Flash floods are rapid and destructive flooding events can occur within a few minutes or hours after a heavy rainfall; Teesta, Sikkim.

PHOTO COURTESY: JALEES ANDRABI

4. Disaster Preparedness through Early Warning Systems

Natural disasters such as earthquakes, glacial lake outburst floods (GLOFs), and flash floods are common occurrences in the Himalayas and have had a significant impact on the lives and livelihoods of the people in the region. This chapter specifically examines the three key disasters in the Himalayas, their impact, and the development of early warning systems for disaster preparedness. There is a compelling demand for early warning systems to prepare for such disasters, and build robust monitoring and mitigation techniques. Challenges in developing warning systems for earthquakes, GLOFs, and flash floods are also briefly discussed, and recommendations for the development of early warning systems are provided. The chapter emphasizes the importance of understanding these natural disasters and their impacts in order to improve disaster preparedness in the Himalayas.

4.1 Introduction

The Himalaya presents a complex and diverse set of multi-hazard facets. The region is prone to earthquakes, landslides, flash floods, avalanches and GLOFs. The frequency and intensity of these hazards are compounded by a range of factors including population density, steep slopes, fragile ecosystem and anthropogenic activities. Earthquakes are the most frequent and potentially catastrophic hazards in this region. In addition, these hazards are often interlinked with one triggering the other. For example, earthquakes can trigger landslides, which can block rivers and cause floods. Climate change is exacerbating many of these hazards, with rising temperatures causing glaciers to melt and changing precipitation patterns leading to more intense rainfall and snowfall events. Therefore, managing the multi-hazard facets of the Himalayas is a complex challenge that requires a holistic and integrated approach involving a range of stakeholders from governments to local communities.

The Himalayan region has experienced many major earthquakes throughout history, with some reaching magnitudes of 8 to 8.5. These earthquakes can generate a massive amount of energy and cause tremendous damage to nearby cities. Hence, it is crucial to develop an early warning system to help mitigate the impact of earthquakes (Mishra, 2023). NCS is the nodal agency of the Government of India for monitoring earthquake activity in the country. Predicting earthquakes is currently not possible as the physics of earthquakes is not yet fully understood. Therefore, the development of an early warning system for earthquakes is necessary for all earthquake-prone regions of the world (Mishra, 2023).

early warning system

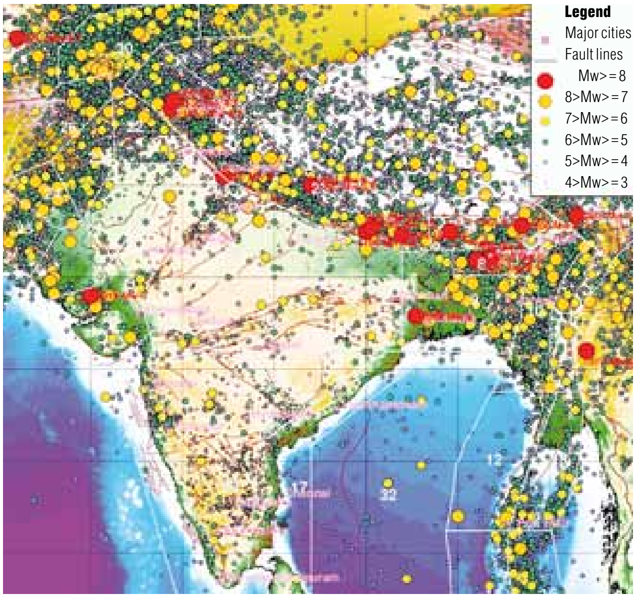
GLOFs are a serious threat to the Himalayan region and downstream areas. The expansion or formation of new lakes in the cryospheric regions is turning areas more hazardous and the impact is likely to exacerbate in the coming years (Meloth, 2023). ICIMOD is an organisation studying and working on issues related to high mountain areas, particularly in the Hindukush Himalayan region. ICIMOD conducts research, develops solutions, and provides policy advice to governments and local communities. By collaborating with local communities, ICIMOD looks for applications that meet the needs of those living in the region (Jackson, 2023).

Hindukush Himalayan region
local communities

Flash floods are another common natural disaster in the Himalaya, particularly during the monsoon season (June to September) when heavy rainfall can trigger sudden and intense flooding in mountainous regions. Flash floods can be particularly devastating in the Himalayas due to the steep terrain, high population density, and vulnerability of the communities that live there. Therefore, the impact forecasting system for flash floods is a critical tool in mitigating disasters and making informed decisions for communities and governments. Early warning systems focus on providing information about the location

flash floods
vulnerability

Fig. 4.1: Distribution of different seismic events across the Indian sub-continent dating from 2600 BCE until 2021 CE



Source: Mishra, 2023

Map not to scale

and magnitude of an event, while impact forecasting provides estimates of the potential consequences of an event. This information helps decision makers determine which areas require the most attention and resources (Singh, 2023c).

4.2 Understanding Natural Disasters in Himalayas and its Monitoring

4.2.1 Earthquakes

risk mitigation
strategies
potential impact

The seismic activity in the Himalayan region is characterised by a total of 68,342 events dating from 2600 BCE until 2021 CE (Fig. 4.1). Among these 28,425 were main shocks with a magnitude greater than three on the moment magnitude scale. Furthermore, the region has experienced a total of 26 main shocks with a magnitude greater than eight, indicating the occurrence of extremely powerful earthquakes. These statistics highlight the significant seismicity of the area and emphasise the need for appropriate disaster preparedness measures and risk mitigation strategies to mitigate the potential impact of seismic events on the local population and infrastructure.

network
seismological stations

The seismic monitoring network of NCS has undergone significant development in recent years. In 2014, it comprised 84 stations, of which 38 were analog (Fig. 4.2). By 2018, the network had been upgraded to include 115 seismological stations with broadband and strong motion recorders, and V-SAT connectivity. This has allowed for improved detection capabilities of earthquakes of magnitude 3.0 and above in most parts of the country. The network was further strengthened in December 2022, with the addition of 37 new stations, bringing the total number of stations to 152, and enhancing the network's operational capabilities. The NCS has proposed to add 100 new stations to the network over the next three years (2023-2026).

4.2.2 Glacier Lake Outburst Floods (GLOFs)

preparedness
risk assessment
dissemination

Early warning systems for risks in high mountain areas typically involve a four-step approach that includes risk assessment, monitoring, information dissemination, and preparedness (Jackson, 2023). The first step, risk assessment, involves identifying potential hazards and evaluating the likelihood and potential impact of each. The second step, monitoring, involves continuously monitoring key indicators to detect any changes or developments that could pose a threat. The third step, information dissemination, involves sharing relevant information with those who need it, such as the public, emergency responders, and decision-makers. Finally, preparedness involves taking actions to mitigate the potential impact of a threat and having plans in place to respond effectively if necessary. Together, these four steps can help organizations and communities stay informed, prepared, and ready to respond to potential threats.

The process of assessing hazards associated with a lake involves two important steps, namely standardization and prioritization (Jackson, 2023). The first step is to standardize hazard assessment by considering various physical conditions such as the state of the lake, the moraine dam, and the features around the lake. The assessment should be comprehensive and include all relevant indicators, and appropriate weights should be assigned to each indicator. The outcome of this step is a list of PDGLs that need to be evaluated for risk. The second step involves assessing the downstream socio-economic risks that may be associated with each PDGL. This assessment can be achieved by examining the downstream impacts caused by exposure to potential hazards. Based on this analysis, the PDGLs can be categorized according to their level of risk. The aim of this step is to prioritize the PDGLs based on their level of risk, thereby allowing decision-makers to focus their resources and attention on the most critical areas. Overall, the standardization and prioritization process are essential steps in the management of hazards associated with lakes. By following these processes, stakeholders can better understand the risks and make informed decisions about how to mitigate them. This approach can help to ensure the safety and well-being of communities that are located downstream from potentially dangerous geological locations (Jackson, 2023).

geological locations
socio-economic risks
hazards

GLOFs can occur when water trapped by a glacier or moraine is released suddenly (Jackson, 2023). Early warning systems are crucial in preventing or mitigating the impact of GLOFs, but they can be challenging to implement in areas where the water body and area affected by a flood are transboundary, i.e., on different sides of a border.

moraine
regional cooperation

4.2.3 Flash floods Impact Forecasting

Flash floods are rapid and destructive flooding events can occur within a few minutes or hours after a heavy rainfall. They are caused by intense rainfall or the sudden melting of snow or ice, which can overwhelm the capacity of rivers, streams, or drainage systems. Flash floods are characterised by their unpredictability, high velocity, and destructive power,

unpredictability

Fig. 4.2: National seismological network

Source: Mishra, 2023

Map not to scale

impermeable surfaces
urbanization

which can result in the loss of human lives and damage to infrastructure and property. Flash floods are highly prevalent in the Himalayan regions, most common in arid and semi-arid regions with steep slopes, low vegetation cover, and high soil erosion rates (Fig. 4.3). The severity and frequency of flash floods are also influenced by climate change, land use changes, and urbanization. For example, the increased use of impermeable surfaces such as concrete and asphalt in urban areas can reduce the amount of water that can be absorbed by the soil, leading to an increase in runoff and flash floods.

infrastructure
damage

Flash floods are highly dangerous due to their speed and force, and can cause significant damage to infrastructure and property. They can also cause soil erosion, landslides, and damage to crops and livestock. In addition, flash floods can pose a significant risk to human life, as they can trap people in their vehicles or homes and can result in drowning, electrocution, or injury from floating debris.

rainfall forecasting
flood control structure

Flash floods can be predicted and monitored using various methods such as rainfall forecasting, river flow modelling, and satellite imaging (Fig. 4.4). However, the effectiveness of these methods depends on the availability of accurate and timely data, and the capacity of local authorities to respond quickly to flood events. To reduce the risk of flash floods, mitigation measures such as the construction of flood control structures, land use planning, and early warning systems can be implemented.

4.3 Mitigating Natural Disasters: Advancements in Early Warning Systems

4.3.1 Earthquake Early Warning

critical facilities
nuclear plants

Earthquake early warning systems have been developed to alert people of impending earthquakes. The concept was first introduced in America in 1868 by Cooper, who noted earthquake occurrences and predicted future ones. In Japan, Nakamura conducted research on the shaking mechanism to develop early warning systems. However, there is a blind zone where people are not able to be alerted to ground motion that has already started, and the accuracy of these warning systems is not always guaranteed. Early warning systems are crucial for industrial purposes as they provide the opportunity to shut down critical facilities, such as nuclear plants, and for people to take safer positions. The MoES in India is working to develop a regional early warning system using local sensors and shorter warning periods. However, there are challenges, including the lack of medical facilities and the need for accurate estimation of the main cracks of the CAV.

surface wave
epicenter

Earthquake early warning systems are designed to send notifications through communication channels before the arrival of destructive seismic waves, such as the S-wave or surface wave. The time it takes for shaking to reach the alert area can vary from seconds to minutes, depending on the distance from the epicenter. This response time can be maximized by minimizing delays in data processing, communication, and delivery of earthquake early warnings. Therefore, the farther a location is from the epicenter, the greater the potential warning time. The effectiveness of an earthquake early warning system relies on the ability to reduce delays in the various stages of information processing and dissemination, ultimately allowing for more time for individuals to take protective action.

minimising delay
protective action

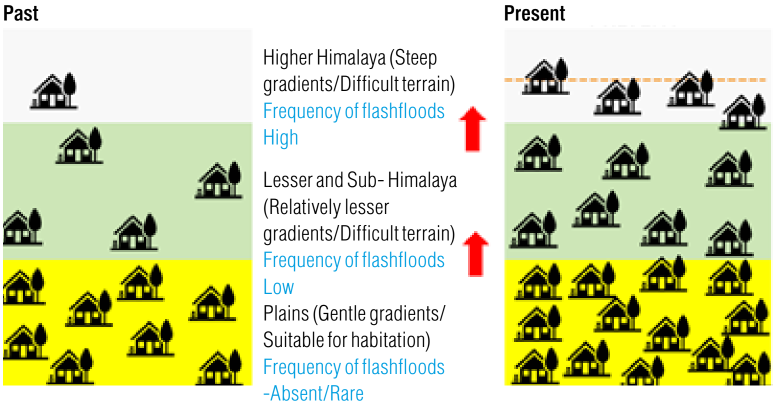
The IIT, Roorkee has also developed an early warning system with support from the MoES, but the recent (November 2022 and January 2023) Nepal earthquake highlighted the need for improved systems. The PPA regional earthquake early warning system for the safety of important structures involving nuclear, thermal, hydroelectric power plants; gas and electric supply network, and the transportation systems postpile strainmeter early warning system proposed by the NCS uses spectral kernel frequency estimation to determine earthquake strength. The computational circuit uses real-time mode and the suspect propagation path to determine areas of potential damage.

regional earthquake
early warning system

4.3.2 GLOF Early Warning

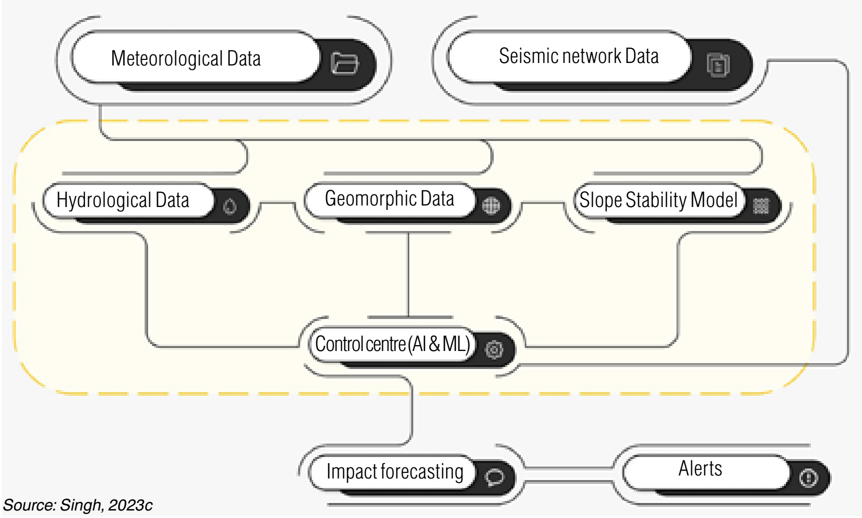
India, Bhutan, Nepal, and other countries in the Himalayan region face significant risks from GLOFs. To mitigate these, several projects have been implemented, including

Fig. 4.3: Himalayan Scenario



Source: Singh, 2023c

Fig. 4.4: Flowchart demonstrating Impact Forecasting Modelling



Source: Singh, 2023c

Thorthormi Tsho
Imja
Tsho Rolpa
PunatsangChhu
PhoChhu

the Thorthormi Tsho, Imja, and Tsho Rolpa glacial lake risk mitigation projects. The Thorthormi Tsho project was carried out between 2008 and 2012 with a budget of USD 4.23 million and co-financing from the Royal Government of Bhutan. It involved lowering the lake level by 5 m and installing a comprehensive early warning system in the PhoChhu and PunatsangChhu valleys. The project identified 31 vulnerable communities that benefited from the mitigation measures.

automatic sirens

The Imja glacial lake risk mitigation project was implemented at an altitude of 5,004 m in Nepal. It involved the installation of sensors and automated early warning sirens linked with a dynamic mass SMS alert system polygon. The project benefits over 71,000 vulnerable people living in 27 settlements. The ICIMOD provided technical support in the project's design. The Tsho Rolpa glacial lake risk mitigation project was implemented in Dolakha, Nepal, at an altitude of 4,580 m. It involved siphoning water to lower the lake level and excavating a three meter wide channel to lower the lake level further. The project also installed an early warning system with 19 automatic sirens in 18 villages, which was upgraded in 2015.

These glacial lake risk mitigation projects have been crucial in reducing the risk of GLOFs in the Himalayan region. By lowering lake levels and installing early warning systems, these projects have helped protect vulnerable communities and infrastructure from the devastating effects of these floods.

4.3.3 Flash Flood Impact Forecasting in Himalayas

Kedarnath
impact forecasting
decision making
preparations

In the past, early warning systems have provided information about impending disasters, but often without an accurate assessment of the potential impact. For example, during the Kedarnath disaster in India, the IMD issued warnings about heavy rainfall in the area, but the warnings did not provide information about the potential consequences of the rainfall. As a result, many people in the area stayed in their hotel rooms, believing that they were safe, but were later swept away in the disaster. Impact forecasting takes into account the potential consequences of an event, such as the number of people likely to be affected, the extent of the damage, and the resources required for recovery. This information helps decision-makers prioritize their response efforts and allocate resources accordingly. For example, if impact forecasting predicts that a particular area is likely to be hit hard by a disaster, decision-makers can allocate more resources to that area to ensure that the necessary preparations are in place.

In recent years, there have been significant advancements in impact forecasting technology. For example, the use of artificial intelligence and machine learning can help predict the potential consequences of a disaster based on historical data and real-time information. Additionally, new debris flow detection technologies using seismic approaches have been developed to detect potential landslides and other disasters before they occur.

4.4 Challenges

Despite the advancements there are several challenges in developing early warning systems. The challenge faced in earthquake early warning systems is the response time, or lead time, which is crucial for saving lives. The time it takes for seismic waves to travel to different locations can vary greatly, with a minimum of six seconds to reach Dehradun and 66 seconds to reach Delhi. Even a fraction of a second can be important for safety, so it is essential to develop the technology to predict earthquakes. This requires leveraging advancements to understand the predictability of earthquakes based on valid principles in physics. There are many tectonic processes that contribute to earthquakes, and the history of the seismo-tectonic zone provides a long term early warning for understanding where to live and what to do in case of an earthquake. It is important to take advantage of this information for earthquake warning and develop a system similar to monsoon, storm, cyclone, and tsunami warning. An early warning system for earthquakes is an urgent need, as there are many tectonic deformations in the Himalayan range and surrounding areas that have the likelihood to generating significant earthquakes.

seismic waves
seismo-tectonic zone

The NCS is monitoring earthquakes across the range of 0 to 40 ° N and 60 to 100 ° E, with 152 seismological stations across the country and are continuously increasing the number of stations to understand earthquake records and behaviour, and are analyzing seismograms to provide earthquake parameter warnings. However, providing this information to the public quickly enough is the challenge, as earthquakes can destroy in a matter of minutes (Mishra, 2023).

seismological stations

The earthquake early warning system currently in place is more of a post earthquake disaster phase early warning, providing information on the latter phase arrivals of seismic waves such as shear and surface waves. The warning system involves creating shaking maps to understand the maximum and minimum areas impacted by the earthquake. It is crucial to determine which disastrous phase is going to hit where and at what time to provide adequate warnings. Challenges in developing an early warning system include making the network dense enough to provide accurate information and avoiding false alarms that could cause chaos. Himachal Pradesh has been selected as a testing ground for the early warning system, and it is hoped that significant progress will be made within 2023-2024.

testing ground

In the case of glaciers, there is the lack of continuous mass balance series data, which is crucial in understanding glacier behaviour. Accurately predicting the effect of a disaster still poses a challenge. For instance, monitoring a large number of potential disaster zones can be difficult, and not all areas may be monitored equally. Additionally, the accuracy of impact forecasting is often limited by the availability of historical data and real-time information. Hence, impact forecasting is an essential tool in mitigating disasters and making informed decisions for communities and governments. While there have been significant advancements in impact forecasting technology in recent years, there are still challenges to accurately predicting the impact of a disaster. By improving monitoring and collaboration

mass balance
potential disaster zones
mitigating disasters

between different agencies and organisations, there is a potential to continue to improve the ability to predict and prepare for disasters.

4.5 Recommendations

Despite encountering numerous obstacles when it comes to impact forecasting and developing an early warning system, following recommendations can be adopted for disaster preparedness and enhancing our early warning systems.

i. Earthquake early warning systems require sufficient response time and increased number of seismological stations (Mishra, 2023).

ii. Providing earthquake parameter warnings quickly is essential to save lives, which may be enhanced through networking and involvement of local agencies (Mishra, 2023).

iii. More comprehensive and standardised monitoring of potential disaster zones is needed for improved impact forecasting (Jackson, 2023).

iv. New technologies like UAVs and remote sensing can be used for data collection in potential disaster zones (Singh, 2023c).

v. Improvement in modelling efforts required, especially for cryospheric changes (Ravichandran, 2023a).

vi. Need to generate more knowledge to gain a better understanding of cryospheric changes and their potential impacts (Ravichandran, 2023a).

vii. Effective adaptive and mitigation strategy required to mitigate risks and uncertainties (Ravichandran, 2023a).

viiii. There is a need to building regional , transboundary and global cooperation to address the problem of GLOF (Jackson, 2023).