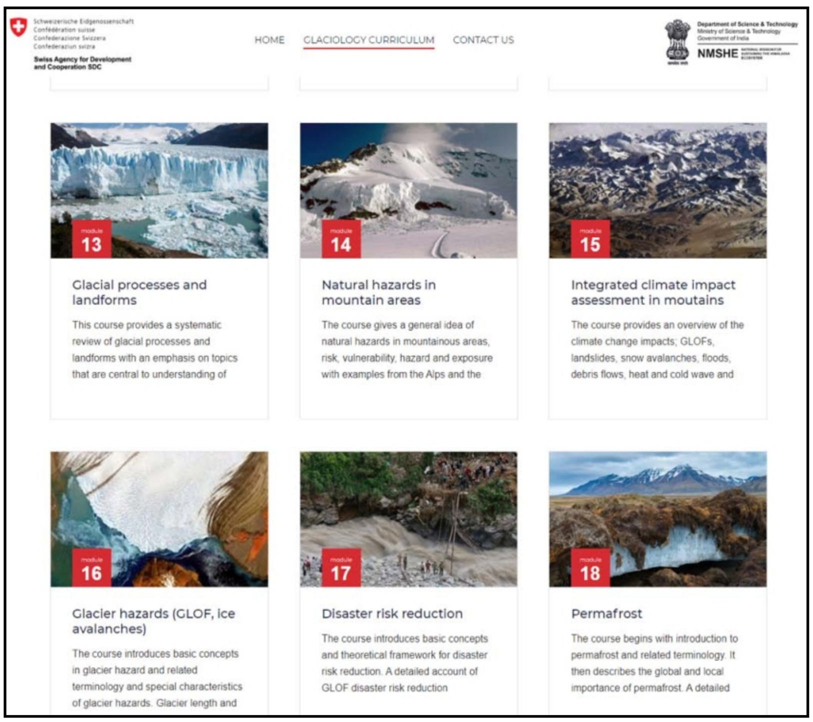

Fig. 8*: Training modules relating to glacier hazards and disaster risk management, produced under the Indo-Swiss Capacity Building Programme on Indian Himalayas Climate Adaptation Programme (IHCAP– 2019- http://glaciology.in/curriculum/).*

For professionals, courses and **workshops** should be organized to familiarize with the topic and to **provide platforms of mutual exchange with other national and international experts**. Such workshops should be used, to present and promote the present guidelines on the management of GLOF risks. For instance, the IHCAP database (cf. **Fig. 8**) provides useful online material on related topics. Since, more frequent occurrences of GLOFs due to rapid change in the climatic system are expected, keeping up to date with the tools and techniques of the subject matter is necessary for efficient management of the catastrophic hazards.

It is recommended to establish a systematic database of past GLOF disasters and emergency situations. Such a database is important in order to extract best practices and lessons learnt from past event, and eventually to further develop and adjust these guidelines according to new insights gained over time. This event database should include the following aspects for each GLOF or LLOF case: observed environmental conditions; assessment of outburst susceptibility and scenarios of possible future developments; institutional roles and responsibilities including communication; risk reduction and mitigation measures undertaken; consequences of the event; a critical reflection and lessons learnt and actions to be taken further.

6. Disaster Response

*GLOF response in India can build on **well-established disaster response procedures** at national, state district, and community levels. Response strategies need to consider a **multi-hazard perspective**, considering that access and evacuation routes, and relief camps could be damaged not only by GLOFs, but also other mountain hazards. In the recovery phase, it is important to **reflect upon lessons** learnt from the event, to ensure long term risk reduction. The SOP on "Averting Threats Emanating from Glacial Lake Outburst Floods (GLOF) in the Indian Himalayan Region" provides detailed actions and steps to be taken by respective authorities in the event of an outburst flood. {Chapter 7}*

Local communities are always first responders in case of a catastrophic event in remote rural areas. Organization of training within those communities is therefore critical to achieve a good response in case of a disaster. Such training and preparation should 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).

First-order response actions include (i) search and rescue operations and (ii) emergency relief measures, including logistics for medical treatment. This **planning** has to consider that in case of GLOF and LLOF disasters, access to affected settlements and sites is often hampered due to the destruction of access roads.

Following emergency response, **post-disaster damage and need assessments** need to be carried out. Also, the event and related response measures should be analyzed critically in order to extract lessons learnt and improve related procedures for future events. Reconstruction works should consider the lessons learnt from past events and follow a build-back-better strategy.

Standard Operating Procedure (SOP) on 'Averting Threats Emanating from Glacial Lake Outburst Floods (GLOF) and Landslide Lake Outburst Flood (LLOFs) in Himalayan Region':

The Standard Operating Procedure (SOP) lays down the guidelines and actions to be taken by the various agencies during the crisis event of disaster. The SOP is implemented in **three stages** which are also discussed in detail in the main guidelines document. The Incident Response System (IRS) for managing the GLOFs and LLOFs in a standardized manner will be effective to incorporate in line with procedures.

1. Stage I - India Meteorological Department (IMD) and Snow & Avalanche Study Establishment (SASE), Central Water Commission (CWC), Survey of India (SOI), National Remote Sensing Centre (NRSC)-ISRO etc. will play an important role to ensure continuous weather monitoring to approach the site and to facilitate decision making in case of emergency. The support of NDMA/ SDMAs/ National Crisis Management Committee (NCMC)/ Defence Crisis Management Group (DCMG) plays a crucial role in advance preparation to activate control rooms, update all records, set up expert teams for preparing brief action plans for the GLOFs and LLOFs disaster risks.

2. Stage II - planning of evacuation strategies with the help of CWC, ITBP, Local Police, Local communities and managed by State Disaster Management Authority (SDMA). Securing and establishment of shelter homes, camp sites and forward staging areas, communication facilities, safety devices, stocking logistics can be handled with assistance from Army/ State Admin/ BRO forces. Clearing of debris and using controlled use of explosives, high-pressure water jet, for creating channel to release impounded water must be closely monitored. CIMFR, Army, BRO, explosives experts in the States can play a crucial role in handling this.

3. Stage III- looks forward for regular monitoring (field and aerial) after a GLOF event, till the situations normalizes. It is worthwhile to consult satellite imagery in order to compare pre and post event changes in various properties of the flow of water. State Admin/ CWC/ NRSC/ NTRO/ NDMA can lead on this part.

7. Research And Development

***Repeated monitoring using advanced space-borne and terrestrial technology** is required for regular re-assessment of lakes across the entire IHR as conditions continue to rapidly evolve. Challenges remain during the monsoon months, when cloud cover is persistent and may prevent detection of dangerous lake development using optical imagery. Promising alternatives include **radar-based systems** that can penetrate cloud cover. For GLOF hazard assessment and modelling, recent efforts address the **integration of cascading processes** into numerical modelling tools. Beyond technical challenges, few GLOF risk assessments have adequately **integrated socio-economic components** of exposure and vulnerability, requiring strengthening of bridges between the physical and social sciences. {Chapter 8}*

In long river valleys of the Himalaya, **GLOFs can extend over 100 km**, transforming their flow characteristics over this distance as they erode and deposit large amounts of sediment. This **complexity is an ongoing challenge** for scientists who try to see whether modelled patterns of erosion and deposition match those observed in reality for documented GLOFs. However, data on such observations are rarely available due to the logistical and financial challenges associated with producing repeat topographic surveys of often remote and largely inaccessible valleys. While latest modeling tools show great potential for **simulating entire chains** of mass movement and outburst processes, there is still extensive research required to validate and refine these models in the Himalayan context. Historical records and flood reconstructions can serve as vital inputs for understanding flood processes in the wider IHR.

There is significant potential to **expand the use of local knowledge** for disaster risk management. Local populations in the IHR have long-standing experience in dealing with hazards and risks from glacial lakes. When considering the common lack of observational data in remote mountain regions, local knowledge can provide valuable information on past conditions and events. Furthermore, the use of **participatory approaches** to assess community-level vulnerability, exposure and response capacities to GLOFS are called for, requiring the involvement of and collaboration with social scientists. Engaging the local population in **joint-knowledge production** is considered indispensable for effective community-based disaster risk management.

In relation to climate warming and cryospheric change, a primary challenge concerns the anticipation and assessment of hazards resulting from a fundamental paradigm change from glacial to former glaciated landscapes characterized by the presence of many more lakes than seen today. Modelling and **anticipating 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.

The formation of **new lakes** located within increasingly proximity to steep and destabilizing mountain headwalls has the potential to greatly enhance regional risks from far-reaching GLOF events in the future. However, **future-orientated risk management** relating to low-probability events with extreme damage potential is especially difficult to integrate into planning, policymaking and decision taking. Furthermore, the expected penetration of humans with their infrastructure for tourism, traffic or hydropower into previously inaccessible high mountain areas must be considered for disaster risk management.

8. Regulation and Enforcement

A well drafted techno-legal regime focused on urban and rural areas located downstream of GLOF hazards in the Himalaya is necessary to **prevent** future developments in the hazardous areas and **protect** the existing ones. Regulations and enforcement are required in **three key domains** - namely, (i) a Himalaya GLOF Mitigation Policy based on the latest building standards/regulations at central/state/ local level; (ii) a Himalaya GLOF Mitigation Strategy which must focus on implementation and strict enforcement of laws/ regulations and accountability. (iii) a no habitation/construction zone in the GLOF hazard area as determined from robust and up-to-date hazard and risk mapping studies across the Indian Himalayan Region. {Chapter 9}

To address the special problems of towns and villages located in GLOF susceptible areas, necessary modifications must be made to the **Model Town and Country Planning Bye-laws** (2016) which have explicitly called for natural hazards to be considered in development planning, highlighting the role of hazard maps in this process. Furthermore, guidelines for **land use zoning** make specific recommendations in relation to earthquake, landslide, cyclone and flood prone areas (however, no specific mention is made for GLOF hazards), including protection measures for essential service buildings and installations, and prioritization of types of buildings such as defense installations, public utilities, and lifelines. Consideration should also be given to the **National Building Code (NBC)-2016** published by the Bureau of Indian Standards which lays down a set of minimum provisions to protect the safety of the public regarding structural sufficiency, fire hazards and health aspects in buildings; the code also covers aspects of administrative requirements and bye-laws including building services. Reference should also be made to the **NDMA disaster management guidelines** on landslides, floods and urban flooding and the **National Landslide Risk Management Strategy** (2019) which are relevant to GLOF. The Environmental Regulations and Environment Impact Assessment (EIA) according to the notifications of the Ministry of Environment, Forest and Climate Change (MoEFCC) must also be included in the Techno-Legal regime.

The planning and development are state subjects and therefore, State Governments must suitably incorporate the modification in their respective Planning Legislation(s), so that regulation for land use zoning for natural hazard prone areas may be notified by the Competent Authority under the above legal provision. At the local level, the Municipal Authorities and Panchayats shall regulate the development/construction of buildings through the building bye-laws as followed in their respective areas.

Recommendations

A task committee should be formulated to draft specific regulations need to be developed concerning the increased risk of future GLOF/LLOF events and give its recommendations within a year. 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. 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. Moreover, 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.

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 land use planning.

Hazard maps, according to the federal guidelines express three degrees of danger, represented by corresponding colors: 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, development is generally prohibited. In the **blue** zone, development is strongly regulated, while in the yellow zone 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.

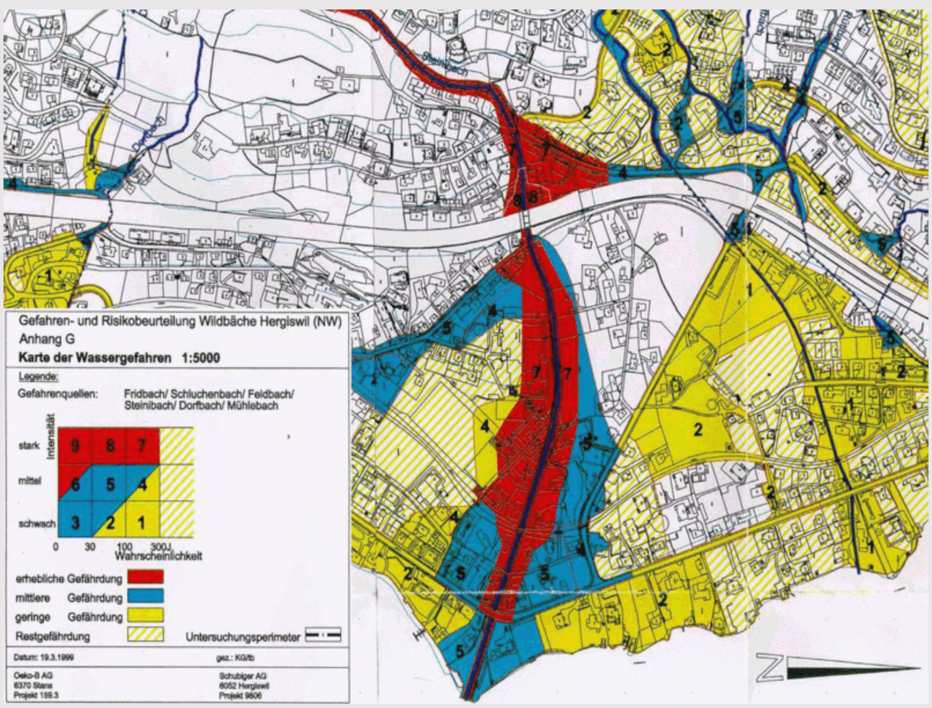

Fig. Box 1: Example of a flood hazard map for the village of Hergiswil, central Switzerland (http://www.planat.ch/en/authorities/hazard-maps)

9. Action Plan and Implementation

Comprehensive disaster management plans will be prepared at the National, State and District levels. At the National level, the plan will focus on various aspects of disaster management including **preparedness, mitigation and response**. 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. These plans will be subjected to approval from NDMA, will include various aspects of Glacial and Landslide Hazard management especially GLOF and LLOF.Short-term, mid-term and long-term plans need to be incorporated as given in the compendium on management of GLOFs and LLOFs risks and hazards. {Chapter 10}

There is no Nodal Ministry and Agency identified for the subject on glacial studies including GLOF/ LLOF. Therefore, it is proposed to identify Ministry of Jal Shakti (MoJS) as Nodal Ministry and CWC as Nodal agency for the glacial studies including GLOF and LLOF.

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.

In the annual expenditure plans, specific allocations will be made for carrying out disaster awareness programmes, maintaining preparedness and for undertaking mitigation efforts. The various measurement for GLOFs 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 National Disaster Risk Management Fund/ State Disaster Risk Management Fund (NDRMF/ SDRMF) could be utilized for the purchase of equipment for GLOF preparedness and mitigation, and for rescue and relief operations.

A national level ***Centre for Glacial Research, Studies and Management (CGRSM)*** will be established by the MoJS under the umbrella of 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 national laboratory of the Council of Scientific and Industrial Research (CSIR) 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.

In the field of geotechnical investigation and research, the CGRSM will coordinate and collaborate with the national and international Institutions such as NCPOR-Goa, NRSC-ISRO, IIRS-ISRO, WIHG, HIMCOSTE, GSI, 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).

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.

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.

Comprehensive National GLOF Mitigation Project (CNGMP): The NDMA has proposed to take up a Comprehensive National GLOF Mitigation Project (CNGMP) whose aims and objectives will be developed and finalized in due course. In a broader sense, it will consider the assessment and mapping of risks and vulnerabilities, reduction in severity, establishment of monitoring and EWS systems, capacity development, implementation of R&D programs, mitigation and preparedness, associated with GLOFs and LLOFs hazardous disasters.