

2025

HELP Global Report on Water and Disasters



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Preface by Dr. Han Seung-soo
HELP Global Report on Water and Disasters 2025



Dear Readers,

I am pleased to share with you the HELP Global Report on Water and Disasters 2024-2025, the 7th volume of the annual series that compiles experiences, lessons learned and good practices in dealing with major disasters on Earth in recent months.

This year was relatively calm in terms of human casualties from water disasters. Looking at the top ten disasters that caused major human casualties, there were only three water-related disasters, which is fewer than usual, and none of them resulted in more than 1,000 deaths. However, the most serious of these disasters, the floods in Chad, claimed the lives of over 500 people. Meanwhile, economic damage caused by water disasters is increasing significantly. Nine water disasters are ranked among the top ten disasters that caused the most economic damage of all disasters. Disasters occur at different times, so it could be said that there were fewer water disasters this year by chance, but the fact that disasters causing major economic damage have increased cannot be overlooked. This is because it is believed that the potential for disaster damage in cities is increasing.

In recent years, the influx of population into cities has been increasing. According to the United Nations' Habitat, the global urban population rate currently exceeds 55%, and is predicted to reach 68% by 2050. Of this, the population living in slums exceeds 900 million. Water disasters in cities where populations and assets are concentrated, including slums that are vulnerable to disasters, can cause significant damage

The flood disaster that occurred in Barcelona, Spain in 2024 clearly demonstrated the devastating damage that urban flooding can cause. At the initiative of the UN Secretary-General, efforts are underway to ensure that everyone in the world receives early warnings by 2027. We at HELP have great respect for these efforts, and we are committed to promoting them. However, we would like to frankly point out that the development of early warning systems alone will not significantly reduce the economic damage caused by disasters.

In order to mitigate the human and economic damage caused by disasters, especially water-related disasters, it is essential to invest in water disaster prevention infrastructure such as dams, levees, and waterways. In fact, in the heavy rain disaster that occurred in the Valencia region of Spain from the end of September 2024, which is also reported in this report, small and medium-sized cities around Valencia suffered devastating damage, but the damage to Valencia itself was minor. Learning from the lessons of the great flood of 1957, Valencia constructed a drainage channel to prevent floodwaters from entering the city. The floodwaters caused by the heavy rains of 2024 were safely diverted by this drainage channel, and the city center of Valencia, which was protected by the drainage channel, did not overflow.

HELP has been working on the issues of water and the economy, as mentioned above. The Principles on Investment and Financing for Water-related Disaster Risk Reduction is one of the results of HELP's activities, and we encourage readers to visit HELP's official website to see the results of these activities. HELP also undertakes the HELP Flagship Initiative, a long-term analysis project led by volunteer members on water disasters and the economy, including water and poverty. We hope you will keep an eye on the progress of these activities.

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In the past 20 years, 3.8 billion people have been affected by water-related disasters. Extreme natural phenomena caused by water, such as heavy rain, floods, and droughts, will undoubtedly continue to occur. Although these phenomena may become more severe due to climate change, there is no turning back. I sincerely hope that many people involved in water and disasters will read this book and use it to help create a society with less disaster risk.

A handwritten signature in black ink, appearing to read 'Han Seung-soo'. The signature is fluid and cursive, with a large loop at the end.

Dr. Han Seung-soo
Chair, High-level Experts and Leaders Panel on Water and Disasters (HELP)
Former Prime Minister of Republic of Korea

1

Overview of Water-related Disasters in 2024

Kenzo Hiroki

*Professor, National Graduate Institute for Policy Studies (GRIPS)
and Coordinator of High-level Experts and Leaders Panel on Water (HELP)*

Water-related disasters in 2024 resulted in death toll of 10,708 (of which 8,465 by flood and storm and 2243 by wet mass movement), affected people of over 129.8 million (of which 96.7 million by flood and storm, and 29.5 million by drought), and economic loss of 219.0 billion US Dollars (of which 205.4 billion USD by flood and storm and 13.3 billion USD by drought) worldwide.

Water-related disasters in 2024 were characterized by their larger share of economic loss out of all disasters. Shares of water-related disasters are 63.9 % for deaths, 77.6% for number of affected people, and 90.5 % for economic loss. This share of economic loss by water-related disasters (90.5 %) was substantially above the average (74.9%) of the recent 20 years in 2004-2023. The death toll in 2024 was 0.46 times of that in 2023 (23,330) whereas the number of affected people and economic loss were 1.81 and 1.52 of those in 2022, respectively.

1.1 Human loss and number of affected people by water-related disasters in 2020

The year 2024 was characterized by larger economic loss and smaller number of human losses. In 2024, 10,708 people lost their lives by 333 water-related disasters (e.g., floods, tsunamis, slides and debris flow, storms, and droughts) out of total yearly death of 16,753, meaning that 63.9 % of deaths were caused by water-related disasters. The death toll is 0.46 times higher than 23,330 in 2023 and 0.85 times than 12,569 in 2022. There have not been significantly large disasters with 1,000 or more deaths in 2024. The flood disaster by Hurricane Daniel in Libya happened in 2022, resulting in deaths of 12,352, is reported in this volume for 2024-2025 because of late arrival of data and account of the disaster due to the country situation.

According to EM-DAT (International Disaster Database) of Centre for Research on the Epidemiology of Disasters (CRED), 129.8 million people were affected by water-related disasters out of 167.2 million of people affected by all disasters, meaning 77.6 % of disaster-affected people were caused by water-related disasters. Deaths by water-related disasters is 59% of that of the average in the recent 20 years (18,281 in 2004-2023). Death Toll by Disaster Type (2023 vs. average 2004-2023) are shown in Figure 1.1. Top 10 severest disaster events by number of affected people in 2024 are shown in Table 1.2. The increasing trend of number of affected people by water-related disasters continue due to, inter alia, climate change, population growth, and urbanization. In the recent twenty years (2004-2023), number of people affected by water-related disasters is 3.75 billion and accounts for 94% of total (3.98 billion). Heavy rain and flooding in Pakistan immersed around 40% of the national territory, resulting in deaths of over 1,700 people. The year 2022 was also marked by series of

droughts, resulting in death toll of 2,601 and affected people numbering 206.9 million.

Table 1.1 Death Toll by Disaster Type (2024 vs. average 2004-2023)

Event	2024	Average (2004-2023)	Rate (2024/average of 2004-2023)
Drought	0	1,169	0.00
Flood	5,883	5,570	1.06
Mass movement (wet)	2,243	800	2.80
Storm	2,582	10,742	0.24
Subtotal by water-related disasters	10,708	18,281	0.59
Earthquake	602	36,876	0.02
Extreme temperature	5,247	10,198	0.51
Mass movement (dry)	16	16	1.00
Volcanic activity	10	77	0.13
Wildfire	170	96	1.77
Subtotal by the other disasters	6,045	47,263	0.13
Grand Total	16,753	65,544	0.26

Source: UNDRR using EM-DAT (International Disaster Database)

Table 1.2 Top 10 severest disaster events by number of deaths in 2024

(Bold letter by water-related disasters)

Country	Name of event	Death toll
Saudi Arabia	Heat Wave	1,301
Afghanistan	Severe Winter	1,197
USA	Heat Wave	1,006
India	Heat Wave	733
Papua New Guinea	Landslide	670
Chad	Flood	576
Pakistan	Heat Wave	568
Japan	Earthquake	551
Myanmar	Typhoon Yagi	460
Niger	Flood	396
Share of water-related disasters	3/10 events	1,432/7,458=19.2%

Source: 2024 EMDAT Report

Table 1.3 Top 10 severest disaster events by number of affected people in 2024

(Bold letter by water-related disasters)

Country	Name of event	Death toll
Bangladesh	Heat Wave	33.0 million
Zambia	Drought	9.8 million
Philippines	Typhoon Trami	9.7 million
India	Flood	8.0 million
Zimbabwe	Drought	7.6 million
Philippines	Typhoon Gaemi and Prapiroon	6.5 million
Malawi	Drought	6.1 million
Bangladesh	Flood (August)	5.8 million
Bangladesh	Flood (June-July)	5.1 million
Bangladesh	Tropical Cyclone Remal	4.6 million
Share of water-related disasters	9/10 events	63.2 million/96.2 million=65.7%

Source: 2024 EMDAT Report

1.2 Economic loss by water-related-disasters

Water-related disasters in 2024 were characterized by their larger share of economic loss out of all disasters. The overall economic loss by water-related disasters in 2023 was US\$ 219.0 billion, or 90.5 % of total loss of US\$ 242.0 billion by all disasters. In comparison, the share of economic loss by water related disasters in the recent period for 20 years in 2004-2023 was 74.9%. Storms, floods, and droughts hit and caused severe damage in various parts of the world. Economic loss by drought was 13.3 billion USD, 1.2 times of the average of recent 20 years whereas those by floods and storm kept the largest share at 205.4 billion USD. The annual loss of 219.0 billion USD was 1.39 times of the average of US\$ 157.0 billion in the recent twenty years of 2004-2023. 9 out of ten top economic loss disasters were water-related.

Table 1.4 Top 10 severest disaster events by economic loss in 2024

(Bold letter by water-related disasters)

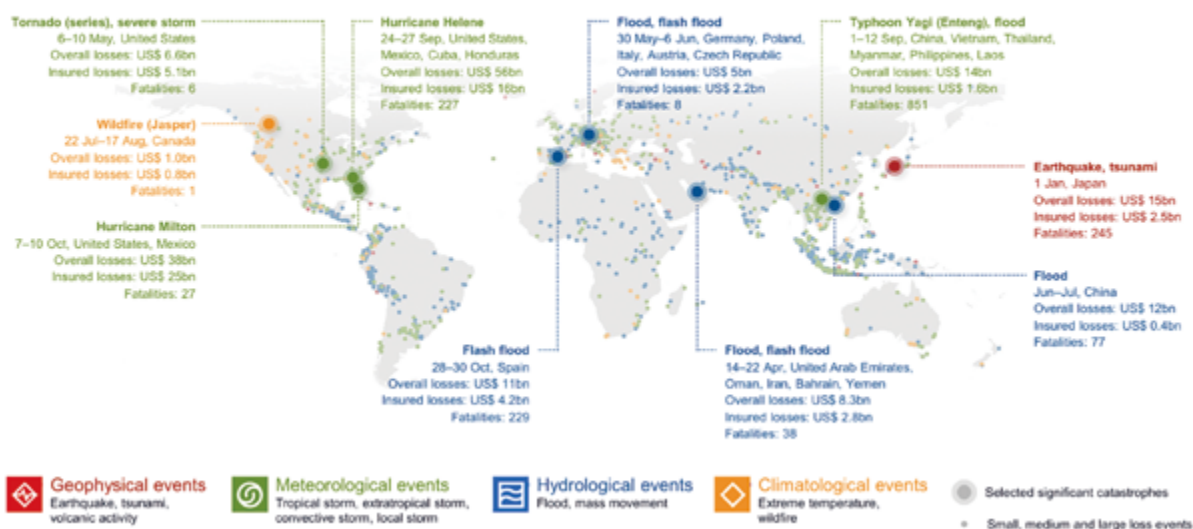
Country	Name of event	Economic loss
(US Dollars)	Earthquake	34 billion
USA	Hurricane Helene	56 billion
USA	Hurricane Milton	38 billion
Japan	Earthquake	15.0 billion
Spain	Flood	11.0 billion
USA	Hurricane Beryl	7.2 billion
Brazil	Flood	7.0 billion
USA	Storm (May)	6.6 billion
Brazil	Drought	6.0 billion
USA	Storm (March)	5.9 billion
USA	Drought	5.4 billion
Share of water-related disasters	9/10 events	143.1 billion/158.1 billion= 90.5%

Source: 2024 EMDAT Report

Fig. 1.2 Map of natural catastrophe loss events 2022

Nat cat loss events 2024

Natural catastrophes caused overall losses of US\$ 320bn worldwide



Source: Munich Re, NatCatSERVICE, 2025

Source: Munich Re. Natcast 2024

11/05/2025:

https://www.munichre.com/content/dam/munichre/mrwebsitespressreleases/MunichRe-NatCat-2024-world-map.pdf/_jcr_content/renditions/original./MunichRe-NatCat-2024-world-map.pdf

1.3 Major water-related disasters in 2024

Disasters continued to occur in all continents of the world (Fig. 1.2). Major water-related disaster events with deaths of over 300 include floods in Chad, Typhoon Yagi in Myanmar, and Floods in Niger. Water-related disasters inflicted large economic loss. They include 6 top-ten severest economic events by hurricanes and floods in the U.S.A. totalling the loss of 132.1 billion USD or 83.6% of total economic loss by the all of top-ten disasters as well as a flood in Valencia, Spain, a flood event in Brazil, and a drought event in Brazil. Earthquake in Japan partially caused human and economic loss by tsunami.

2

Floods in Spain caused by a DANA in October 2024

Jose Luis Martin-Bordes

Water Resources Expert & Ramiro Martinez Costa,
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1. Chapter Summary

In October 2024, a severe DANA (Isolated High Level Depression)¹ triggered unprecedented flooding across large parts of eastern Spain, overwhelming rivers, urban areas, and rural landscapes. The floods caused widespread loss of life, severe damage to homes, businesses, transport, and essential services, and left entire communities isolated for days. The disaster exposed the particular vulnerability of certain social groups and highlighted the immense social, economic, and environmental toll that extreme weather events can produce.

The response combined both strengths and weaknesses. Forecasts and monitoring systems helped anticipate the event, but the alerts sent by the competent institutions to the population and municipalities arrived late, preventing timely action and limiting their effectiveness in reducing the disaster's impact. Urban planning had reduced exposure in some areas, yet many existing settlements remained highly vulnerable. Civil society played a decisive role in the immediate aftermath, with volunteers and local organizations providing rapid support when official response capacities were overwhelmed. Meanwhile, recovery and reconstruction efforts revealed the value of technical innovation and the need for stronger institutional continuity.

Key lessons learned emphasize the importance of improving the communication of early warnings, embedding disaster preparedness into daily life through education and awareness, and sustaining these efforts over time to counter society's tendency to forget past crises. They also underline the need for innovation in risk assessment and reconstruction, the value of community solidarity, and the necessity of governance systems that ensure preparedness and resilience are treated as permanent priorities rather than temporary responses.

2. Overview of the Disaster

2.1 Description of the event and timeline

In late October 2024, an intense weather system known in Spain as a DANA (Isolated High-Level Depression), unleashed torrential rains over Valencia (figure 1) and surrounding regions, triggering flash floods, river

¹ The expression DANA is the technical denomination of the meteorological phenomenon – also called, more informally, “gota fría” (cold drop) – which consists of a mass of air that detaches from a very cold current and descends on another of warm air, producing great atmospheric disturbances accompanied by very intense precipitations. These effects are further intensified by humidity currents that rise from an overheated sea, which load the atmosphere with water vapor. When this vapor condenses as the cold air mass interacts with the warm, moist air, it produces torrential rains and storms of exceptional intensity.

overflow, and widespread devastation. The event began on 29 October, when the Spanish State Meteorological Agency (AEMET) issued orange and then red weather warnings as rainfall accumulated rapidly over southern and interior zones of Valencia. By midday, several rivers and ravines were overflowing, including the Rambla del Poyo, which exceeded its alert threshold. Rainfall totals across many locations during the day reached extraordinary levels, as shown below.



Figure 1: Location of the Valencian Autonomous Community and affected area.

2.2 Scientific explanation of the causes

From a meteorological point of view, the DANA episode we are referring to falls within a multi-day event that affected much of southeastern Spain (not only Valencia) and had already been forecast almost a week in advance by AEMET. The main meteorological data of the event were compiled in a specific AEMET report entitled “REPORT ON THE METEOROLOGICAL EPISODE OF TORRENTIAL AND PERSISTENT RAINFALL CAUSED BY A DANA ON OCTOBER 29, 2024”².

On Tuesday the 29th, the situation from the previous day continued. The upper-level depression displayed a leading jet exceeding 100 knots, further deepening the surface low-pressure systems located over the Gulf of Cádiz and the Alborán Sea, with the consequent acceleration of the easterly flow along the eastern façade of the Iberian Peninsula. During this day, several mesoscale convective systems (MCS) developed, affecting wide areas of the eastern peninsula. The presence of several precipitating structures, in the form of a convective train (storms moving in line, one after another over the same area for a long period of time) embedded within the MCS, affected the Valencian Community - specifically much of the province of Valencia (figure 1) - and the area of the Alcaraz and Segura mountain ranges in the south of the province of Albacete.

² https://www.aemet.es/documentos/es/conocermas/recursos_en_linea/publicaciones_y_estudios/estudios/informe_episodio_dana_29_oct_2024_.pdf

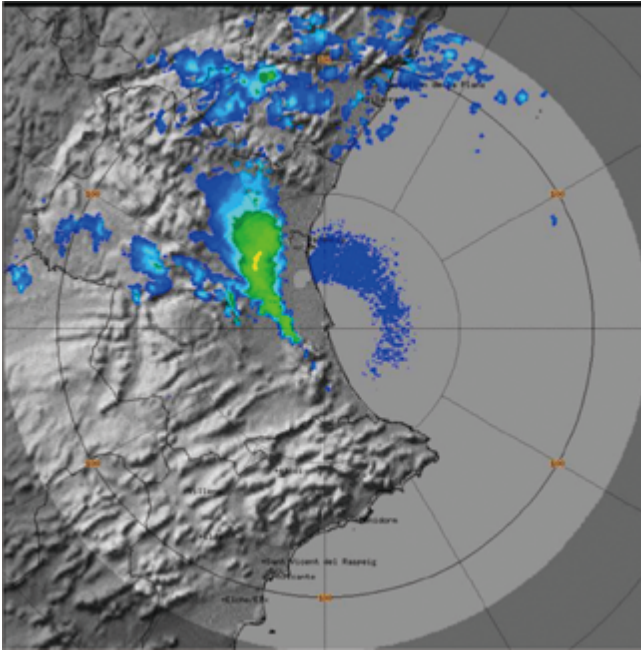


Figure 2: Images from the Valencia precipitation radars at 16:00. The convective, train-type structures that at those times were affecting the interior of the province of Valencia stand out. (Source: AEMET)

The situation had been flagged by AEMET as early as October 20, with initial warnings issued under some uncertainty, but which were later confirmed in the bulletins of October 25 and 26, and especially on October 27, 28, and 29 with repeated special warnings about the expected intensity of the rainfall, based on the monitoring of the atmospheric situation and the evolution of the DANA, particularly for the Valencian Community. All of these warnings were confirmed, with the total precipitation recorded over the 24 hours of October 29 shown in figure 3 below.



Figure 3: Accumulated precipitation on October 29, 2024. (Source: AEMET and River Basin Authorities).

As the figure illustrates, the highest values were recorded in the province of Valencia, but significant amounts also fell further southwest, in the provinces of Albacete, Murcia, Granada, and Málaga. Hereafter, we will focus only on what happened in the province of Valencia (229 fatalities including 3 people still missing), as the magnitude there was far greater than in the other provinces, where there were also 8 additional fatalities (7 in Castilla-La Mancha and 1 in Andalusia).

The maximum values recorded at the rain gauge in Turís, in the province of Valencia (AEMET station 8337X), are particularly significant, with the following measurements: 185 mm in 1 hour, 621 mm in 6 hours, 720 mm in 12 hours, and 772 mm in 24 hours, comparable to the world record values observed³ for rainstorms of durations ranging from 1 minute to two years, as can be seen in the following figure 4:

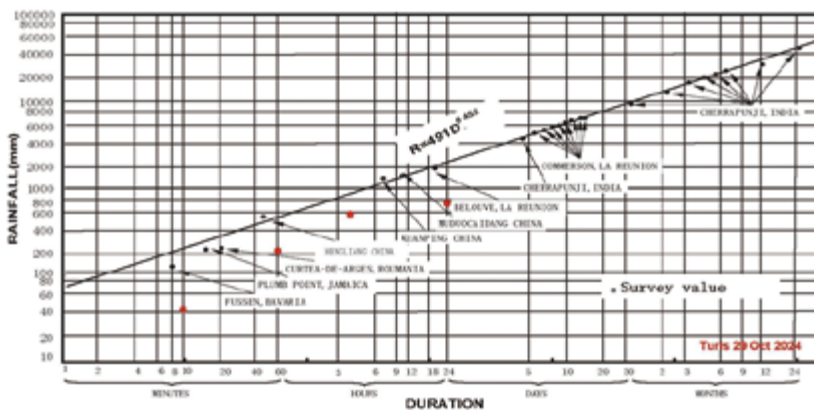


Figure 4: World's greatest known point rainfalls and their enveloping curve formula. (Source: WANG Guo-an, LI Bao-guo et al. 2026)

From a hydrological point of view, the consequences of these DANAs in this region are well known. The most dangerous situation in such cases is determined by the presence of mountain ranges near the Mediterranean coast, which cause a rapid lifting of air masses -laden with moisture and driven by easterly winds - leading to their ascent, cooling, and rapid condensation. This in turn produces large concentrations of water flow in relatively small river basins.



Figure 5: Geographical location of the affected basins.

³ WANG Guo-an, LI Bao-guo, WANG Jun-liang. World's greatest known point rainfalls and their enveloping curve formula[J]. *Advances in Water Science*, 2006, 17(6): 824-829.

In the province of Valencia, the main basins affected were those of the Poyo Ravine and the Magro River (a tributary of the Júcar), and to a lesser extent the lower section of the Turia River, which runs through the city of Valencia (figure 5). These basins are characterized as follows:

- Turia River – flows through the city of Valencia, with a basin of 6,400 km². It has several reservoirs in its upper and middle course, and within the city of Valencia it is diverted to the sea under the “South Plan Project.”
- Magro River – a tributary of the Júcar (the main river of the region), with a catchment area of 1,500 km². It includes the Forata Reservoir⁴, located in its middle basin, with a capacity of 37 million m³.
- Poyo Ravine – more of a ravine than a river, with a catchment area of about 420 km² and no reservoirs.

The main impacts occurred in the smaller catchment, the Poyo Ravine basin, which is consistent with its hydrological characteristics: torrential rainfall, short runoff concentration time, absence of reservoirs and dense land occupation.

The Poyo basin reaches a maximum altitude of 1,050 m a.s.l. and extends 43 km before discharging into the L’Albufera lagoon (rather than directly into the sea).

Its hydrography is complex due to the presence of a semi-endorheic area in the middle course. As a result, the channels of some ravines disappear as they flow into this zone, while others originate from it, without a direct hydraulic connection between them. These features contribute to a high flood risk, since there are no clearly defined riverbeds and extensive flood-prone areas have historically been occupied by human activity.

The lower half of the Poyo basin is subject to intense land-use pressure. It forms part of the southern metropolitan area of Valencia, where numerous residential and industrial developments coexist with critical transport infrastructure - including roads, motorways, and railway lines. Approximately 400,000 people live in this area.

A gauging station was installed in the Poyo River basin as part of the Automatic Hydrological Information System (SAIH) managed by the Júcar River Basin Authority (CHJ). This monitoring system provides real-time data every five minutes. The Poyo station, located beneath the A3 highway bridge, was equipped with ultrasonic sensors to measure water levels and controlled a catchment area of 182 km².

According to publicly available data from the CHJ, the hydrograph (figure 6) shows an initial peak of just over 200 m³/s at 11:30 a.m., which gradually declined until 17:00. At that time, a sharp surge occurred, with flows in the ravine rising to 2,000 m³/s in just two hours. At 18:55, the sensors ceased to function, as the bridge was overwhelmed by a violent flow laden with debris, including vehicles. Previous studies had estimated the 500-year return period flow for this basin at around 1,200 m³/s, meaning the observed flood far exceeded expected design thresholds.

⁴ This reservoir played a key role during the event, reducing inflows of more than 2,100 m³/s to an outflow of only about 1,000 m³/s. This significant decrease in discharge, along with the delay of the flood peak, undoubtedly had a very beneficial effect on the downstream communities of the Magro basin (towns such as Montroy, Real, Alcudia, Guadassuar, and Algemesí). However, it was not sufficient to prevent all casualties, which were more numerous in Utiel, located in the upper basin of the same Magro River.

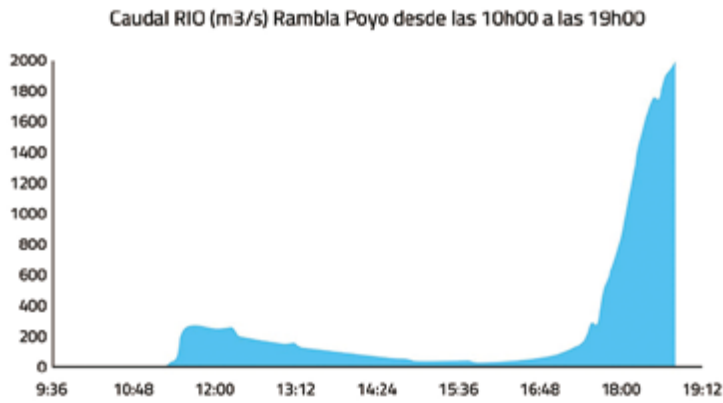


Figure 6: River discharge (m³/s) – Poyo Ravine from 10:00 to 19:00. (Source: SAIH CHJ)

Initial post-event studies have estimated that peak flows likely reached 2,800 m³/s during the DANA of October 29. Several earlier studies had identified a second downstream location as a key reference point for flow measurements in different simulations. This site is at the crossing of the Poyo Ravine with the so-called Pista de Silla road (V-31). It is commonly used in studies to quantify the total basin contribution at the entrance to the Albufera Natural Park, which begins just beyond the V-31 road. Previous research had estimated the 500-year return period flow at this point to be 1,420 m³/s. However, initial post-event calculations suggest that flows here may have reached 3,500 m³/s (figure 7).

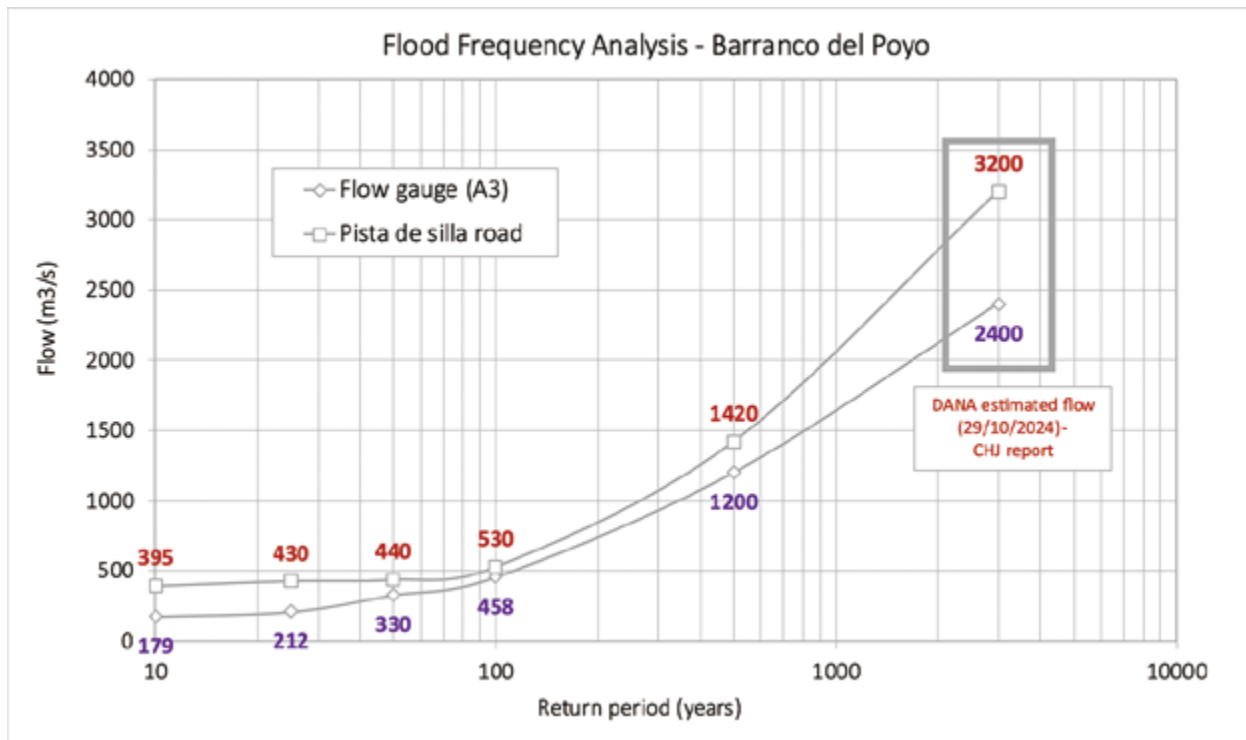


Figure 7: Flood frequency analysis – Poyo Ravine. (Source: authors' own figure)

2.3 Summary of the floods' impacts

The death toll in the Valencian Autonomous Community rose to around 230 people, and the damage to infrastructure, transport networks, cultural heritage, and housing was immense. Emergency phone lines were overwhelmed as calls for rescue in flooded homes and vehicles came in, and many areas remained cut off. Recovery and identification of victims, along with restoration of damaged infrastructure, extended well into the following months. By way of summary of the impact of these floods, the following key figures should be highlighted:

- 229 fatalities (including 3 missing persons)⁵
- 306,000 people affected across 103 municipalities
- 11,242 homes damaged
- More than 10,000 elevators damaged, many still out of service, significantly restricting daily life for people with reduced mobility
- 124 public education centers affected (11% of the total in the province of Valencia)
- Severe damage to health infrastructure: 61 health centers, 3 hospitals, 8 day-care centers, and 101 veterinary clinics
- More than 64,000 businesses affected: 78% in the services sector, 12% in construction, 8% in industry, and 2% in agriculture
- 140,000 vehicles damaged (85% declared total loss) (figure 8)
- 803 km of roads, 560 km of railways (figures 9 and 10), and 380 bridges and culverts affected
- Total economic impact: 17,800 million €

In addition, the DANA struck vulnerable groups the hardest, affecting around 100,000 elderly people and some 60,000 migrants and foreigners.



Figure 8: Damage caused in the town of Picanya.

⁵ Another official victim has recently been added, raising the total to 229, as one of the deceased women was eight months pregnant and her unborn child has also been counted.

Table 1⁶ below summarizes all the data on the impacts of the DANA across different sectors.

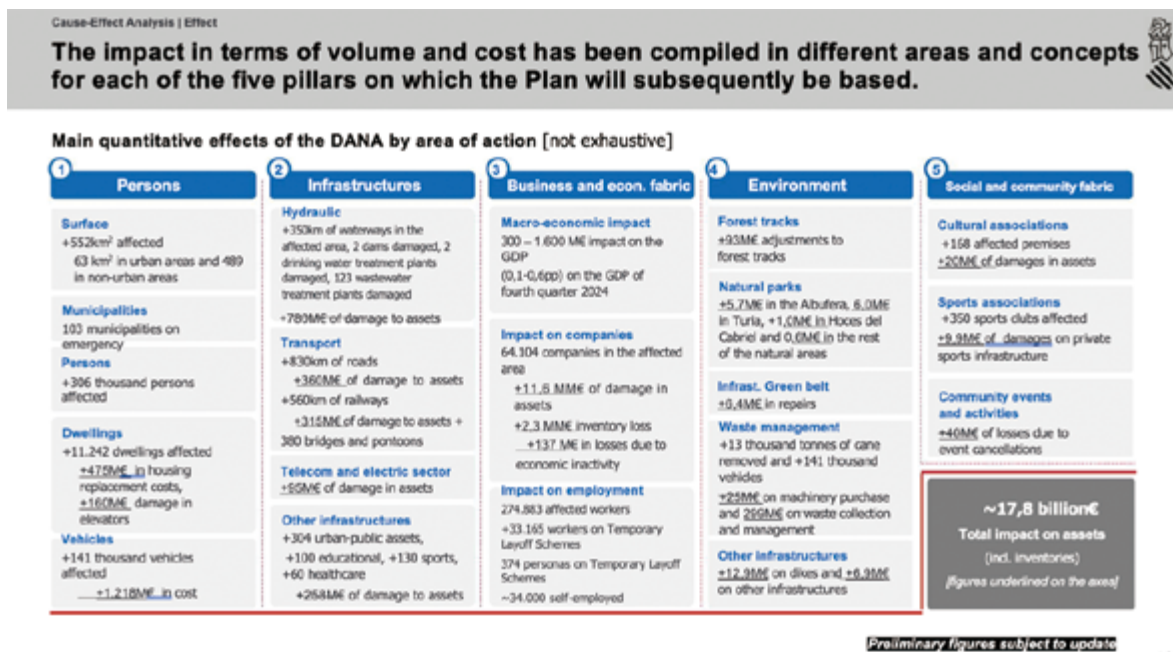


Table 1: Main quantitative effects of the DANA by area of action,
 (Source: Generalitat Valenciana, <https://recuperacio.gva.es/es/informe-de-diagnostico>)

All these figures highlight the truly extraordinary nature of this event from the meteorological, hydrological, human, and socio-economic perspectives. One aspect to emphasize is the near-total isolation (roads, railways, telephone networks, etc.) of the affected area for several days and even weeks, which greatly complicated and delayed the arrival of the first aid efforts.



Figure 9 (left): Regional Railway Commuter Lines C1 and C2 in Alfafar.
 (Source: Manu Fernández (AP/LaPresse)).



Figure 10 (right): Regional Railway Commuter Lines C1 and C2 in Massanassa.
 (Source: Manuel Bruque (EFE, El País))

⁶ Data taken from the Diagnostic Report (April 3, 2025), of the Plan Endavant (Recovery and Reconstruction Plan for the area affected by the DANA) by the Second Vice-Presidency and the Department for the Economic and Social Recovery of the Valencian Autonomous Community. Generalitat Valenciana.
<https://recuperacio.gva.es/es/informe-de-diagnostico>

From a technical standpoint, in the weeks following the event, all available data were collected and processed, allowing for a very precise definition of the flooded area and the water depths observed at numerous locations, as shown in the following figure 11 taken from the GIS Viewer of the Generalitat Valenciana⁷.



Figure 11: GIS Viewer of the Generalitat Valenciana

Using this data, the Júcar River Basin Authority (CHJ) developed a 3D simulation model with sediments that faithfully reproduces what occurred. This tool has been extremely useful in guiding design decisions during the reconstruction process. In summary, more than 552 km² were directly affected, of which 63 km² correspond to urban areas and 489 km² to non-urban areas.

Severe environmental damage must also be noted in the Albufera of Valencia lagoon, a highly valuable RAMSAR site, into which the Poyo ravine flows. The lagoon received all kinds of contaminants and debris, along with a massive amount of sedimentation material.

Another important issue is the very high number of vehicles affected, and the fatalities linked to them. This was undoubtedly the result of the lack of a timely and adequate warning that should have suspended normal daily activities and alerted the public to the dangers of moving vehicles or attempting to rescue them. A very significant number of victims are related to the latter case, when they entered underground car parks to try to save their cars and were fatally trapped.

3. Response to the Disaster

The coordination of disaster response has faced challenges due to the complexity of existing regulations, which leave certain responsibilities insufficiently defined. To help assess the scale of the resources mobilized, a summary of the official data provided by the Presidency of the Government of the Kingdom of Spain on 19 November 2024⁸, entitled “Update of Data from the Government of Spain”, is presented below.

⁷ https://visor.gva.es/visor/?capasids=SIOSE_2015&IDIOMA=ES

⁸ <https://www.lamoncloa.gob.es/info-dana/paginas/2024/191124-datos-seguimiento-actuaciones-gobierno.aspx#:~:text=V%C3%ADctimas,causas%20relacionadas%20con%20la%20DANA.>

Armed Forces:

- Troops deployed: 8,499 personnel in total, of whom 2,103 belong to the Military Emergency Unit (UME) (figure 12 left).
- Psychological support: 22 psychologists and 2 psychiatrists mobilized.
- Missions carried out: 2,259.
- Specialized vehicles and equipment: 2,032 in total, including the strategic projection vessel Juan Carlos I (LHD), 12 helicopters, 115 engineering machines, 1,776 intervention and transport vehicles, 28 drones, 34 ambulances, and 16 search dogs.
- Essential supplies distributed in the past 24 hours (19 November 2024):
 - 3,500 liters of bottled water
 - 800 kg of food
 - 1,000 kg of hygiene products
 - 2,400 kg of clothing
- Water and sludge extraction equipment: 17 heavy extraction teams and 190 light units, including 91 fire engines and 99 motor pumps.
- Infrastructure works: Preparation continues for the installation of temporary bridges in Cheste, Ribarroja de Turia, and Picaña. Assembly of the Mabey bridge structure has begun in Buñol-Dos Aguas.
- Additional support: Assistance is being provided in sludge management, cleaning of treatment networks, removal of accumulated waste at collection points, clearing of vehicles clustered near populated areas, and road cleaning.

State Security Forces and Corps:

- Personnel deployed: 9,728 agents in total, including 11 psychologists (figure 12).
 - National Police: 4,438 agents.
 - Civil Guard: 5,290 agents.
- Specialized vehicles and equipment mobilized: 1,900 in total, including 1 airplane, 10 helicopters, 85 drones, 10 boats, 23 buses, and more than 800 all-terrain vehicles.
- Reinforcement of citizen service points:
 - Civil Guard: 4 Mobile Citizen Service Offices (OMAC): 1 in Catarroja, 2 in Paiporta, and 1 itinerant office covering the municipalities of L'Horta Sud (Picanya, Beniparrell, and Lloc Nou de la Corona).
 - National Police: 6 Mobile Documentation Offices located in Alfafar, Benetússer, Chiva, Paiporta, Sedaví, and Utiel.
- Identity documents issued: 1,758 National Identity Cards (DNIs) issued through the mobile offices, of which 169 were processed in the last 24 hours (19 November 2024).
- Customs Surveillance: 12 officers deployed, supported by 1 patrol vessel and 2 drones.



Figure 12 (left): Entrance to the underground parking lot at Bonaire shopping center in Aldaia.

Transport:

- The Ministry of Transport is responsible for rebuilding 36 local infrastructures damaged by the DANA across nine municipalities in Valencia (figures 13 and 14).
- To date (19 November 2024), 148 km out of 160 km of affected state roads have been restored.
- The viaduct over the Poyo ravine has been reconstructed.
- 150 machines and 400 workers are engaged in road works.
- 147 machines and 319 workers are deployed on railway repairs.
- Renfe (national railway company) train has increased the number of trains serving regional line C1 (Silla–Gandía) by two units.
- On lines C1 and C2, between Alfafar and Sant Lluís, the three tracks (966 m) have been reconnected on the Valencia–Sant Lluís side; ballast laying and leveling works continue. Between Alfafar and Massanassa, geotextile placement and ballast filling on Track 1 are being completed, with paired rails installed over 600 m.
- On the Talayuelas–Landete section of the N-330 (km 228–238), at km 230, drainage infrastructure has been permanently replaced with a system of greater capacity than the original.



Figure 13 (left): Bridge of the Regional Commuter Railway Line C3 in Cheste. (Source: MITECO)

Figure 14 (right): CV-429 road over the Mijares del Magro River. (Source: RTVE)

Digital Networks:

- Restoration of 218,200 fixed telephone lines out of the 220,000 initially affected (99.2%).
- Restoration of 298,500 mobile telephone lines out of the 300,000 initially affected (99.5%).

Local authorities played a vital role in ensuring the provision of basic services and coordinating with emergency responders on the ground. At the same time, civil volunteers, NGOs, and local associations quickly mobilized to provide food (figure 15), shelter, medical assistance, and psychosocial support, often filling critical gaps and ensuring aid reached vulnerable groups. These examples demonstrate how coordination between central government, regional authorities, security forces, and civil society contributed to mitigating the disaster's impact and accelerating the first stages of recovery.



Figure 15: Food distribution posts in Paiporta. (Source: JL. Martin-Bordes)

In the affected area there was already a wide range of regulations, flood risk reduction and management plans, and information systems that, in principle, should have substantially mitigated the effects of such an extraordinary event.

From the perspective of planning and regulation, the earliest reference is the PATRICOVA (Territorial Action Plan on Flood Risk Prevention in the Valencian Community)⁹. This is a territorial planning and land-use management instrument designed and implemented by the Valencian Autonomous Community, which is the competent administrative authority. The first version was approved in January 2003 and later revised and updated in October 2015. The main objective of this plan is to impose restrictions on the occupation of flood-prone land¹⁰. To this end, it relies on hazard and flood-risk maps¹¹ that define different levels across the entire territory of the Community, together with specific regulations that establish what can and cannot be done at each level. However, it did not have retroactive effects on land already occupied within flood-prone areas. For information

⁹ <https://mediambient.gva.es/es/web/planificacion-territorial-e-infraestructura-verde/patricova-plan-de-accion-territorial-de-caracter-sectorial-sobre-prevencion-del-riesgo-de-inundacion-en-la-comunitat-valenciana>

¹⁰ For these purposes, the concept of “flood-prone” is an administrative matter, which defines the degree of flood risk based on the probability of flooding.

¹¹ Which may be refined or supplemented with more detailed studies, or with more accurate and up-to-date sources of information.

purposes, it also included a catalogue of planned actions by the various competent administrations to eliminate or reduce already consolidated risks.

The implementation of PATRICOVA in 2003 represented a major step forward, as it enabled the prohibition and rejection of a large number of proposed new urban developments (mostly at the municipal level) that sought to occupy flood-prone land.

Similarly, at the national level, since 2009 Spain has had the SNCZI (National System for Mapping Flood Zones)¹², managed by the Ministry for Ecological Transition and Demographic Challenge. This system was created to implement Spain's obligations under the EU Floods Directive (Directive 2007/60/EC on the Assessment and Management of Flood Risks), adopted in 2007.

The SNCZI provides a server offering highly detailed information on numerous variables related to flood risk: hazard levels and maximum water depths associated with different return periods, delimitation of the public hydraulic domain, inventories of dams and reservoirs, hydrometric networks, and more. These data can be accessed through its own online viewer, as shown in the figure 16 below (with a detail window), which also allows data downloads.

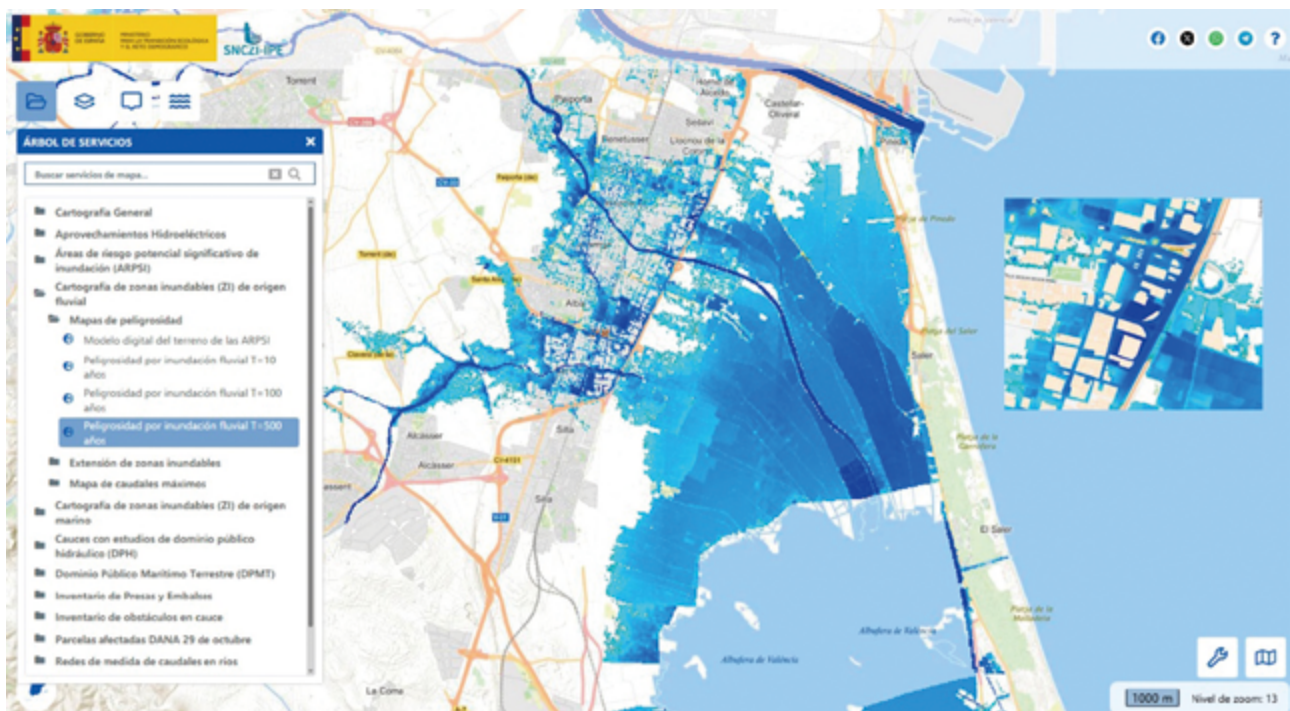


Figure 16: Flood hazard – 500-year return period. (Source: SNCZI)

¹² <https://www.miteco.gob.es/es/agua/temas/gestion-de-los-riesgos-de-inundacion/snczi.html>

Similar to what exists under PATRICOVA (at the regional level in the Valencian Community), the Government of Spain has progressively approved updates to the State Regulation on the Public Hydraulic Domain (RDPH)¹³, in order to establish land-use restrictions in flood-prone areas.

Since their implementation, the flood maps of the SNCZI have replaced those of PATRICOVA 2003 and 2005, as they provide a much higher level of detail for the application of regulations. In all cases, in Spain such restrictions apply only to areas at risk of flooding with up to a 500-year return period.

As for infrastructure execution plans, the main reference is the one formulated in 2006 by the Júcar River Basin Authority (CHJ) - the river basin organization responsible for the Poyo, Magro, and Turia catchments. This plan aimed to provide a comprehensive solution to flood risk in the Poyo basin, with the objective of eliminating urban flood risk for a 500-year return period.

To achieve this, the plan proposed a set of measures: hydrological–forestry corrections in the headwaters, the establishment of controlled flood retention zones, and two diversions to the “South Plan” scheme. The total estimated cost for these works was €220 million.

Unfortunately, none of these measures were ever implemented. The plan was developed into project designs between 2007 and 2009, and then entered its administrative and, above all, environmental approval process. In 2011, it received a positive environmental declaration, but the 2012 economic crisis halted this type of investment. In 2018, the process was reactivated, but new environmental and land protection regulations required the procedures to be redone. By the time the DANA of October 2024 struck, none of the works envisaged in the 2006 plan had been carried out.

In any case, a preliminary analysis has now been carried out to estimate the potential positive impact that the implementation of the 2006 plan would have had. The magnitude of rainfall and discharges during the 2024 DANA was so extraordinary (with a statistical return period estimated at around 3,000 years) that, had the measures (designed for a 500-year return period) been implemented, they would only have reduced material damages by about 20–30% (put simply, maximum water depths of just over 2 meters instead of 3).

The prevention of such a high number of fatalities, however, depends on a different set of measures - particularly those related to emergency management, and above all, the public alert system.

By contrast, in the Magro–Júcar and Turia basins, numerous interventions have been carried out over the last decades¹⁴, which have proven effective even in the face of such an extraordinary DANA event. All these action

¹³ <https://www.boe.es/buscar/act.php?id=BOE-A-1986-10638>

¹⁴ Above all, as a consequence of the major floods in the Turia in 1957 and in the Júcar in 1982, following the failure of the Tous dam under construction. As mentioned, the Forata dam on the Magro River managed to retain slightly more than half of the peak flood flow during the 2024 DANA.

plans have been integrated into the Flood Risk Management Plans (PGRI) formulated by the Júcar River Basin Authority (CHJ)¹⁵, in compliance with the EU Floods Directive of 2007. Unfortunately, over all these years, investment in measures for the Poyo basin has been practically nonexistent - even though, as noted, their contribution to reducing overall damage would have been limited.

Regarding information systems, the available infrastructure is certainly extensive. For precipitation monitoring and forecasting, AEMET provides observation, prediction, and warning tools, producing fully public and accessible products that support emergency preparedness and management.

For hydrological and hydraulic data, the SAIH systems (Automatic Hydrological Information Systems), operated by all Spanish river basin authorities, provide real-time data every 5 minutes from thousands of observation points (rain gauges, thermometers, flow gauging stations, reservoir levels, dam gate positions, canal discharges, etc.). These data are also publicly accessible¹⁶.

All this information was properly used by many public institutions, private entities, and individuals, who took the necessary preparedness measures (suspension of activities, relocation to safe areas, etc.). However, the timely delivery of alerts and critical information to the general public did not occur as effectively as required.

In Spain, there is a well-developed and comprehensive regulatory framework for emergency management and civil protection, including flood-related emergencies. At the same time, Spain has a unique distribution of responsibilities, with many competences assigned to the Autonomous Communities (regional entities made up of one or several provinces). This high level of decentralization can sometimes make the application of emergency response protocols more complex. While in most situations the division of responsibilities is clearly defined, in certain cases interpretation may vary, which can lead to inconsistencies.

In broad terms, Spanish and regional legislation distinguishes four levels of emergency (0, 1, 2, and 3). Regional authorities are responsible for declaring the applicable level at any given time, as well as for directing emergency management for levels 0 to 2. Level 3 is reserved for major emergencies that severely affect more than one Autonomous Community; in such cases, the Ministry of the Interior may declare Level 3 and assume overall command. However, the exact interpretation of when an emergency reaches this “generalized severity” threshold is not always entirely clear.

What still requires clarification is why the general alert to the population (via the ES Alert system) was not issued until 20:11 on 29 October - at a point when most of the victims had already been affected—despite reports of possible casualties having been received 7 to 8 hours earlier.

¹⁵ <https://www.chj.es/es-es/medioambiente/GestionRiesgosInundacion/Paginas/PlanGestionRiesgosInundacion.aspx>

¹⁶ As an example, this access to the Júcar SAIH, the first to be implemented in Spain since 1983: <https://saih.chj.es/mapa-lluvias>

5. Anecdotes and Specific Cases

In an event of this magnitude, countless stories of deep human interest emerged. Many involve dramatic rescues, often improvised from balconies and first-floor windows, that saved people being swept away by the torrent. Sadly, there were also tragic cases where attempts failed, and others were carried away helplessly by the floodwaters.

There were also remarkable stories of solidarity among those trapped in the thousands of vehicles stranded on flooded roads. Many survived by abandoning their cars and finding safety in nearby trucks, which provided more secure shelter.

Tragically, however, some stories ended in loss. One such case was that of an elderly couple living on the ground floor near the Magro River in Utiel. When floodwaters rapidly rose to nearly three meters inside their home, the husband - unable to move his wife, who was in a wheelchair, to the upper floor - chose to remain by her side, sharing a tragic fate together. Similar situations affected many elderly residents on ground floors who, lacking timely warnings, did not have enough time to reach safety. Particularly devastating was the case of a nursing home in Picanya, where six residents lost their lives after being unable to be evacuated to higher floors in time.



Figure 17 (right): Volunteers helping with cleaning tasks in Paiporta. (Source: JL. Martin-Bordes)

Another negative aspect was the spread of misinformation and fake news. Numerous false rumors circulated widely, amplified by fast-moving channels that lacked any form of verification. The most notable case related to the DANA was the rumor that thousands of victims were expected to be found in the large underground car park (2,500 spaces, on two levels) of the Bonaire shopping center in Aldaia (figure 12 left). Videos and audio recordings spread, claiming that security forces had confirmed this. Fortunately, the reports proved entirely false. No victims were found thanks to the shopping center's emergency plan, which was activated in time and included measures such as closing access to the car park. Only a few empty, damaged vehicles belonging to employees who had left them there before the plan was activated were discovered.

Many of the false rumors circulating during the floods carried a strong emotional charge and were designed to generate indignation, fear, or distrust in public institutions. A recent study¹⁷ by professors from the Polytechnic University of Valencia and the International University of Valencia highlighted that in “disaster situations, misinformation often exploits uncertainty and erodes trust in institutions, creating confusion and amplifying tensions”.

Amid this, however, the most remarkable experience was the wave of solidarity (figure 17). The floods left the affected area almost completely cut off, delaying the arrival of official aid. When assistance did arrive, the scale of the tasks was overwhelming. In response, thousands of volunteers spontaneously organized themselves, many coming from distant parts of Valencia and beyond, walking daily to the devastated areas to help with whatever was needed - cleaning, clearing debris, providing food, water, medicine, and emotional support.

The contrast was striking, just 300 meters across the South Plan (Plan Sur) lay the unaffected city of Valencia, where daily life continued as normal. One pedestrian bridge across this channel, linking the neighborhoods of San Marcelino and La Torre, became the symbolic entry point for thousands of volunteers heading on foot each day to assist the flooded communities. In recognition of this extraordinary show of solidarity, the City Council of Valencia has named it the “Bridge of Solidarity.”



Figure 18: “Bridge of Solidarity over the Turia river”

On the other hand, the South Plan (Plan Sur) infrastructure also acted as an unintended barrier for certain flood runoffs in the southern flooded area (Saleta Ravine). As shown in figure 19, these flows could not follow their natural drainage path to the sea, since the old channel was blocked by the construction of the South Plan. Instead, the waters ran parallel to the right bank of the new channel, causing severe damage and significant loss of life in the urban areas they encountered - particularly in the districts of Valencia known as the *Pedánias del Sur* (Southern Outlying Neighborhoods).

¹⁷ “Disinformation During the 2024 DANA Crisis in Spain. Analysis, Characteristics, Typologies and Denials” in <https://rua.ua.es/server/api/core/bitstreams/4eff3381-425c-4c52-a927-dec2ae74fee5/content>



Figure 19: South Plan (Plan Sur) infrastructure also acted as an unintended barrier for certain flood runoffs in the southern flooded area (Saleta Ravine)

6. Good Practices and Lessons Learned

The floods caused by the October 2024 DANA in Spain revealed both the strengths and challenges of disaster response and recovery. From technical innovations in forecasting and hydrological modeling to community solidarity and robust policy frameworks, several good practices emerged that offer valuable lessons for governments, NGOs, and researchers alike. The following five highlight successful interventions, institutional and community-based practices, and key takeaways that can guide more resilient preparedness and recovery in the future.

1. Advanced Forecasting and Monitoring Systems

Spain's meteorological and hydrological agencies (AEMET and CHJ) provided highly detailed forecasts and real-time hydrological monitoring through the SAIH system, offering critical data on rainfall and river flows. These tools proved their technical value and can be replicated to strengthen early warning systems in other regions.

Takeaway: Both national and regional governments and basin authorities should expand investment in monitoring infrastructure and ensure effective public dissemination of warnings.

2. Institutional and Policy Frameworks on Flood Risk

The PATRICOVA plan in Valencia and the SNCZI national mapping system were highlighted as robust land-use and risk assessment instruments aligned with the EU Floods Directive. These tools successfully prevented new developments in flood-prone zones, showing the importance of regulatory instruments even if not retroactive.

Takeaway: Policymakers and planners should enforce zoning restrictions and update flood risk maps regularly to prevent further exposure.

3. Innovation in Hydrological Modeling for Reconstruction

After the disaster, the CHJ developed a 3D sediment simulation model that accurately reproduced the flooding dynamics and sediment flows. This model guided design decisions during reconstruction and provided technical lessons for basin-scale flood management.

Takeaway: Researchers and technical agencies should integrate post-disaster data into innovative models to guide resilient infrastructure planning.

4. Community Solidarity and Volunteer Mobilization

With official aid delayed by isolation of the area, thousands of volunteers spontaneously organized to clean debris, distribute food and water, and support victims. Civil society networks became essential in bridging gaps during the first response phase.

Takeaway: NGOs and local associations should be formally integrated into disaster response protocols, with institutional recognition of their role.

5. Awareness, Preparedness, and Institutional Continuity

One of the most important lessons from the DANA disaster is the need to ensure that awareness and preparedness are not temporary responses but permanent, institutionalized practices. While the floods initially triggered strong public attention and solidarity, experience shows that collective memory tends to fade quickly, weakening long-term resilience. To address this, it is essential to strengthen citizen preparedness and education through continuous programs embedded in schools, workplaces, and community organizations. These initiatives should equip people with knowledge of self-protection measures, emergency protocols, and risk awareness, thereby building both individual and collective resilience.

At the same time, awareness must be sustained through institutionalized campaigns that combat the “short memory” effect. This includes organizing annual public drills, workshops, and communication initiatives that keep risk prevention visible in daily life. Such activities should be formally integrated into regional and municipal planning frameworks, ensuring that they are not left to chance or short-term funding. By anchoring preparedness and awareness in both education and policy, authorities can guarantee continuity, prevent complacency, and create a culture of resilience that extends across generations.

Takeaway: Governments should institutionalize public education and drills to keep communities prepared, and researchers can support by evaluating long-term behavioral impacts of awareness programs.

7. Recovery and Reconstruction after the DANA Disaster

The recovery and reconstruction process after the DANA disaster of October 2024 has been shaped by coordinated efforts at the regional, national, and European levels. The Generalitat Valenciana launched Plan Endavant to restore living conditions and strengthen social and economic resilience. In parallel, the Ministry for the Ecological Transition and the Demographic Challenge (MITECO) and the Júcar River Basin Authority (CHJ) developed a complementary plan focused on repairing infrastructures, rehabilitating ecosystems, and enhancing flood preparedness, supported by technical studies from CEDEX. At the European level, Spain activated the EU Solidarity Fund (EUSF), securing urgent financial assistance to co-finance rehabilitation and reconstruction measures. Together, these initiatives illustrate a comprehensive strategy to not only recover from the disaster but also build a more resilient and sustainable Valencian territory. More information about the scope of these plans can be found in the links provided below.

7.1 Recovery and Reconstruction Plan of the Valencian Community

The Generalitat Valenciana launched Plan Endavant¹⁸ in response to the devastating DANA of October 2024, with the aim of restoring living conditions, reviving economic activity, and rebuilding social life in the affected areas while reinforcing resilience against future climate risks. The plan is structured around seven fundamental objectives, twenty-eight general objectives, over one hundred specific objectives, and more than three hundred initiatives. Its strategy is built on four strategic pillars - People, Economy, Environment, and Social Fabric - supported by two transversal foundations: Infrastructure and Governance.

Early achievements included the restoration of essential services such as habitability, health, and education, along with financial support to vulnerable households. Businesses also received aid, with measures directed at Small and Medium-sized Enterprises (SMEs), self-employed workers, and agricultural producers, as well as continuity support for commerce, tourism, and the agrifood sector. On the environmental front, riverbeds, forests, and natural parks were cleaned and partially restored, while waste management systems were reinforced with emergency landfill planning.

Community recovery was fostered through grants for sports clubs, cultural associations, and music groups, together with the rehabilitation of schools, sports facilities, and cultural centers. Meanwhile, repair works began on judicial and public buildings, and governance structures were deployed to ensure transparency and encourage participation through consultation tables with citizens and experts.

Looking forward, Plan Endavant prioritizes resilience through modernized infrastructure, ecological restoration, improved disaster preparedness, and stronger social protection. Its ambition is not only to recover from the DANA but also to transform the Valencian territory into a safer, more sustainable, and cohesive community prepared for future challenges.

¹⁸ <https://recuperacio.gva.es/es/plan-endavant>

7.2 Plan for the Recovery and Improvement of Resilience against Flooding in the Territory Affected by the DANA in the Valencian Community

In response to the catastrophic DANA floods of October 2024, the Ministry for the Ecological Transition and the Demographic Challenge (MITECO), together with the Júcar River Basin Authority (CHJ), launched a comprehensive Recovery and Resilience Plan¹⁹. Its main purpose is to restore living conditions, re-establish economic activity, and rehabilitate ecosystems in the affected territories, while at the same time preparing them for the growing risks of climate change and future floods.

The plan combines emergency response with medium- and long-term actions, ranging from repairing damaged infrastructures to implementing prevention measures and nature-based solutions such as reforestation, wetland restoration, and improved floodplain management. Among the most urgent rehabilitation efforts, priority was given to restoring water supply and sanitation services, with more than 600,000 people initially left without access. The CHJ²⁰ ensured continuous water distribution, repaired critical hydraulic infrastructures, and replaced damaged sensors of the Automatic Hydrological Information System (SAIH) to regain real-time monitoring capacity.

At the same time, large volumes of debris - including vehicles, vegetation, and sediments - were cleared from riverbeds and channels to reduce the risk of new blockages and flooding. Environmental recovery actions were launched to rehabilitate forests, rivers, and wetlands, with special focus on the Albufera Natural Park, severely impacted by sedimentation and pollution. Infrastructure repair covered roads, urban drainage networks, and dams, while coordination mechanisms between state, regional, and local administrations guaranteed rapid execution and transparent oversight.

At the request of the Ministry for the Ecological Transition and the Demographic Challenge (MITECO), the Centre for Hydrographic Studies (CEDEX) is collaborating in the development of detailed studies to reconstruct the DANA episode of October 29. The first phase focuses on the Barranco del Poyo basin, with the aim of determining the flows generated along the different existing channels and, subsequently, identifying the areas that were flooded, the infrastructures affected, as well as quantifying the sediments carried by the current and assessing the influence of the collapse of bridges and other infrastructures.

Together, these actions reflect the commitment of the MITECO, and the CHJ to move beyond emergency response and build a safer, more resilient Valencian territory, capable of withstanding future climate and hydrological extremes.

¹⁹ <https://www.miteco.gob.es/content/dam/miteco/es/agua/participacion-publica/inundaciones/Propuesta%20plan%20resiliencia%20DANA%20CV%20consulta%20p%C3%BAblica.pdf?>

²⁰ <https://www.chj.es/es-es/ciudadano/Atencionalciudadano/Paginas/Info-DANA.aspx?>

7.3 Spain's activation of the EU Solidarity Fund (EUSF) in response to the 2024 DANA floods in the Valencian Community

Spain has formally applied to the EU Solidarity Fund (EUSF) to co-finance recovery, rehabilitation, and reconstruction measures in the Valencian Community following the devastating DANA floods of October 2024. In March 2025, the European Commission approved an advance payment of €100 million from the EUSF²¹ - the maximum advance allowed - to begin addressing eligible emergency, rehabilitation, and reconstruction actions. Spain's full application, submitted in January 2025, requested approximately €4.403 billion in total aid, allocated among the Central State, the Generalitat Valenciana, and affected local municipalities. The Government²² has initiated distribution of the advance amounts to the Valencian Community (ca. €30.8 million) and to municipalities (ca. €23.5 million), on condition that compliance is ensured with EU rules on procurement, control of funds, and avoiding double funding.

8. First-Hand Observation of Damage and Rehabilitation after the DANA: Professor Kenzo Hiroki's Technical Mission to the Valencian Community

On 8–9 December 2024, Mr. Kenzo Hiroki, Professor Emeritus and Adjunct Professor at the National Graduate Institute for Policy Studies (GRIPS) in Japan, visited the areas affected by the DANA. He was accompanied by the authors of this chapter on a technical tour of several locations: the upper basin (Chiva, Cheste), the middle basin of the Poyo ravine (Paiporta, Picanya, Torrent) (figures 20 and 21), and the lower basin along the V31 corridor (Catarroja, Massanassa, Benetúser, Sedaví, among others). The program also included a visit to the Albufera de Valencia lagoon. During the visit, Professor Hiroki observed first-hand the extensive damage to landscapes and infrastructures caused by the DANA, as well as the significant rehabilitation efforts still underway in many municipalities.



Figure 20 (left): Damaged vehicle depot in the Alfafar industrial estate. (Source: JL. Martin-Bordes)

**Figure 21 (right): In the Poyo riverbed, under the A3 highway bridge:
location of the SAIH Júcar flow-gauging station. (Source: JL. Martin-Bordes)**

²¹ https://ec.europa.eu/regional_policy/whats-new/newsroom/31-03-2025-commission-pays-an-advance-of-eur100-million-to-spain-for-post-dana-storm-recovery_en?

²² <https://www.lamoncloa.gob.es/lang/en/gobierno/news/paginas/2025/20250603-dana-eu-solidarity-fund.aspx?>

3

Pakistan’s Consecutive Floods of 2024 and 2025: A New Era of Climate Extremes and the Race for Resilient Forecasting Systems

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EXECUTIVE HIGHLIGHTS

Flood risk in Pakistan appears to be increasing in frequency, not just severity.

The sequence of major floods since 2022 signals a new climate risk baseline.

Early warning and preparedness save lives.

Lower mortality in 2024 compared to 2022 demonstrates the impact of improved forecasting and early evacuation.

Progress is real, but uneven.

The 2025 floods highlight remaining gaps in last-mile communication and rapid-onset flood response.

Repeated floods amplify long-term vulnerability.

Successive disasters strain recovery, infrastructure, and livelihoods, reinforcing the need for anticipatory action.

Pakistan offers global lessons for climate resilience.

Investments in early warning, preparedness, and anticipatory financing provide practical models for other climate-vulnerable countries.

INTRODUCTORY CONTEXT: From Mega-Flood to New Normal

Pakistan has a long history of major flood disasters, but both the severity and frequency of these events have accelerated sharply since 2010. The 2022 floods were a benchmark in scale, causing more than 1,700 fatalities and affecting over 33 million people nationwide (Government of Pakistan et al., 2022). In 2024, severe monsoon flooding again impacted millions across multiple provinces, and early assessments from the 2025 floods indicate yet another year of significant inundation. Taken together, the back-to-back floods of 2022, 2024, and 2025 events suggest that Pakistan may now be facing a pattern of recurrent, climate-driven flood emergencies rather than isolated extremes. This new era of frequent mega-floods raises critical questions for the country’s evolving risk landscape and its efforts to build resilience:

- Acceleration of climate-driven extremes: The 2022 floods were widely regarded as a once-in-a-generation event, yet 2024 saw another major flood emergency. This sequence prompts important considerations regarding shifts in monsoon behaviour and Pakistan’s emerging hazard baseline.

- Persistent systemic vulnerabilities: Land-use practices, encroachment on floodplains, basin governance challenges, and likely longstanding underinvestment in early warning systems and disaster risk reduction continue to amplify the scale of each event.
- Gaps in early warning and anticipatory action: The 2023 HELP chapter on Pakistan did not address early-warning systems. A comparative look at 2022 to 2024 may shed light on whether improvements in forecasting and dissemination contributed to the lower recorded casualties in 2024, and what gaps remain apparent in the evolving 2025 events.
- Risk-Based Decision-Making: Pivot from reactive responses to anticipatory, risk-informed actions. Pakistan is adopting impact-based forecasting and anticipatory action approaches so that warnings trigger aid before floods hit. For example, in August 2025, an anticipatory financing system was activated based on flood forecasts, releasing funds early and enabling humanitarians to support 54,000 people ahead of the flood peak. This proactive model links forecasts to predefined triggers and Standard Operating Procedures (SOPs), allowing timely evacuations, pre-deployment of relief, and other preventive measures. Early warning is most effective when it translates into risk-based decision-making and early action.
- Depth versus frequency of impacts: Although preliminary figures suggest lower mortality in 2024, the number of people affected remains extremely high. Repeated climate extremes striking an already weakened system may be generating cumulative, long-term economic and social consequences that exceed the immediate damage of any single event.
- Global implications: Pakistan's experience may foreshadow the trajectory of many climate-vulnerable countries. It offers an important case study for climate-resilient water governance, forecast-based financing, and multi-hazard preparedness.

While not all of these questions can be answered definitively within a single chapter, framing the 2024 and 2025 floods within this broader pattern provides essential context for understanding Pakistan's rapidly evolving climate and water-risk environment. This chapter, therefore, explores how the country is entering a new era of recurrent, climate-driven flood extremes and how the events of 2024 and 2025 offer critical lessons for early warning, anticipatory action, and systemic water-governance reform.

(1) Floods of 2024 and 2025: Scale, Impacts, and Early Signals

The 2024 monsoon floods were devastating in scope, with continuous heavy rains (60% above average) causing inundation across large parts of Sindh, Balochistan, Punjab, and Khyber Pakhtunkhwa (KP). An estimated 368 people lost their lives and over 78,000 homes were damaged or destroyed in 2024. The 2025 flooding (concentrated in mid-August) was marked by torrential cloudbursts and flash floods in northern Pakistan; in KP alone, over 300 fatalities were reported within days. These events, coming back-to-back, highlight a concerning trend of increasingly frequent large-scale floods. While smaller in absolute numbers than 2022's record-breaking disaster (which affected 33 million people and submerged one-third of the country), the 2024 and 2025 floods suggest that 2022 may not have been an outlier. 2022's "once-in-a-century" mega-flood was followed by major floods just two and three years later, indicating that extreme floods are becoming frequent rather than rare. Notably, 2024's death toll (around 368) was far lower than 2022's (1,700+), a possible sign that improved preparedness and early warnings saved lives. However, 2025 saw another spike in mortality (some 700 fatalities reported nationwide by August), highlighting that progress remains uneven and that hazard severity continues to vary.

A fundamental lesson is that better risk assessment, effective early warning, and community readiness can significantly reduce the human toll of floods. In 2024, authorities took proactive measures (such as Sindh's local evacuation alerts and rain emergency) that likely averted greater loss of life. By contrast, the sudden 2025 flash floods in mountain areas exposed gaps in last-mile warning dissemination and emergency response for fast-onset events. Governance and infrastructure shortcomings continue to amplify each flood's impact: settlement in floodplains, weak enforcement of zoning laws, and clogged drainage turned heavy rains into humanitarian crises. Meanwhile, socio-economic vulnerabilities especially among rural poor, women, and children mean disasters have disproportionate and lasting effects on the most marginalized. Many flood-hit communities were already living in poverty; repeated shocks are pushing them further into destitution and food insecurity.

(2) Contrasting Flood Dynamics Across Consecutive Years

2.1 Description and Timeline (2024 and 2025)

The back-to-back floods of 2024 and 2025 have underscored Pakistan's increasing exposure to climate-driven disasters. While neither year reached the catastrophic scale of the 2022 mega-floods, the recurrence of intense monsoon events demonstrates that such hazards are no longer isolated incidents but a consistent feature of the country's climatic reality. The implementation of improved early warning systems and disaster response measures in 2024 helped mitigate the scale of fatalities and infrastructural damage in some regions. However, the deadly flash floods of 2025 exposed weaknesses in preparedness for fast-onset flooding, particularly in the mountainous north. Key challenges such as communication deficiencies, limited evacuation resources, and the vulnerability of certain social groups remain unresolved. As Pakistan braces for the likelihood of recurring severe floods, the need for proactive and localised disaster management policies has become increasingly clear.

These consecutive flooding events illustrate the pressing need to integrate climate resilience and sustainable development strategies to safeguard vulnerable populations and mitigate the human and economic costs of future disasters.

The 2024 Monsoon Floods

The year 2024 underscored Pakistan's vulnerability to extreme weather, as the country experienced widespread and devastating monsoon floods. During July and August, rainfall across Pakistan surged 60% above the long-term national average, with southern Sindh and eastern Balochistan seeing precipitation levels over 300% higher than usual, surpassing the anomalies recorded in 2010 and 2022 (ACAPS, 2024). Such intense rainfall triggered severe riverine and flash floods, primarily impacting Sindh and Balochistan, with 550,000 people affected and over 78,600 homes damaged or destroyed. The toll included 368 fatalities, with children constituting more than 150 of the deaths (ECHO, 2024). Despite these significant challenges, improved disaster preparedness helped avoid higher casualties, particularly compared to the catastrophic 2022 floods, which had claimed around 1,740 lives.

The 2024 flooding demonstrated the critical role of timely interventions, such as the government's declaration of 13 districts as "calamity-hit" to mobilise emergency response funds and expedite evacuations. By early September, tens of thousands of people, including around 143,000 in Sindh alone, were evacuated as cloudbursts breached embankments and flooded vast areas (OCHA, 2024). While the temporal and spatial scale of the 2024 floods was less extensive compared to the 2022 disaster, when one-third of Pakistan's land and 33 million people were affected, the recurrence of devastating floods underscored a shifting climate risk profile for the country. For many communities, particularly in low-lying districts of Sindh that experienced repeated inundation from 2022 to 2024, the floods reinforced the realisation that such climatic events are becoming increasingly common and drastic.

The 2025 Flash Floods

In contrast to 2024, the 2025 monsoon season brought a starkly different flooding dynamic to Pakistan. Erratic and uneven rainfall during the summer monsoon culminated in a series of high-intensity flash floods, primarily devastating the northern mountainous regions of Khyber Pakhtunkhwa (KP) and Gilgit-Baltistan (GB), as well as parts of northeast Punjab. Between August 10 and August 20, 2025, a cluster of extreme storms resulted in rainfall levels 30–36% above the August average in several districts, including Shangla, Buner, and Swat (NDMA, 2025). These triggered catastrophic landslides and flash floods that wiped out villages and claimed at least 900 lives nationwide, with 246 children among the victims (UN OCHA, 2025). The rapid onset and localised nature of these flash floods made them especially deadly, giving communities in narrow, flood-prone valleys little opportunity to evacuate.

The 2025 floods affected 5.8 million people, a figure second only to the 2022 deluge in recent history, and necessitated the evacuation of 2.4 million residents—exceeding even the record evacuation count of 2022 (UN OCHA, 2025). Key regions like Dera Ghazi Khan (Punjab) and D.I. Khan (KP) faced devastating flooding for a second time after being profoundly impacted in 2022. Additionally, the northern regions of GB suffered

from recurring glacial lake outburst floods (GLOFs), further complicating relief efforts. Unlike the widespread and prolonged inundation in 2022, the flooding in 2025 was marked by its spatial variability and sudden onset, with minimal impact in southern regions like Sindh. These events revealed critical gaps in local warning communication systems and emphasised the compounded vulnerability of children and women, who were disproportionately affected by the disaster. As floodwaters drained southward by mid-September, authorities were tasked with managing an immense relief effort in the north and preparing for potential high flows in southern river systems.

2.2 Understanding the New Hazard Baseline

The sequence of 2022, 2024, and 2025 floods strongly suggests that climate change is shifting Pakistan's flood regime. Scientific attribution studies have already found that extreme 5-day rainfall in South Asia is significantly more likely and intense due to global warming (+1.2 °C). For Pakistan, climate projections indicate a future increase in both mean monsoonal rainfall and the frequency of high-end rain events. The "new hazard baseline" is one in which an increasing number of monsoon seasons now carry a heightened flood risk, either through prolonged deluge (as in 2022 and 2024) or flash flooding (as in 2025). Multiple factors, both meteorological, hydrological, and anthropogenic, contributed to the severity of the 2024 and 2025 floods. These include intensified monsoon dynamics, regional rainfall anomalies, glacial melt events, and the cumulative effect of saturated soils from prior floods, all superimposed on systemic vulnerabilities:

Intensified monsoon and rainfall extremes: Climate data indicate that Pakistan's monsoon is growing more erratic but also capable of delivering extreme precipitation in short periods. In 2024, the country experienced its wettest monsoon in over a decade, with July and August rainfall far above historical norms. The Pakistan Meteorological Department (PMD) reported that August 2024 was the second-wettest on record for some regions. Such anomalies were driven by a persistent monsoon low that stalled over the subcontinent, funneling moisture from the Arabian Sea deep into Pakistan. Similarly, in August 2025, a severe monsoon trough was anchored over northern Pakistan, leading to massive cloudburst events. An active western depression also merged with monsoonal flows, a dangerous combination that produced record rainfall in KP's mountainous catchments. For instance, meteorological stations in KP recorded 5-day rainfall totals roughly 75% heavier than would be expected in a non-warmed climate – an indication of climate change's influence on precipitation intensity. In short, the monsoon itself is a primary culprit: it delivers larger bursts of rain in localised areas, overwhelming rivers and drainage systems.

Rainfall anomalies and spatial variability: 2024 brought countrywide heavy rainfall, it was particularly anomalous in the south. Sindh province saw rainfall 6 to 7 times higher than normal in August 2024, mirroring the pattern of 2022 (when Sindh got 726% of normal August rain). This exceptional southern rainfall caused prolonged standing water and slow runoff (as the terrain is flat and downstream). In 2025, by contrast, the anomaly was spatially focused: northern regions received extreme rainfall (e.g. 36% above normal in parts of Punjab, and likely far higher above normal in KP), whereas southern Pakistan remained closer to average. This north-

south flip-flop underscores the variability of monsoon behaviour. It meant that in 2025, the Indus River's upper tributaries (Swat, Kabul, etc.) experienced flash floods, which then contributed to high flows downstream, but luckily the lower Indus was not simultaneously hit by rain (avoiding a nationwide flood crest). Nevertheless, local cloudbursts in narrow valleys (like Shangla's) had a catastrophic impact due to orographic enhancement of rainfall.

Role of Glacial Lake Outburst Floods (GLOFs): In both 2022 and 2025, glacier melting and GLOF events exacerbated flooding in the mountainous north. Pakistan's northern areas host thousands of glacier-fed lakes, and rising temperatures have increased the frequency of GLOFs. During the 2025 floods, at least a few GLOFs were triggered in Gilgit-Baltistan – essentially sudden surges of meltwater when glacial lake barriers failed. These GLOFs generated destructive flood waves downstream, hitting communities that might otherwise have been safe from rain-induced flooding. For example, the village of Hasanabad in Hunza saw a GLOF in August 2025 that washed away a key bridge (the exact location had a GLOF in 2022). The concurrence of extreme rainfall and glacier melt (due to an intense heatwave earlier in the summer) created a compound hazard: saturated moraines and high lake levels set the stage for GLOFs as soon as heavy rain fell. This pattern was also observed in 2022, when an unusually warm spring caused rapid snow/ice melt, priming the upper Indus for flooding once the rains arrived.

Soil saturation and multi-year pressure: By 2024, Pakistan's soils and waterways had not fully recovered from the record 2022 flooding. In southern Sindh, for instance, large tracts of land remained waterlogged well into 2023 due to slow drainage. This meant that when new heavy rains fell in 2024, the threshold for flooding was lower – the ground could absorb little additional moisture. Some districts faced flooding with a smaller trigger than in the past because their natural storage capacity was compromised. Additionally, infrastructure weakened by the 2022 event (damaged embankments, etc.) failed more quickly in 2024 under renewed stress. By 2025, northern Pakistan's catchments were similarly saturated: KP had received unusually high pre-monsoon rainfall in spring 2025 (and heavy snowmelt), so the August downpours ran off immediately, causing flash floods. In essence, consecutive disasters allowed no time for full recovery of natural and built defences, creating a compounding effect. Analysts noted that although 2024's rainfall was slightly less extreme than 2022's, certain areas flooded nearly as badly because baseline conditions remained fragile.

2.3 Human, Social, and Systemic Impacts of Recurrent Flooding

The impacts of the 2024 and 2025 floods have been far-reaching – causing tragic loss of life, mass displacement, extensive damage to infrastructure, and major economic setbacks. Moreover, because these floods struck in close succession (on top of 2022's devastation), their cumulative impacts are even greater, with affected communities facing prolonged recovery challenges.

The human cost of the 2024 and 2025 floods in Pakistan has been devastating, compounded by their proximity to the catastrophic floods of 2022. In 2024, approximately 368 lives were lost, including over 150 children,

predominantly in vulnerable communities where children and women were disproportionately affected (ACAPS, 2024). Fatalities were often due to drowning, diseases, or the destruction of homes, which left many individuals unable to escape. Approximately 300,000 people were displaced during the 2024 floods, including 143,000 from Sindh and roughly 168,000 from Balochistan. Many sought shelter in emergency camps set up in public schools or along embankments. For these communities, the burden was particularly heavy as many were still recovering from the 2022 disaster. By mid-2025, the numbers were even more alarming: at least 929 individuals had died, including 246 children (UNICEF, 2025). The flash floods in the northern areas, particularly in KP, were acutely deadly due to their suddenness and nighttime occurrence, vastly increasing the risk for families who had little warning or ability to evacuate.

The displacement triggered by the 2025 floods was unprecedented. Nearly 2.9 million people were evacuated as floodwaters inundated extensive regions, mainly in Punjab – a precautionary measure reflecting the scale of the crisis (UN OCHA, 2025). Despite this, the social and psychological consequences of repeated displacement became evident. Thousands of families continued to live in makeshift shelters built after the 2022 floods, only to experience these shelters being destroyed in 2024 and 2025 floods. The lack of stability disrupted children’s education, exacerbated mental health issues such as PTSD, and created conditions rife for disease outbreaks in overcrowded relief camps. For many affected individuals, the shared trauma of losing homes, loved ones, and livelihoods on multiple occasions proved to be a recurring and compounding burden on the already vulnerable population (daleel-madani.org).



WASH

Every flood triggered a public health emergency by damaging water and sanitation systems. In 2024, floodwaters contaminated thousands of wells and hand pumps in Sindh and Balochistan, leading to major outbreaks of waterborne diseases. UNICEF reported that in certain flooded areas of Balochistan, nearly half of tested children under five had diarrhoea in the aftermath. Health facilities were also hit over 300 clinics and 1,300

schools (many used as shelters) were damaged by 2024's floods, limiting healthcare access. The government and aid agencies scrambled to provide clean water through tankering and distributed chlorine tablets, but many communities resorted to unsafe sources. Consequently, cholera, typhoid, and dengue cases spiked in late 2024 (IFRC, Oct 2024). The 2025 floods compounded these challenges on a larger scale. By September 2025, an estimated 1,060 water supply schemes had been damaged in KP alone, and open defecation became rampant in displaced settlements due to latrine destruction. Flooded areas of Punjab and Sindh saw a surge in malaria and dengue; e.g., over 725 dengue cases were confirmed in one Charsadda camp after the 2025 flood. Humanitarian updates in 2025 described critical shortages of safe water in many districts. Aid efforts provided emergency WASH services – e.g. by mid-Sept 2025, UNICEF was trucking safe water to around 96,000 people and had set up filtration plants for 7,500 people daily in Punjab but needs far outstripped supply. The floods also disrupted immunization and disease surveillance programs, raising concerns of secondary health crises. In addition, indirect flood-related fatalities occurred due to disease – for instance, children weakened by malnutrition in flood camps succumbed to diarrheal disease. The WASH impacts of these floods underscore how infrastructural damage can prolong suffering and mortality well beyond the initial event.

(3) What Worked, What Struggled, and Why?

Systemic gaps in Pakistan's disaster response became evident during the 2024 and 2025 floods. One critical issue was the lack of effective early-warning systems for flash floods, especially in remote and mountainous regions. Many communities in KP reported receiving little to no warning ahead of devastating flash floods, which cost lives and highlighted the limitations of existing communication systems. Expanding community-based warning networks and investing in localised siren systems remain pressing needs.

Logistical challenges also constrained Pakistan's relief efforts. Remote areas, particularly in Balochistan and KP, faced significant delays in receiving aid due to damaged infrastructure and harsh terrain. Extreme weather conditions often grounded rescue helicopters, while inaccessible roads further complicated the delivery of essential supplies. Innovative solutions such as drone technology or the development of robust transport networks in vulnerable regions could enhance future response capacity.

Coordination and resource allocation, though improved in 2024 and 2025, were not without flaws. Instances of overlapping assessments and the duplication of efforts, particularly between federal and provincial agencies, were reported. Furthermore, the uneven distribution of aid underscored issues of equity, as vulnerable groups, such as women-headed households and people with disabilities, often faced greater challenges in accessing relief resources. Strengthening transparency, accountability, and oversight in aid distribution remains important to ensure fairness and transparency.

(4) From Forecasts to Early Action

Unlike in 2022 (when many communities were caught off guard by the record rains), in 2024 the Pakistan Meteorological Department (PMD) and National Disaster Management Authority (NDMA) issued frequent flood advisories starting in July. When forecasts in late August 2024 predicted extreme rainfall, the Sindh provincial government took a notable step, declaring a “rain emergency” on 25 August. This declaration put local administrations on high alert: officials in vulnerable districts were instructed to evacuate communities from low-lying areas, pre-position rescue boats, and prepare relief camps before the heaviest downpours. As a result, when record rainfall struck on 1–2 September, many at-risk villages in Sindh and Balochistan had already moved to embankments or other safe ground. For example, provincial reports indicate that 13,000+ people were evacuated from riverine villages of Dadu and Jamshoro districts ahead of a controlled dam release on 1 September (Sindh Relief Dept., 2024). District authorities used mosque loudspeakers, local radio, and SMS alerts to warn residents, a practice not widely employed in 2022. These proactive measures unquestionably saved lives. Indeed, 2024’s floods had roughly one-fifth the fatalities of 2022’s in Sindh, in part because of early evacuations and avoidance of overnight flash floods. Officials later contrasted this with 2022, when delayed warnings and evacuation hesitancy contributed to the high death toll.

4.1 Scaling Flood Forecasting as a National Resilience Strategy: The USD40 Million GCF Investment in Flood Forecasting

A cornerstone of Pakistan’s preparedness push is a major project to upgrade the nation’s flood forecasting and early warning system, supported by the Green Climate Fund (GCF). In 2023, the GCF approved a \$40 million grant (part of a larger climate resilience package) dedicated to modernizing Pakistan’s hydro-meteorological network and forecasting capabilities. This investment recognizes that robust early warnings are the first line of defense in a flood-prone climate.

Purpose and Components: The GCF-funded project aims to create a state-of-the-art Flood Early Warning System (FEWS), from high-tech sensors to community alerts. Key components include:

Hydromet Monitoring Infrastructure: GCF supported GLOF II project, alone installed 284 new automatic weather stations and river discharge gauges in flood-prone districts to fill data gaps (especially in Balochistan and KP). Also, deployment of two Doppler weather radars (one in South Punjab, one in Balochistan) to improve real-time rainfall detection, as prior to 2023 radar coverage had blind spots in those regions.

Forecasting Models and Data Systems: Upgrading PMD’s computing and modeling platform. The project is equipping PMD with high-resolution numerical weather prediction models and coupling them with flood inundation models. This will allow impact-based forecasts – predicting not just rainfall but which specific areas will flood and how deep. The goal is to extend reliable flood lead times to 5–7 days for rivers and at least 6–12 hours for flash floods.

Communication and Dissemination: Developing a multi-channel alert system. This includes cell broadcasting tech (sending emergency alerts to all phones in an area, even without subscriptions), alarm sirens in vulnerable communities (some solar-powered sirens are being piloted in KP), and integration with community radio and the Pakistan citizen’s portal app for push notifications. Importantly, it also involves training local officials in interpreting forecasts and taking early action (so warnings don’t get “stuck” at the district office).

Capacity Building: Training personnel from PMD, NDMA, and provincial departments in the new systems. Also, conducting community awareness programs about the improved EWS so the public gains trust and knows how to respond.



Figure: Newly set-up AWS for flood forecasting in Gilgit (2025) under GLOF II project

Once implemented (target by 2027), this project should significantly enhance Pakistan’s ability to see disasters coming and respond in time. For example, with additional radars and gauges, PMD will monitor rainfall and river flows in near real-time across the country’s river basins – enabling more pinpoint warnings. The modeling upgrades are expected to produce flood inundation maps up to 10 days in advance for major rivers, identifying which villages are likely to flood so evacuations and defenses can be planned precisely. For communities, the goal is that every at-risk person receives alerts (via siren, SMS, or local volunteer) well before floodwaters arrive. In quantitative terms, the project aims to cut the warning dissemination time down to <30 minutes (currently it can take a few hours for district warnings to propagate to all villages). Additionally, by analyzing historical data, the FEWS will help refine trigger thresholds for forecast-based action – linking with the kind of anticipatory financing described above.

Another expected benefit is improved data integration for decision-making. The new system will link meteorological data with risk information (e.g., vulnerability maps), so that warnings come with guidance for

sectoral decision-making. The other GCF supported project, such as FP108 (Transforming the Indus Basin with Climate Resilient Agriculture and Water Management), demonstrated risk-based decision-making for food security in Panjab and Sindh provinces.

This forecasting upgrade is a critical piece of Pakistan's broader resilience strategy. Accurate, timely warnings are a low-regret adaptation measure – they cost far less than physical infrastructure and can greatly reduce loss of life and property by enabling early action.

(5) Anecdotes & Human Stories

Pakistan's northern regions, home to more than 13,000 glaciers, play a critical role in national water supply, agriculture, and hydropower. Rising temperatures, however, are accelerating glacier retreat and increasing climate risks, including highly variable water availability and Glacial Lake Outburst Floods (GLOFs). Currently, 33 high-risk glacial lakes threaten an estimated 7.1 million people. These impacts are not evenly distributed: women and girls are often disproportionately affected, bearing the burden of water collection, which can limit educational opportunities and increase vulnerability.

In response, targeted interventions are beginning to make a difference. A GCF-funded project implemented by UNDP (FP018) has supported flood risk management, improved water access, and women's empowerment in glacier-dependent communities. These efforts are reflected in voices from the field, which reveal there are signs of hope:

- Samana, a teacher, highlights how irrigation channels now allow her and others to focus on education.
- Muneeba and Saleha (9th graders) aspire to be a doctor and lawyer but still face challenges like long walks to school.
- Anees, a 10th grader, says: "We go to school without any worry about having to fetch water."



Photo (GCF project FP018 from UNDP)

- UNDP 2024: “Two Floods in Two Years” – A Farmer’s Ordeal: Muhammad Ayub, a 45-year-old farmer from Khairpur, Sindh, saw his entire village submerged in both 2022 and 2024. In a UNDP field interview (Oct 2024), Ayub recounted that, in 2022, his family had clung to the roof of their mud house for two days until they were rescued by boat. They rebuilt a shack on the same plot using aid money. Then, in August 2024, heavy rains returned: “We heard the warning on the radio and moved to the road embankment,” Ayub said. “From there, we watched the water retake our home.” Ayub’s family spent six weeks in a tent camp. He described the camp conditions as rough – not enough latrines, children falling ill – but he is grateful no lives were lost in 2024 due to the warning. By 2025, Ayub had relocated his family to a nearby town on slightly higher ground, saying he “could not go through a third flood.” His story reflects thousands like him: families hit by repeated floods who must decide whether to rebuild or retreat, often at significant personal cost.

(6) Good Practices and Lessons Learned: From Emergency Response to Risk-Informed Action

Pakistan’s consecutive floods have revealed critical lessons and scalable practices for resilience.

1. Early Warning Must Reach the Last Mile: Forecasts must be translated into timely, local action. In Jhang, Punjab, a “flood warden” system helped evacuate thousands before the Chenab overflowed. The success of forecast-based financing in 2025 (supporting 54,000 people pre-flood) shows that early warnings paired with early funding can save lives. Pakistan is now institutionalising this through a Forecast-Based Action Task Force.

For example GCF GLOF project (FP018), Transforming the Indus Basin with Climate Resilient Agriculture and Water Management (FP 108), Integrated climate risk management for strengthened resilience to climate change in Buner and Shangla (SAP039) supporting to enhance multi-hazards EWS and risk based decision making

2. *Community-Led Solutions*: Indigenous practices like raised earthen platforms (“chounras”) and ring embankments proved effective in Sindh and South Punjab. These low-cost, locally driven adaptations protected homes and livestock. NDMA’s training of local masons in flood-resistant construction is helping scale such solutions. GCF supported Recharge Pakistan: Building Pakistan’s resilience to climate change through Ecosystem-based Adaptation (EbA) and Green Infrastructure for integrated flood risk management (FP207)

3. *Build Back Better*: Rebuilding to higher standards is essential. Raised-plinth schools in Sindh remained intact during 2025 floods, unlike conventional structures. Sindh’s pilot of controlled spilling channels to divert floodwater is another example. Pakistan has updated building codes for flood zones, but enforcement remains key.

4. *Social Protection and Inclusion*: Pakistan’s use of the BISP cash transfer program enabled rapid relief. Gender-sensitive measures like separate spaces for women and child-friendly safe zones were introduced in camps. UNICEF’s trauma support and hygiene outreach through mothers’ groups are models for inclusive preparedness.

5. *Adaptive Governance*: The National Flood Protection Plan-IV and National Adaptation Plan reflect a shift toward nature-based solutions and stricter land-use enforcement. Implementation and sustained funding are now the challenge.

6. *Climate Advocacy and Global Solidarity*: Pakistan’s leadership in establishing the Loss & Damage Fund at COP27 has positioned it as a key voice for climate justice. Continued advocacy is essential to secure operational support and funding.

Practice	Description	Impact (2022–2025)
Flood Wardens (Jhang)	Community volunteers for evacuation alerts	Thousands evacuated before flood peak
Raised Plinth Schools (Sindh)	Elevated, reinforced school structures	Survived 2025 floods, used as shelters
BISP Emergency Cash Transfers	Rapid disbursement via social safety net	Millions received timely relief
Ring Embankments (Rajanpur)	Community-built flood barriers	Villages remained dry in 2025
Controlled Spilling Channels	Engineered flood diversion paths	Reduced damage in flood-prone zones
Forecast-Based Financing	Pre-triggered aid based on flood forecasts	54,000 people supported pre-disaster

(7) Recovery, Reconstruction and Resilience-Building: Breaking the Cycle of Repeated Loss

Pakistan is actively seeking to diversify and scale up its funding for recovery and resilience, recognising that traditional aid alone is too uncertain and slow. The succession of significant floods in 2022, 2024, and 2025 severely compounded Pakistan’s recovery challenges, especially in regions repeatedly hit, such as Sindh and Balochistan. Communities that were still rebuilding after 2022 saw their gains erased by the 2024 floods, forcing many to restart from scratch. For example, parts of Khairpur (Sindh) inundated in 2022 flooded again in 2024, a setback described in field reports as both “demoralising and impoverishing” (UNDP, 2024). Overall, post-2022 recovery efforts have struggled to keep pace with new emergencies. Compounding shocks also left remote districts underserved, as resources were stretched thin – by mid-2025, officials acknowledged that several hard-hit areas of interior Sindh and Balochistan remained without adequate support. This overlap of disasters strained government institutions: the National Disaster Management Authority (NDMA) and provincial agencies had to juggle ongoing reconstruction projects with new relief operations, leading to “response fatigue” among staff. Development funds were repeatedly diverted to emergency relief, delaying planned infrastructure works. Pakistan’s Public Sector Development Programme, for instance, underwent multiple reallocations to address flood damages, slowing progress on longer-term initiatives (Economic Affairs Division, 2024). Local authorities, especially in Balochistan, reported being overwhelmed after back-to-back crises in 2022 and 2024, leading to less proactive responses by 2025 as capacity and morale were depleted. In short, successive floods have

greatly strained recovery capacity, leaving vulnerable communities stuck in a cycle of rebuilding and reeling from new shocks.

A significant impediment to recovery has been the slow disbursement of international aid pledged after the 2022 floods. At the January 2023 Geneva donor conference, about \$10.9 billion was pledged for Pakistan’s flood recovery and resilience plan. However, by mid-2024, only a fraction of that had materialised – roughly \$3.06 billion (28%) had been disbursed by June 2024 (Table). These shortfalls directly hampered reconstruction, as millions remained in temporary shelters longer, and infrastructure repairs proceeded slowly. The funding gap and slow donor delivery effectively stalled parts of the Resilient Recovery Framework (4RF) that Pakistan launched after 2022. By early 2025, the government candidly reported that less than 20% of the \$16 billion in identified recovery needs had been met, putting many resilience-building projects on hold. Despite these hurdles, Pakistan has begun pivoting its recovery approach to emphasise “building back better” for greater resilience.

The table below summarises some key financing mechanisms deployed for flood recovery and resilience:

Financing Mechanism	Source & Purpose	Status (2025)
Geneva Pledges (Jan 2023)	\$10.9B mainly in loans & grants from WB, ADB, countries for 2022–24 recovery	Around 28% disbursed by mid-2024; remainder ongoing (project-tied)
UN 'Loss & Damage' Fund	New global fund for climate disaster losses (Pakistan co-led creation)	Established 2022; not yet operational (Pakistan lobbying for early rollout)
Green Climate Fund Projects	Grants for resilience (e.g. \$40M EWS upgrade, \$77M wetlands/flood mgmt)	Approved; implementation 2023–2028 (initial work underway in 2024–25)
Climate Support Levy	New Rs.2.5/L carbon levy on fuel to fund climate adaptation	Effective July 2025; expected \$60M/yr revenue for resilience fund
Resilience Bond (proposed)	Sovereign bond to raise private capital for flood defenses & infrastructure	In design; government exploring guarantee to issue in 2024–26
Forecast-based Insurance	Parametric flood insurance (Global Shield) for fast payouts post-disaster	Plan submitted; seeking donor backing for premium. Target start 2024
Pakistan Diaspora Fund	Voluntary donations/investments from expats earmarked for rebuilding	Launched 2023; \$5M raised so far, financing housing & school projects

It's worth noting that independent analyses show that investing in resilience now is far cheaper than repeated disaster losses. For example, the World Bank found that every \$1 spent on flood risk reduction in Pakistan could save \$4 in relief and damages. Yet, before 2022, Pakistan spent only about 5–7% of its disaster-related expenditures on risk reduction vs. 93–95% on post-disaster response (ADB report, 2021). The financing mechanisms above aim to flip that script by dedicating money upfront to risk reduction and preparedness. If they succeed – e.g., if a Resilience Bond fund's robust floodwalls prevent a major city from flooding – the dividends will be enormous in avoided losses.

7.1 Financing Mechanisms

Pakistan is pursuing innovative blended-finance strategies to fund its climate-resilience and water-sustainability goals. A core approach is to de-risk projects through concessional finance, guarantees, and insurance to mitigate market risks in water and flood management. For example, the Green Climate Fund (GCF) provides grants and first-loss equity that blend with private capital, effectively insuring investors against initial risk and attracting co-financing. GCF has approved \$304 million across ten projects in Pakistan – including the \$77 million Recharge Pakistan ecosystem-based flood management plan – largely structured as grants or low-interest loans to de-risk large-scale adaptation investments. This concessional funding serves as an anchor, giving commercial lenders confidence through guarantees or senior-junior capital structures. Pakistan's climate financiers are also exploring parametric insurance (e.g. under the G7's Global Shield initiative) to provide automatic payouts when extreme flood thresholds are exceeded, again reducing risk for both communities and investors by ensuring liquidity during disasters.



Figure: Financing mechanism to de-risk the market (Fakhruddin, 2025)

Aligned with these efforts, the government is aggressively working on capital mobilisation by tapping a mix of public, private, and philanthropic funds. It launched a National Climate Finance Strategy (2023) to coordinate resource flows and established a Climate Finance Unit to engage donors, multilateral banks, and impact investors. International climate finance is being actively courted: Pakistan helped galvanise the new Loss and Damage Fund as G77 chair at COP27, and it expects this fund (once operational) to provide grant resources for post-disaster rebuilding. Domestically, Pakistan is boosting its climate funding – for instance, by imposing a “Climate Support Levy” on fuels (Rs2.5–Rs 5 per litre) to raise dedicated adaptation revenue. This levy and other fiscal tools will channel public funds into resilience projects, which can then be blended with philanthropic

donations (e.g. Pakistan’s diaspora-funded initiatives) and private capital via public–private partnerships.

To attract investors, Pakistan is emphasising bankable project structures in its water and resilience programs. Projects are being designed with clear revenue streams or savings to ensure repayment. For example, new urban drainage and water-treatment projects are exploring user-fee models or cost savings through reduced flood damage, making them viable for investment. The government is even considering a sovereign “Resilience Bond” that would monetise future avoided losses: investors fund flood defences now and are repaid over time from the economic savings those defences generate (a pay-for-success concept under study). Additionally, all proposals undergo rigorous cost–benefit and climate risk appraisals to meet international standards, thereby improving their creditworthiness and appeal to lenders. This focus on sound project economics and transparency is intended to reassure investors that resilience initiatives can deliver reliable returns or outcomes.

(8) Preparing for 2026 and Beyond

Pakistan’s recent flood disasters underscore that “business-as-usual” approaches in disaster management are increasingly inadequate in an era of climate extremes. The country is gradually pivoting toward a forward-looking, preventive approach, but much work remains to institutionalise these changes. As Pakistan prepares for 2026 and beyond, several persistent gaps must be addressed to build true resilience:

Last-Mile Warning and Education: Although early warning has improved, ensuring every community understands and trusts warnings is an ongoing effort. Plans are in place to install sirens and expand community volunteer networks, but these need rapid implementation. Additionally, continuous public education on flood risks (e.g. drills in schools, hazard awareness campaigns) is needed so that warnings prompt swift action. By 2026, Pakistan aims to have all high-risk districts covered by community-based early warning systems (NDMA Vision 2026).

Logistical Readiness: The 2025 experience revealed that even well-forecast floods can challenge logistical capacity. Investing in more rescue equipment (boats, helicopters), stockpiling relief supplies strategically around the country, and improving the disaster transport fleet (e.g. high-clearance trucks, temporary bridges) will be critical. The National Logistics Cell is undertaking a review to procure such assets by 2026. Strengthening local infrastructure (e.g. building all-weather access roads to remote areas) is a long-term solution to ease future relief operations.

Governance and Coordination: While institutional coordination improved, a clearer framework for unified command in mega-disasters would help. For instance, streamlining how provincial and federal agencies share information and resources in real time could reduce any delays. Continuing joint trainings and simulations involving civilian agencies and the military (as started in 2023) will improve familiarity and trust. Clarifying NDMA and PDMA roles so that there’s no hesitation in drawing on national support is also key – perhaps by codifying triggers for federal intervention in provincial disasters to remove any stigma or political reluctance. Moreover,

community governance structures like village disaster committees should be strengthened and formally linked to DDMA plans, ensuring a bottom-up flow of information and needs during crises.

Resource Mobilization and Sustainability: A major priority is to secure sustainable funding for DRR and recovery. The government has taken steps like the climate levy and exploring insurance; these must be seen through. By 2026, targets could include fully capitalizing the National Climate Resilience Fund (with domestic and international input) and operationalizing the parametric insurance scheme for floods, so that money is readily available when needed. Ensuring that recovery funds reach intended projects (avoiding diversion or inefficiency) is equally important – transparency mechanisms such as public tracking of reconstruction funds (a dashboard exists for the 4RF) should continue to be used to maintain donor and public confidence.

Implementation of Resilience Plans: Pakistan has developed numerous plans – the challenge now is executing them. For example, the Adaptation Plan calls for restoring 10,000 hectares of wetlands and mangroves by 2030 as natural flood buffers, and building 5,000 km of protective embankments or elevated roads. Getting these projects off the ground will require dedicated project management and community involvement. Similarly, enforcing land-use in floodplains may require tough political decisions (e.g. relocating frequent-flood villages or compensating landowners to keep flood zones clear). The next few years will test whether the country can move from policy to action on these fronts. Success would mean that by the time the next mega-flood threat looms, some protective systems are in place (wetlands absorbing runoff, homes built on higher ground, etc.), reducing the scale of emergency needed.

Persistent gaps remain. Last-mile warning delivery is uneven to many remote communities in Khyber Pakhtunkhwa, which received no official alert before catastrophic flash floods in 2025, relying only on local alarms, and thus, resulting in significant loss of life that may have been reduced with earlier warnings. Logistical constraints continue to hamper relief in hard-hit areas; during 2024, for example, several Sindh villages were cut off by road, delaying aid access and necessitating boat transport. Governance fragmentation still poses hurdles: while NDMA–provincial coordination improved overall, there were instances of confusion (e.g. KP initially hesitated to request international assistance in 2025). Finally, resource mobilisation remains a challenge. Domestic funds were stretched, and by October 2025 the UN’s flood appeal noted critical unmet needs in early recovery. In sum, Pakistan’s post-2022 reforms in early warning, evacuation, and anticipatory financing demonstrably saved lives in 2024–2025, but building truly resilient disaster response will require closing remaining gaps in community preparedness, infrastructure, and inter-agency coordination

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4

March 2025 Earthquake Impact on Dams in Myanmar

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ABSTRACT

This paper provides an overview of the impacts of the March 2025 earthquake on dams in Myanmar. It is organized into three sections: the first describes the 28 March 2025 earthquake, the second examines its effects on dam infrastructure, and the third outlines potential recovery pathways as part of the initial phase of the nationwide Dam Safety Project.

Myanmar's dam inventory was originally developed under the World Bank-supported Ayeyarwady Integrated River Basin Management (AIRBM) Project. It was produced as a byproduct of the work of seconded government officers from eight ministries, who operated within a multidisciplinary team guided by the then Secretary of the Advisory Group and informed by a philosophy of integration and co-leadership across the water sector. This effort resulted in an inventory of more than 860 hydraulic infrastructures nationwide, accompanied by a comprehensive GIS map. The 28 Mar 2025 major earthquake damaged more than 586 dams (of various sizes) in Myanmar. The paper focuses on dam safety and offers recommendations for short-, medium-, and long-term recovery in the context of Myanmar's ongoing polycrisis—characterized by political instability, socioeconomic disruption, armed conflict, and the accelerating impacts of climate change. Priority areas requiring urgent attention are identified.

It highlights priority recovery needs in the short, medium, and long term, and underscores the relevance of Myanmar's National Adaptation Programme of Action (NAPA), which identifies key water-sector priorities such as dam condition assessment, construction of small-scale impoundments, climate-resilient infrastructure development, and improved rainfall-runoff modeling for early-warning systems. The Myanmar's National Adaptation Programme of Action (NAPA), completed in 2012 under the GEF program for least developed countries within the UNFCCC framework. According to World Bank assessments, Myanmar is considered the second or third most vulnerable country to climate change in the region, following Vietnam and Thailand.

Meanwhile, local coordination efforts to overcome fragmented approaches are gaining momentum. The Myanmar National Committee on Large Dams (MNCOLD) and the Transformative Water Learning Partnership—comprising more than 70,000 engineers, architects, and multidisciplinary water professionals—are engaging in sustained dialogue to develop practical and collaborative solutions for dam safety. The recovery plan is envisioned in several phases, beginning with self-reliance measures implemented using local expertise and resources, followed by professional-level international collaborations co-created with global partners.

In conclusion, this paper encourages water professionals who are able to think beyond conventional approaches—and who understand the realities of the Planetary Era and the associated planetary risks—to engage in dialogue on dam safety in Myanmar, guided by a commitment to the “do-no-harm” principle.

Section I. The March 2025 Earthquake

A powerful 7.7-magnitude earthquake struck central Myanmar (Burma) near Sagaing on March 28, 2025, at 12:50 local time. It was followed by a significant aftershock of Mw6.4 (or Mw6.7 in some reports) approximately 11 to 12 minutes later. They looked like a double strike. It was a strike-slip event along the major tectonic structure known as the Sagaing Fault, which accommodates lateral motion between crustal blocks in the region (See Fig.1). After that several strong tremors and multiple aftershocks came, marking the most catastrophic earthquake in Myanmar since the Maymyo earthquake of 1912 (See Fig.2). The destruction was immense: nearly 50,000 residential buildings, thousands of monasteries and schools, and hundreds of hospitals were reduced to rubble. According to the official figures 65,096 houses and buildings, 2,514 schools, 4,317 Buddhist monasterial living quarters, 6,027 pagodas and temples, 350 hospitals and clinics, **170 bridges, 586 dams** and 203 sections of the Yangon–Mandalay Expressway, the country's main highway, had been damaged or destroyed. Central Myanmar remains in crisis as early monsoon rains and soaring temperatures compound the earthquake related destruction. The Department of Meteorology and Hydrology has now recorded over 175 aftershocks—including tremors near Nay Pyi Taw and Wundwin—while official figures report 3,723 deaths, 5,104 injuries and 84 people missing. 6.3 million people—almost 2 million of them children—across 58 townships urgently require life-saving assistance (UNICEF Myanmar). Critical infrastructure, including the Naypyitaw’s new airport and numerous highways, also sustained severe damage.

The neighboring countries like China, India and Thailand were very first to arrive at the disaster area and supporting the victims and needy people. Later Japan, Russia and other nations joined in and almost 50 countries helped the Earthquake victims, however, the aid could not reach to remote areas and conflict zones.

Physical access issues caused by collapsed bridges (Sagaing Bridge and few others), damaged roads and airports, and fuel/electricity shortages that stopped convoys reaching remote towns. MIMU/rapid assessments specifically noted Sagaing town and many rural Sagaing townships, numerous townships in Mandalay Region (Amarapura, Kyaukse, Tada-U, Meiktila, Pyinmana, and Pyin Oo Lwin areas were heavily hit) and parts of Bago and southern Shan / Inle Lake area and that many rural townships reported little or no outside assistance in the early days.

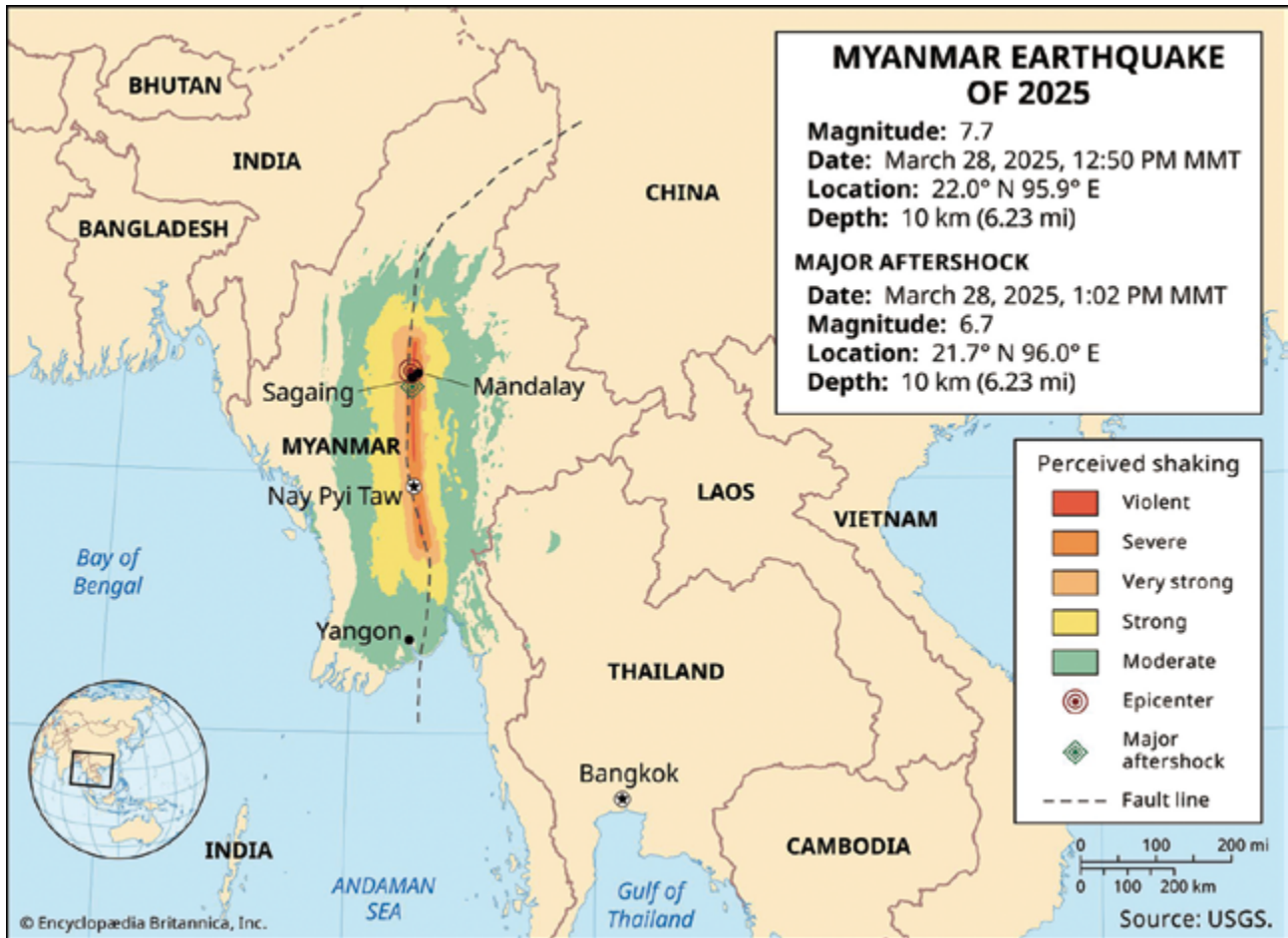


Fig.1: Location Map of the Myanmar Earthquake on 28 Mar 2025 (Source: USGS)

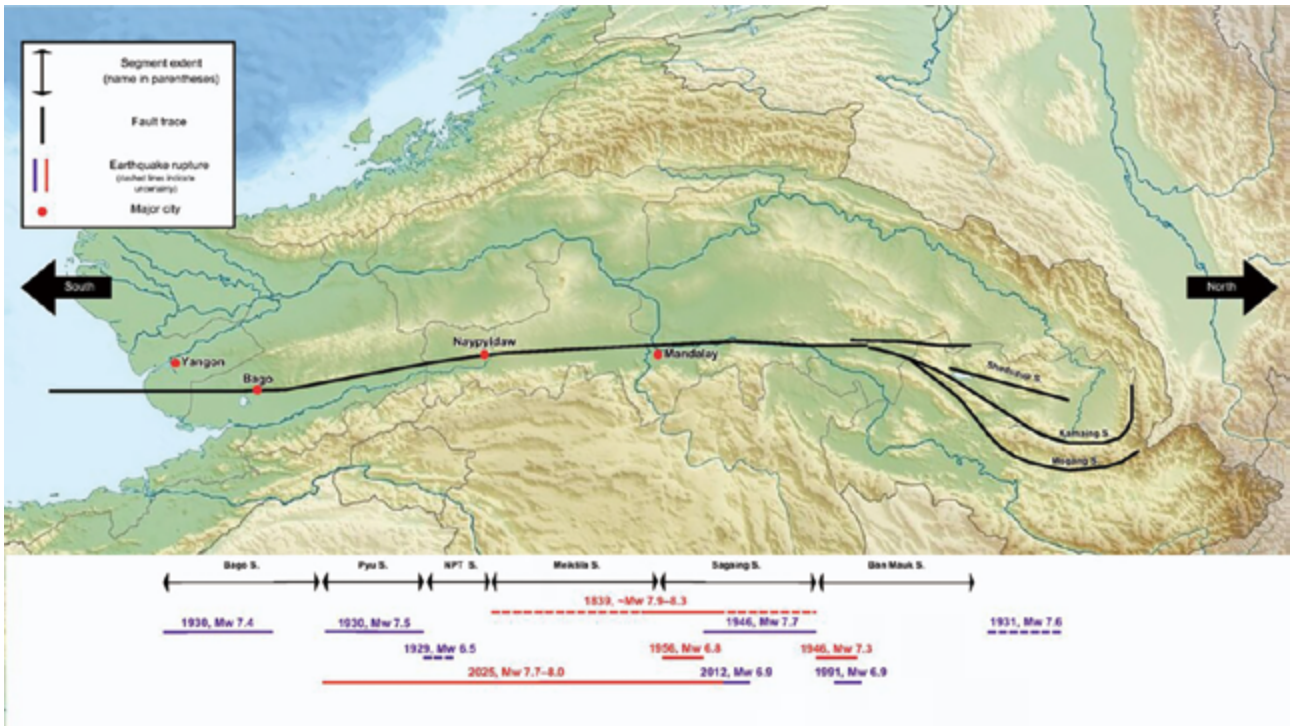


Fig. 2: Historical Earthquakes in Myanmar with fault trace, chronology and strength
 (Source: Wikipedia)

In Mandalay and Sagaing, tragedy struck during prayers when at least 500 Muslims were killed in mosques. In Sein Panyat, one of Mandalay’s poorest neighborhoods, the initial quake caused limited structural damage, but fires ignited moments later, rapidly engulfing the area. Within minutes, all 400 homes were destroyed, leaving more than 2,000 people homeless (See Fig. 3).



Fig. 3: Sein Pan Ward, Mandalay seen after being engulfed in flames due to the earthquake, photo by Kofoehtet, own work (Source: Wikipedia)

In response to the widespread devastation, the authorities declared a state of emergency across six areas: Sagaing, Mandalay, Magway, eastern Shan State, Naypyidaw, and Bago. The United Nations estimated that over 28 million people in these regions required humanitarian assistance. In a rare move, the Myanmar government formally requested international aid to support rescue and recovery operations.

The earthquake's impact extended beyond Myanmar's borders. India, Laos, China, Bangladesh, and Thailand also reported tremors. In Bangkok, a high-rise building under construction collapsed, trapping several dozen workers and underscoring the far-reaching effects of the disaster across the region.

1.1. Losses and damage

- In Myanmar, approximately 5,104 people were injured, and 3,768 people died. (See data discrepancy explanation¹)
- Nearly 22 million people, which is over a third of the population of Myanmar – require humanitarian assistance.

Amid the ongoing polycrisis in Myanmar—marked by overlapping humanitarian emergencies, fragile governance, and widespread infrastructure damage—the recent earthquake and its powerful aftershocks have deepened the suffering of already vulnerable populations. In response, several countries and nongovernmental

¹ *Annex-1*

organizations have mobilized to join local efforts, working tirelessly to support survivors and deliver life-saving assistance. The first nation to arrive at Myanmar is the Chinese rescue team followed by India and Thailand, then followed by several countries from Asia and Europe. Much of the aid has been concentrated in Naypyitaw, Myanmar's present capital, and Mandalay, the nation's second-largest city after Yangon, where population density and damage levels are particularly severe. However, smaller and more remote communities have also been profoundly affected. In these rural areas, shattered communication networks and impassable roads have severely limited the flow of information, making it difficult to assess needs and deliver timely support.

Among the most urgent priorities following such a devastating event are addressing both the immediate and long-term health and mental health needs of survivors. Vulnerable groups—especially internally displaced people, older adults, and those already facing poverty or conflict-related trauma—are at heightened risk. Ensuring access to medical care, psychological support, and stable living conditions is essential not only for survival but also for fostering recovery and resilience in the months and years ahead.

The discrepancies in data

Reported deaths and injuries differ by source and date. Early official/State Administration Council (SAC) figures were lower; UN / independent assessments and later tallies reported much higher numbers. Early reports from 28 Mar 2025 to end of March had lower death and injury figures and these rose in early April as more data came in.

Building/housing damage numbers were large and continue to be updated (e.g., the UNU-INWEH estimate of 157,000 buildings damaged).

Economic damage estimates came later (May) in broader assessments (e.g., the World Bank).

The “people affected” and/or “in need” figures run into the millions within the bracket of 5 to 9 million (*approximately 17% of the country's population*), showing the disaster's wide footprint.

Death toll reported by SAC was approximately 1,700 deaths in early reporting (first days) and total number became 3003. By 2–3 April many UN / agency summaries and rapid assessments were reporting ~2,700–3,700+ deaths and ~4,500–5,000 injured (figures continued to be revised upward). (MIMU)

Some estimates based on modelling and remote sensing warned the true toll could be substantially higher (USGS-based projections cited by rights groups and some analysts), with very large uncertainty. (Human Rights Watch)

1.2. People affected and infrastructure damages including houses & buildings

Agencies and rapid assessments reported millions affected. Published estimates in the immediate response period put the affected population in the central corridor in the millions, reports quoted figures from ~5 million up to ~9 million affected or in need in the quake footprint, depending on methodology (See Fig.4). WHO and MIMU/COAR described very large numbers displaced and they can be newly vulnerable.

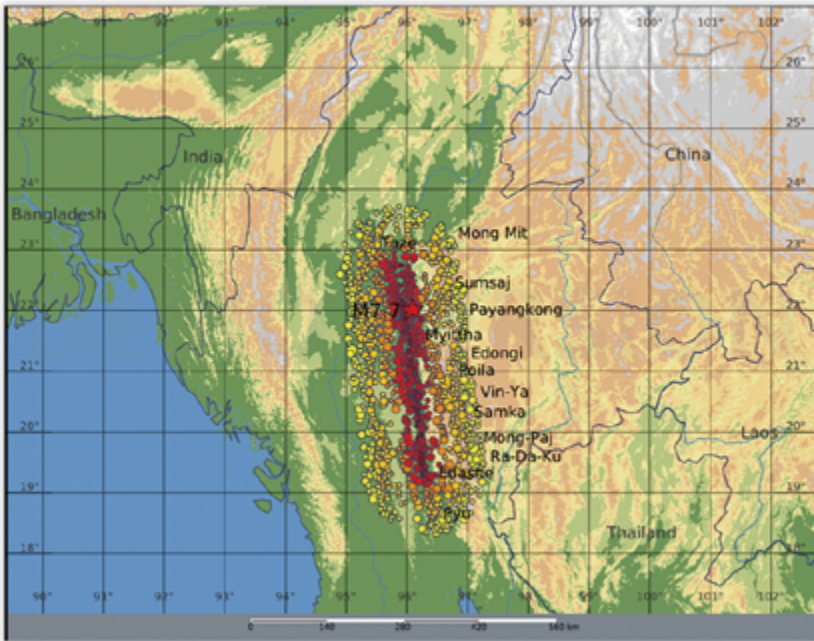


Fig. 4: Map showing estimated degree of damage (black to yellow) in settlements marked as dots (Source: Wikipedia)

Shelter / houses: cluster and assessment reporting indicated tens of thousands of houses damaged or destroyed (many reports cited ~50,000+ affected households and WHO/partners noted >10,000 buildings collapsed or severely damaged in early satellite/field estimates), MIMU data. (See Fig.4)

1.3. Economic (direct physical) damage

The World Bank’s rapid GRADE assessment estimated total direct damage to buildings and infrastructure at about US\$10.97 billion (best estimate), with a plausible range of about US\$6.24 billion to US\$15.82 billion. Mandalay, Sagaing and Bago regions accounted for the largest shares. (This is direct physical damage only; recovery costs and indirect economic losses are expected to be larger.)

Multiple independent assessments and rights/humanitarian organisations found that large swathes of the worst-affected rural areas — especially in Sagaing Region and parts of northern Mandalay Region — were hard or impossible for many international responders to access in the immediate days after 28 March. Reasons included: Active conflict and contested control (many rural township areas are under the control of resistance / ethnic armed groups rather than the SAC), with restrictions imposed by the State Administration Council (SAC). (MIMU)

Deliberate restrictions / bureaucratic barriers are the reports of the SAC imposing curfews, requiring “permits” or lists for volunteers, internet shutdowns, and limiting who/what can move in/out — all of which hindered local responders and blocked some international access. Human Rights Watch and other organisations documented and warned about these access limitations. (Human Rights Watch)

Physical access issues include collapsed bridges, damaged roads and airports, and fuel/electricity shortages

that stopped convoys reaching remote towns. MIMU/rapid assessments specifically note Sagaing town and many rural Sagaing townships, numerous townships in Mandalay Region (Amarapura, Kyaukse, Tada-U, Meiktila, Pyinmana/Pyin Oo Lwin areas were heavily hit) and parts of Bago and southern Shan / Inle Lake area as well as many rural townships reported little or no outside assistance in the early days. (MIMU)

According to the UNDP’s Myanmar Development Observatory report, access in Mandalay varies sharply between the urban core and rural outskirts. While urban Mandalay remains accessible and administratively functional under SAC control, delivering aid to rural and peri-urban areas has been complicated by damaged roads and bureaucratic delays. (Ref. 16)



Fig. 5: Table showing the vulnerability

1.4. Examples of places repeatedly flagged as not reached or poorly reached

Rural Sagaing Region (multiple townships outside the main towns): many rural areas under non-SAC control reported little to no assistance from the authorities and were difficult for international teams to reach. (MIMU)

Parts of northern / rural Mandalay Region (districts/townships such as Kyaukse, Amarapura, Tada-U, Meiktila and surrounding rural villages) — heavy damage in some towns but less external assistance to outlying, conflict-affected villages. Some townships in Bago and southern Shan (including Inle/Nyaungshwe areas) also reported serious damage and in places difficulty in getting aid in immediately. (MIMU)

Why the “did not reach” problem was particularly acute

The quake hit areas already suffering conflict and displacement, where the pre-existing lack of safe, legal humanitarian access meant many international responders had only remote or local partnerships available to reach people. In practice, local CSOs, faith groups and volunteers were often the first and primary responders, however, they could not reach every village and were constrained by supplies, transport, and the security environment as well as travel bans.

Section II. The 28 Mar 2025 Earthquake's Impact on Dams in Myanmar

The 28 Mar 2025, a powerful earthquake struck central Myanmar, near the cities of Mandalay and Sagaing had unleashed widespread devastation. In the quake's aftermath, officials and aid agencies sounded the alarm not only for the catastrophic damage to homes, roads, bridges and public buildings, but also for large-scale dams across affected regions, raising deep concern about their structural integrity and the potential for dam failures. Ref. 15 (<https://www.reuters.com/world/asia-pacific/myanmar-quake-damaged-buildings-infrastructure-causes-concern-over-dams-red-2025-03-28/?utm>)

The official information stated in Global New Light of Myanmar is the following. Quote, "*The Ministry of Agriculture, Livestock and Irrigation has stated the condition of reservoirs following the earthquake that struck on 28 March 2025. After the earthquake, relevant officials promptly inspected the safety and structural integrity of reservoirs in Nay Pyi Taw Union Territory. Preliminary inspections of 12 reservoirs managed by the Directorate of Water Resources and Improvement of River Systems confirmed that all remain structurally sound. While minor surface damage was observed on some earthen embankments, experts from the dam safety inspection team confirmed that there is no risk of failure. Among the 12 diversion weirs located downstream of the reservoirs, only the Sinthay diversion weirs, measuring 930 feet in width and 20 feet in depth sustained damage over a length of approximately 150 feet. Further detailed assessments are ongoing. Similarly, engineers are conducting inspections on major dams across all regions and states. Initial findings indicate no significant damage and further assessments are underway. Authorities will continue to release updates as needed and the public is advised that there is no cause for concern.*" unquote. Ref.5 (<https://www.gnlm.com.mm/status-update-on-reservoirs-following-earthquake/>)

2.1 Inventory of the Dams in Myanmar

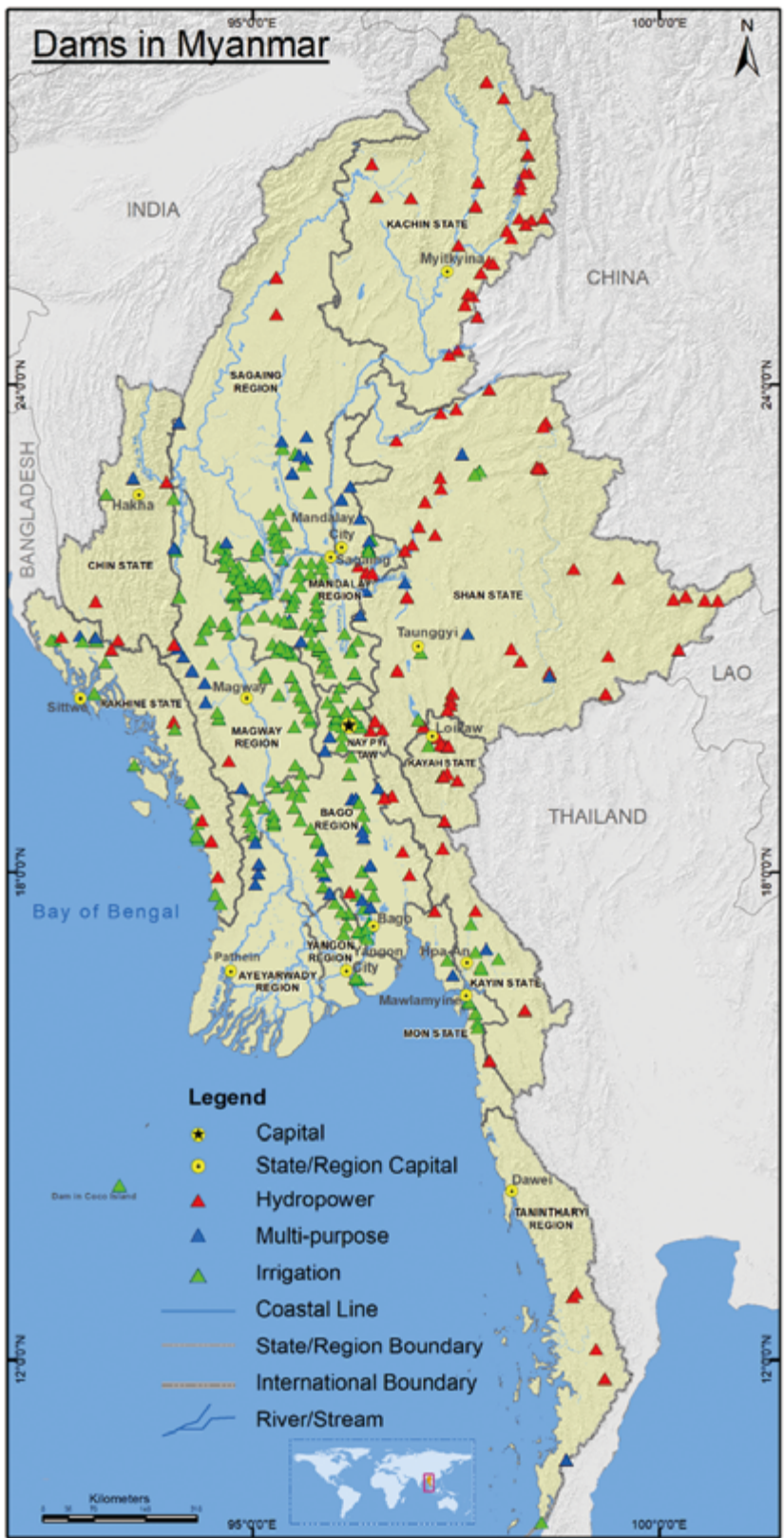
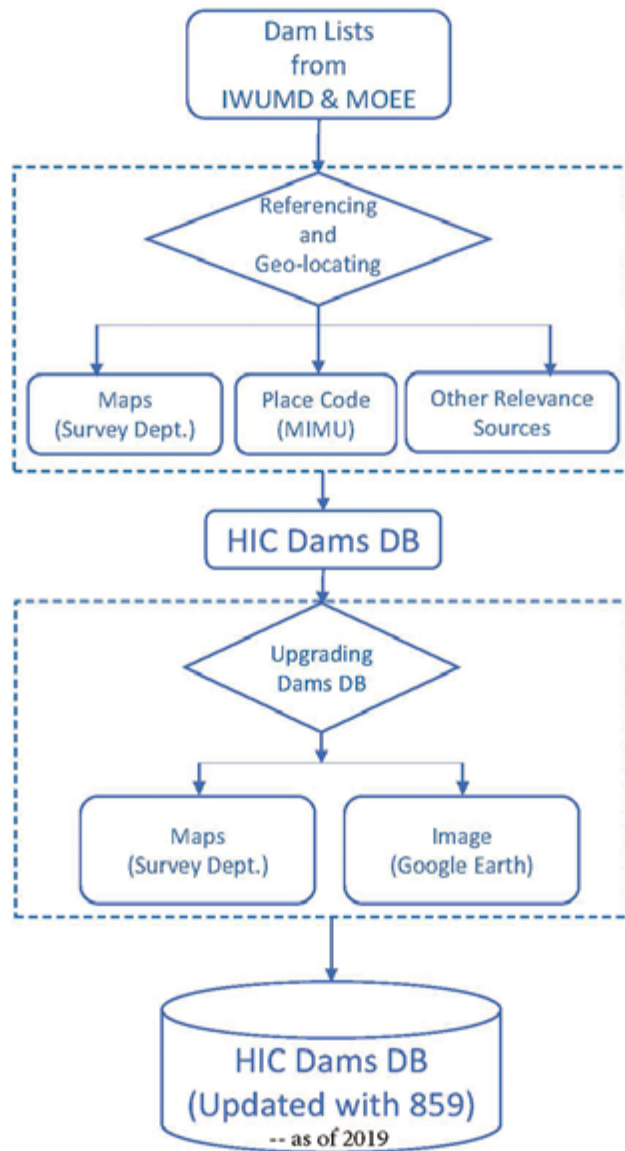


Fig. 6: Dams in Myanmar

Processes of Exploring Dams Locations



Note: By 2024, unofficial sources estimated that Myanmar's dam count could reach as many as 880.

Fig. 7: Process of building up a dam database (on going – need to continue)

2.2. Early assessment operations

After the earthquake, engineers from the relevant departments conducted initial inspections of all dams across the country. No outright-dam-failures were reported, although various levels of damages, from minor to significant damages, were observed. In parallel, the Myanmar National Committee on Large Dams (MNCOLD) formed a field inspection team, which carried out site visits to Nay Pyi Taw and the Bago Region.

The early assessment process consists of two main components. The first involves the MNCOLD Assessment Team, which is conducting inspections for nine dams in the Nay Pyi Taw and Bago regions. The second involves a joint assessment team composed of MNCOLD and the Water Think Tank group of the Transformative Water Learning Partnership (TWLP) Consortium that investigated the 4 primary water reservoirs in Yangon division. These primary reservoirs are Gyobyu Reservoir, Phugyi Reservoir, Hlawga Reservoir, and Ngamoeyeik Reservoir. The second group made a field trip to PhuGyi reservoir and other reservoirs were conducted as individual assessments.

Typical impacts/ damages on dams

- Longitudinal cracks on the dam crest and on the upstream and downstream faces of dam
- Transverse cracks on the dam crest and on both abutments
- Slip circles on the dam crest and on the upstream and downstream faces of dam
- Settlement of dam crest
- Movement of dam crest
- Liquefaction of dam foundation

Main Cause

- High Ground Acceleration or Peak Ground Acceleration (PGA)

2.2.1. MNCOLD Team official assessment on nine dams in Nay Pyi Taw and Bago region

The MNCOLD Team consisted of four senior CEC members: the President, the Vice President, and two additional CEC members. They conducted two field trips to the Nay Pyi Taw and Bago regions to inspect nine high-priority dams. These are Yan Aung Myin Dam, Ye Ngan Dam, Phyu Chaung Dam, Yenwe Dam, Lower Paunglaung Dam, Chaungmagyi Dam, Meihila Lake, Samon Retention Dam, and Ngalaik Dam. See Fig. 8: Location of 9 dams inspected by MNCOLD Team

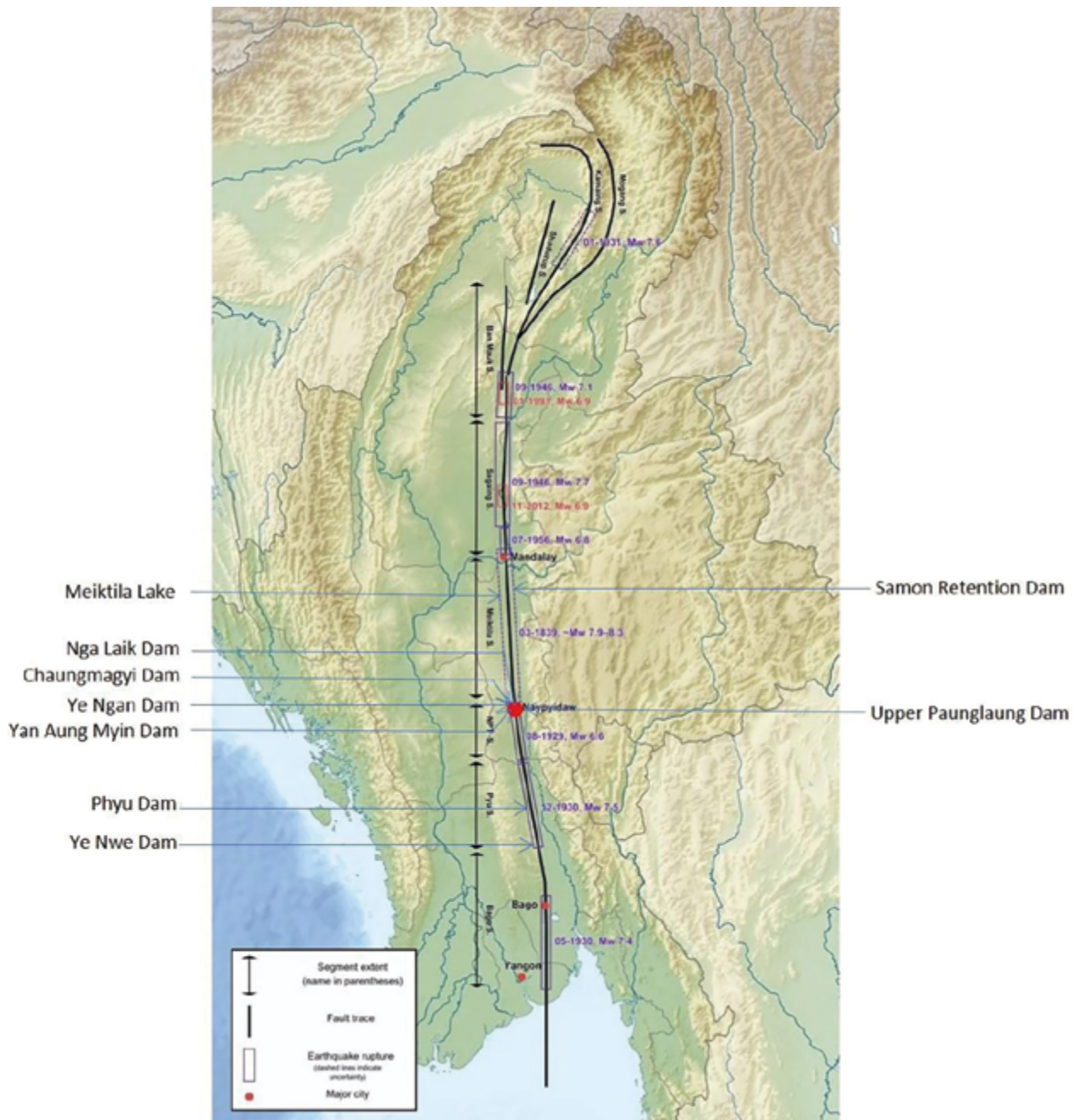


Fig. 8: Location of 9 dams inspected by MNCOLD Team

As all team members are civil engineers specializing in dam engineering, the inspections focused primarily on structural damage to the dams. Seismic aspects were not specifically evaluated, as the team did not include a seismologist. Regarding seismic data, a peak horizontal acceleration of 0.635 g was recorded at the GEOFON Station of the Department of Meteorology and Hydrology (DMH) in Nay Pyi Taw.

The inspection was conducted following the ICOLD technical guidelines, including:

- TB No. 59 – 1987: Dam Safety
- TB No. 62-a – 2008: Inspection of Dams
- TB No. 93 – 1994: Ageing of Dams and Appurtenant Works
- TB No. 58 – 2003: Dam Surveillance Guide

Yan Aung Myin Dam: Situated in Nay Pyi Taw and controlled by Nay Pyi Taw Development Committee as the dam is used for water supply and recreation purposes. Originally an earthen dam is constructed by Irrigation and Water Utilization Management Department for irrigation purpose but it is transferred to the Nay Pyi Taw Development Committee in 2006. The dam is characterized as small dam and located very close to the Sagaing fault.

It was observed 2 feet settlement on the dam crest between R.D 3000 ft to R.D 4060 ft of main dam. Also observed longitudinal crack of 500 ft long and 10 ft depth on the downstream – location at the dam face between R.D 3000 ft to R.D 4060 ft of main dam. Found a seepage crater at the downstream dam toe at R.D 3550 ft of main dam. Observed settlement of 6 ft and longitudinal cracks of 800 ft long and 28 ft depth, 250 ft long and 15 ft depth between R.D 400 ft and R.D 1350 ft of saddle dam (3). Fig. 8: Yan Aung Myin Dam situation after the earthquake

Suggestions for Yan Aung Myin Dam

- To provide inverted filter on the seepage crater at the downstream dam toe of main dam.
- To monitor and measure the seepage daily and make records.
- Closely watch at the downstream dam toe for other seepage crater.
- The dam crest level must be restored and the cracks of the main dam and saddle dam (3) must be repaired and compacted with selected earth before coming monsoon.

Ye Ngan Dam

Situated in Nay Pyi Taw. An earthen dam is constructed by Nay Pyi Taw Development Committee for water supply purpose. The dam is characterized as small dam and located very close to the Sagaing fault. Observed settlement and movement of dam crest and damages of parapets. Observed longitudinal crack of 300 ft and 4 ft depth on the downstream dam face from R.D 500 ft to R.D 1000 ft of dam. Control tower is twisted clockwise and slightly tilted away from dam. Access bridge close to dam is fall off from the pier and conduit is found choked. Releasing water from reservoir by 6 numbers of 6-inch - pipes in syphon action.

Suggestions for Ye Ngan Dam

- The dam crest level must be restored and the crack line on the downstream dam face must be repaired and compacted with selected earth before coming monsoon. Parapets must be repaired.
- The control tower, access bridge and conduit must be repaired.

Phyu Chaung Dam

Situated in Phyu township, Bago division. Constructed a zoned rockfill dam of 245 ft high and 632530 ac-ft storage capacity by Irrigation and Water Utilization Management Department for irrigation, flood control and hydropower purposes. The dam is classified as large dam and located to the west of Sagaing fault. Observed

diagonal cracks from R.D 0.0 ft to R.D 50 ft on the dam crest, longitudinal cracks on the remaining part of dam crest. The cracks are filled with sands slowly and damped with water. Dam crest settlement is observed maximum 2.4 ft at R.D 700ft of dam crest and dam movement to the dam downstream direction is maximum 0.83 ft between R.D 500 ft and R.D 550 ft of dam crest. Crack lines of the dam crest occurred in the portion filled by river bed material over the center core.



Fig. 9: Phyu Chaung Dam Longitudinal Crack on the Dam Crest (R.D 700 ft)



Fig. 10: Phyu Chaung Dam Diagonal cracks at the Dam Left End (R.D 50 ft)

Suggestions for Phyu Chaung Dam

- All the cracks must be repaired and compacted with selected material before coming monsoon.
- The dam crest level must be restored.

Yenwe Dam

Yenwe dam is situated in Kyauktaga township, Bago division. A zoned earthfill dam of 251 ft high and 931800 ac-ft is constructed by Irrigation and Water Utilization Management Department for irrigation, flood control and hydropower purposes. The dam is classified as large dam and it is located to the west of Sagaing fault. Observed dam crest settlement is maximum 2.19 ft at R.D 600 ft and movement of dam crest is maximum 0.85 ft at the same R.D of dam crest. After earthquake, the gauge reading is increased about 2 ft and the piezometer pipe is protruded out 2 ft above the dam crest. It is assumed subsidence due to liquefaction of 55 ft thick sand foundation underneath the dam at the moment of earthquake. As rockfill zone is strengthening from the back of dam at the downstream dam toe, no evident of liquefaction is noticed. Observed transverse cracks at the joint of abutment with both ends of dam.



Fig. 11: Ye Nwe Dam Crack Line at the Left Abutment



Fig. 12: Ye Nwe Dam Crack Line at the Right Abutment

Suggestions for Yenwe Dam

- Open test pits for checking depth of transverse cracks at both ends of dam.
- These cracks must be repaired and compacted with selected earth before coming monsoon.
- The dam crest level must be restored.

Lower Paunglaung Dam

Lower Paunglaung dam is situated in Nay Pyi Taw. A center core rockfill dam of 430 ft high and 549420 ac-ft storage capacity is constructed by Irrigation and Water Utilization Management Department for irrigation and hydropower purposes. The dam is characterized as large dam and it is located to the east of Sagaing fault. Observed longitudinal crack line of 2800 ft, maximum 0.4 ft in width and 2.5 ft in depth in the center of dam crest from R.D 200 ft to R.D 3000 ft. The crack line in discontinuity is filled with sands slowly and damped with water. The open test pits in 100 ft apart are dug and checked the depth of crack line. The trapezoidal channel in 3 ft depth is dug by mini backhoe and filled with selected earth for the whole crack line. Observed no settlement and movement of dam crest during earthquake.



Fig. 13: Lower Paunglaung Dam Longitudinal Crack on the Dam Crest



Fig. 14: Lower Paunglaung Dam Measuring Width of Crack Line

Suggestions for Lower Paunglaung Dam

Upper Paunglaung and Nan Cho retention dams are situated at the upstream of dam. It is advised to follow proper regulations and dam monitoring according to the dam surveillance guidelines for the safety of dam downstream area.

Chaungmagyi Dam

Chaungmagyi dam is situated in Nay Pyi Taw and controlled by Nay Pyi Taw Development Committee. The dam is used for water supply purpose only. An earthen dam is constructed by Irrigation and Water Utilization Management Department and transferred to the Nay Pyi Taw Development Committee in February 2007. It is characterized as an intermediate dam and located very close to the Sagaing fault. Observed transverse crack lines due to differential settlement on the dam crest from R.D 3800 ft to R.D 4000 ft and R.D 5450 ft to R.D 5550 ft. Assumed depth is from dam crest to full reservoir level. The reservoir water level is observed below the full reservoir and below the transverse cracks. Observed longitudinal crack line of 7 ft to 8 ft depth on the dam crest from R.D 4100 ft to R.D 5500 ft. Observed two longitudinal crack lines of 3 ft to 4 ft depth on the upstream dam face from R.D 4100 ft to R.D 4150 ft and from R.D 4700 ft to R.D 5100 ft. Observed longitudinal crack line of 3 ft to 4 ft depth on the downstream dam face from R.D 4200 ft to R.D 5100 ft on the second berm. Observed transverse cracks on the downstream dam face, 4 ft to 5 ft depth between the first and second berm at R.D 5200 ft and 3 ft to 4 ft depth over the rock toe at R.D 5100 ft. Observed maximum dam settlement of 5.7 ft and maximum dam movement of 2 ft to 3 ft to dam downstream direction of dam crest at R.D 5000 ft. Malfunction of the gates of control tower.



Fig. 15: Chaungmagyi Dam Transverse Crack Lines at R.D 3800 ft



Fig. 16: Chaungmagyi Dam Differential Settlement of Dam Crest at R.D 5000 ft



Fig. 17: Chaungmagyi Dam Longitudinal Crack Line on the Dam Downstream Face at R.D 4200 ft

Suggestions for Chaungmagyi Dam

Open test pits for checking depth of crack line. All the observed crack lines must be repaired and compacted with selected earth before coming monsoon. Malfunction of gates must be repaired for releasing water by conduit. The dam crest level must be restored. To measure the collective seepage at the downstream dam toe by V – notch. It is advised proper maintenance and operation according to the dam surveillance guidelines for the safety of dam downstream area.

Meiktila Lake

Meiktila lake is situated in Meiktila township, Mandalay division. It is a manmade ancient lake of more than one millennium and used for water supply and irrigation purposes. The lake is maintained and operated by Irrigation and Water Utilization Management Department. The crest of embankment at Meiktila is a part of Yangon – Mandalay highway. The lake is located to the west of Sagaing fault. Around 70 ft high slip at the downstream face of embankment at Meiktila. Cracks on the surface of highway and currently traffic is closed to public.

Suggestions for Meiktila lake

- To remove debris and provide rock toe with filters only in the affected portion.
- Part of falling earth before the filter lines is left for stability and compacted with selected earth on it.
- After repairs, open traffic to public.

Samon Retention Dam

Samon Retention Dam is situated in Thazi township, Mandalay division. An earthen dam is constructed by Irrigation and Water Utilization Management Department for irrigation purpose. It is characterized as an intermediate dam and located to the east of Sagaing fault. At the moment of earthquake, bursting of sand and water from the ground occurred at the edge of second last concrete slab of emergency spillway. Observed 2 inches of settlement at the edge of concrete slab with 8 ft cutoff.

Suggestions for Samon Retention Dam

- Drilling a hole at the edge of concrete slab and fill with pure sand by applying pressure and plug the hole.

Ngalaik Dam

Ngalaik dam is situated in Nay Pyi Taw. An earthen of 82 ft high and 75000 ac-ft storage capacity is constructed by Irrigation and Water Utilization Management Department for irrigation purpose. It is characterized as large dam and located to the west of Sagaing fault. Due to proper maintenance and operation of dam, it is found no defects on dam, conduit and spillway.

Suggestions for Ngalaik Dam

- Pressure relief wells are installed at the downstream dam toe for relieving pressure and seepage from dam. It is advised all the pressure relief wells must be functioning properly and measure the collective seepage by V – notch at the downstream dam toe.

Reflection

The MNCOLD team could make inspection only on few, not all of the affected dams. This report is not representing for all dams of the whole country. In conclusion, dams are designed for safety in all aspects including earthquake. According to the ICOLD TB No. 72, 2010 Revision, it is mentioned how to select the design earthquakes for dam and related structures. In Myanmar, earthquake design is just to apply seismic coefficient method for dam. During this magnitude 7.7 earthquake, some large dams in Sagaing division and Mandalay division are

found safe. But some small, intermediate and large dams in Nay Pyi Taw and Bago division are found cracks, settlement and movement of dam without any failure. It is concluded that to review the previous earthquake design and modify all dams in accordance with the ICOLD TB No. 72, 2010 Revision. Based on the inspections, recommendations were made concerning the condition and behavior of major existing dams.

2.2.2. Joint assessment team of MNCOLD and Water Think Tank of TWLP Consortium

This is a brief report of the early assessment by MNCOLD Chairperson and Water Think Tank members of the Transformative Water Learning Partnership (TWLP) Consortium.



Fig. 18: The presentation title and contents to the HELP25 meeting on 7 July 2025

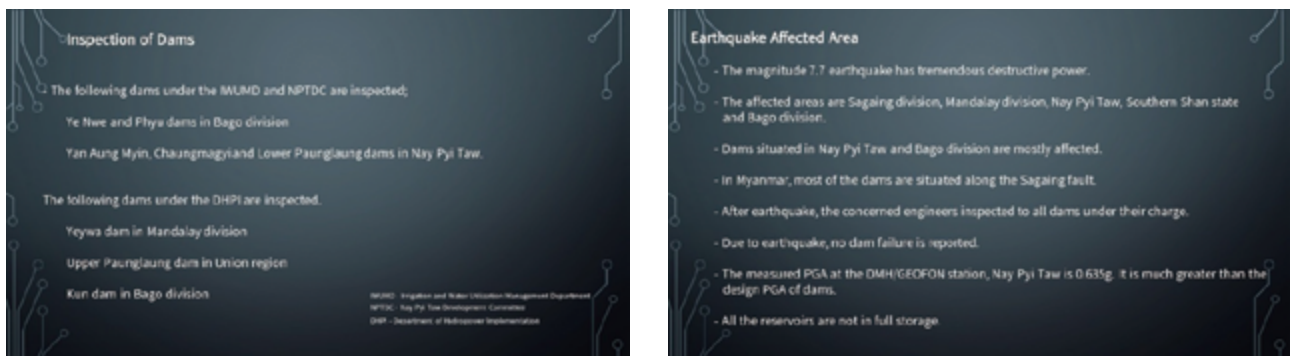


Fig. 19: Inspection of Ye Nwe and Phyu dams in Bago region and Earthquake affected areas

The early assessment process consists of two main components. The first involves the MNCOLD Assessment Team, which is conducting inspections for nine dams in the Nay Pyi Taw and Bago regions. The second involves a joint assessment team composed of MNCOLD and the Water Think Tank group of the TWLP consortium that investigated the 4 primary water reservoirs in Yangon division. These primary reservoirs are Gyobyu Reservoir, Phugyi Reservoir, Hlawga Reservoir, and Ngamoeyeik Reservoir. The second group made a field trip to PhuGyi reservoir and other reservoirs were conducted as individual assessments.

For the residents of Yangon, clean, treated water from Gyobyu, Phugyi, Hlawga, and Ngamoeyeik supports daily needs: drinking, cooking, hygiene, agricultural use and industry use. The groundwater resources become less reliable, due to over extraction and/or contamination by Nargis cyclone in 2008 as well as sea water intrusion, the reservoir system becomes more important. A total of 232 million gallons of water are being distributed

daily for Yangon Region, according to the Engineering Department (water and sanitation) of YCDC. In the past, YCDC provided 205 million gallons of water daily to Yangon residents through water sources such as Ngamoeyeik, Phugyi, Gyophyu, and Hlawga reservoirs. With the completion of the Lagunpyin and Hlaing river-Hlawga water supply projects, the water supply increased from 210 million gallons in May 2021 to 232 million gallons in December 2022. Water from the above sources is being pumped from the Yegu water pumping plant in Mayangon Township to all townships in Yangon. Bala creek, Nyaunhnapin water treatment plant and Aungdagun Water treatment plant are also providing daily water supply to Yangon's growing population. (Global New Light of Myanmar) <https://www.gnlm.com.mm/232-mln-gallons-of-water-distributed-daily-for-yangon-region/>

The network of surface reservoirs, Gyobyu, Phugyi, Hlawga, and Ngamoeyeik, forms the backbone of Yangon's municipal water supply. While they collectively provide substantial water volume, the increasing city population, changing rainfall patterns, and ageing infrastructure present serious challenges. Sustaining Yangon's growth and quality of life will depend on effective reservoir management and expansion of water infrastructure even in the normal situation. At present, 28 Mar 2025 Earthquake impacted on water security in general and dam's maintenance in particular. The assessment of four reservoirs in Yangon division concluded that Phugyi dam has no immediate dam failure, or serious damage, the long-term sustainability should be reinforced. Hlawga reservoir is under threat. Its primary challenges are water scarcity, quality, and infrastructure. The reservoir often experiences low water levels, especially during the hot season, due to insufficient rainfall and high demand from a growing population and industrial zones in Yangon. This necessitates supplying water to some townships on a part-time basis. The watershed of that reservoir needs to be rehabilitated most urgently. Yangon is highly susceptible to climate change, particularly regarding rainfall patterns and hence the availability of water resources is affected. Gyophyu and Ngamoeyeik need more in-depth investigations. Hence dam safety issue in Yangon division is broader than engineering or technology issue.

The significant supporter for Yangon water supply and waste water management came from JICA in the past. JICA's collaboration with the Yangon City Development Committee (YCDC) on major projects, like improving Yangon's water supply, was well underway by Feb 2015 when helping YCDC tackle water loss, theft, and infrastructure issues, indicating a partnership that likely began earlier, but was prominent around that time for water sector development. The principle of managing water resources at the lowest appropriate level is a core component of the Integrated Water Resources Management (IWRM) framework and it is suitable when implementing the following section III, the proposed recovery process.

Section III. The Proposed Recovery Process

The recovery process following the 28 March 2025 earthquake in Myanmar has been extremely complex and protracted, shaped by multiple interdependent factors. The pace and effectiveness of recovery depend largely on the reachability, transportation infrastructure, the level of security, availability of funding, and accessibility in affected regions, the capacity of existing infrastructure, the strength of governance mechanisms, and the impact of ongoing conflict in parts of the country. Areas that remain insecure or difficult to access are experiencing lack of or slower progress compared to relatively more stable regions.

- The World Bank projects that due to the earthquake Myanmar's economy will contract ~2.5 % in FY 2025/26 (due to losses and disruptions) and then later rebound as reconstruction takes hold. Recovery time will depend on many factors: funding, security/access, infrastructure capability, governance, and ongoing conflict in parts of Myanmar.
- Given the scale of damage, full recovery (in infrastructure, homes, services, livelihoods) likely will take several years—not just months. Early recovery (shelter, critical services) may happen in 1–2 years in accessible areas, but full rehabilitation may span 5–10 years depending on resources and stability. The presence of ongoing seismic risk (aftershocks) and conflict complicates the timeline.
- Therefore out-of-the-box thinking is necessary in this situation to design the innovative-recovery-process “for Dams Safety in Myanmar” that will bring local resources and international community to work together on people-centered and self-reliance projects.

3.1 The innovative-recovery-process (proposed)

Proposed Dam Safety Recovery & Development Plan

Short-, Medium-, and Long-Term Three-Phase Strategy

Led by Myanmar Professionals & Communities, Supported by External Partners

Vision

To restore, strengthen, and sustainably manage Myanmar's dams through a community-centered, technically robust, and financially decentralized system that promotes resilience, safety, and long-term water security.

3.2. Phase 1 — Short-Term (0–12 Months) Local Capacity Activation and Development

Objectives

- Address urgent dam safety risks by name of the dam
- Mobilize local engineering and community teams
- Establish project governance structure with transparent financial flows
- Begin rapid assessments and stabilization work

Key Actions

1. Mobilize Local Myanmar Professional Task Teams with local hydrologists, engineers, geologists, ICT and IWRM professionals.
2. Provide rapid training refreshers through remote or onsite local and international experts.
3. Community Safety & Awareness Activation by organizing village-level Dam Safety Guardians; Conduct emergency response drills; Establish communication channels for early warnings.
4. Rapid Technical Assessment; Prioritize dams using a risk-ranking matrix (population at risk, structural condition, hydrological stress, etc.).
5. Emergency repairs (spillway clearing, embankment reinforcement, seepage control).
6. Temporary monitoring instruments (water level gauges, crack meters).
7. Decentralized Financial Support Mechanisms
8. Set up a transparent community + technical team funding pool.
9. Enable international donors to support village tract or township-level dam clusters
10. Set Up Multi-Level Management Model (Initial Stage)
11. Village Level: DSGs for reporting & rapid response
12. Township/District Level: Local technical units for repairs
13. Thematic Coordination Centre: Data standardization and remote technical support

3.3. Phase 2 — Medium-Term (1–3 Years): Structural Rehabilitation & System Strengthening

Objectives

- Upgrade priority dams
- Build strong technical institutions led by Myanmar professionals
- Standardize safety protocols and monitoring systems with a good database
- Create sustainable financial and management models

Key Actions

1. Comprehensive Structural & Hydrological Investigations
2. Rehabilitation & Modernization Works
3. Local Capacity-Building Programs
4. Multi-Level Management Model Advancement
5. Decentralized Financing System Expansion

3.4. Phase 3 — Long-Term (3–10 Years): Resilience, Sustainability & Community-Driven Governance

Objectives

- Achieve international-standard dam safety across Myanmar
- Ensure community ownership and long-term accountability
- Modernize infrastructure to withstand climate-change impacts
- Institutionalize decentralized management

Key Actions

1. Long-Term Infrastructure Upgrades

- Spillway modernization for climate-adaptive flood management
- Structural reinforcement for seismic resilience
- Reservoir sedimentation control & watershed restoration

2. Institutionalizing Community-Led Dam Safety Governance

- Permanent community Dam Safety Committees with annual budgets
- Local water-user associations integrated into dam O&M
- Participatory decision-making on water allocation and maintenance

3. Sustainable Financial Ecosystem

- Hybrid financing model: community contributions + national funds + international partners
- Long-term maintenance endowment funds for each dam
- Incentives for local innovation (e.g., low-cost sensors, remote monitoring tools)

4. Knowledge & Innovation Hubs

- Dam Safety Training Centers in Myanmar
- Research partnerships with global universities and engineering bodies
- Local R&D into low-cost, climate-resilient solutions

5. Integrated Watershed & Climate Resilience Planning

- Catchment restoration programs
- Floodplain zoning and community-based climate adaptation
- Integration with national water resource strategy

3.5. Cross-Cutting Principles for short-term, medium-term and long-term phases

1. Self-reliance Local Leadership First

Myanmar professionals and communities at the center of every step including revenue co-creation.

2. Transparency & Accountability supported by honest and clear communication

Open financial flows, accessible reporting tools, good communication skill, third-party auditing.

3. Multi-Level Governance

Village → Township/District → Regional/National → International support partners.

4. Community Inclusion

Ethnic groups, farmers, women, and youth have formal roles in dam safety decisions.

5. Sustainability & Climate Resilience

Design for extreme weather events and long-term environmental protection.

Conclusions

Quote, Secretary-General's remarks on the UN80 Initiative on 12 May 2025, *"We face real threats to the very fabric, values, principles, and sustainability of multilateralism. But I also sense from many of you a robust determination and political will to ensure the strongest possible United Nations for the 21st century. We must rise to this moment."*, unquote.

3.6. Do No Harm (DNH) Checklist with Sector Adaptation

Hydropower

- Avoid locations with conflict presence or contested governance.
- Assess downstream sediment, fish migration, and displacement risks.
- Ensure transparent benefit-sharing and meaningful FPIC processes (Free, Prior and Informed Consent).

Irrigation - Avoid altering water access in ways that increase inter-group tensions.

- Protect smallholder and minority farmers from land or water loss.
- Promote equitable water distribution and joint management.

Flood Mitigation

- Avoid relocation without community-led planning.
- Do not create upstream/downstream harm shifts.
- Use nature-based solutions before structural ones.

Water Research

- Protect sensitive data (locations, water sources) in conflict zones.
- Use anonymized data collection and informed consent.
- Ensure findings cannot be misused in discriminatory or coercive ways.

Cross-Cutting

- Transparency, inclusion, ethical data, and local ownership must guide all activities.

Conclusions

Quote, Secretary-General's remarks on the UN80 Initiative on 12 May 2025, *"We face real threats to the very fabric, values, principles, and sustainability of multilateralism. But I also sense from many of you a robust determination and political will to ensure the strongest possible United Nations for the 21st century. We must rise to this moment."*, unquote.

The Secretary-General's words remind us that even in the hardest times, determination can light the way forward. Myanmar's earthquake has deepened existing challenges, yet step by step, with steady hearts and shared effort, we can turn despair into hope. As the Buddha taught, lighting a single candle drives away darkness. By working together—leaders, communities, and supporters alike—we can build a Myanmar of lasting peace, resilience, and prosperity, showing that even small, thoughtful actions can create meaningful change. It is time to continue the inventory of dams to complete the dam database, working on dam safety projects (various sizes) with resource mobilization.

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ICOLD World Register on Dams - Large Dams in Myanmar							
No.	ICOLD DAM List for Myanmar	Capacity (1000m ³)	Year of completion	Dam Height (m)	Dam Length (m)	Hydro Power	Dam Owner
1	A ZIN DAM	19029	1991	28	502.9		IWUMD
2	ALAINGN DAM	48106	2003	15.8	1737.4		IWUMD
3	BAINGDA DAM	461201	2003	37.3	426.7		IWUMD
4	BAW NI DAM	43419	1999	25.91	248.47		IWUMD
5	BWET GYI DAM	90279	2004	34.4	1408.2		IWUMD
6	CHI PWI NGE DAM	789	2011	47.5	220	99MW	DHPI
7	DAPEIN (1) DAM	5780	2010	46	211	240MW	DHPI
8	GYOBYU	75000	1940	41	214		YCDC
9	HUMON	2498	1998	24.4	213.4		IWUMD
10	KABAUNG DAM	1083700	2008	61	280.4	30MW	IWUMD
11	KANYIN DAM	178855	2012	59.1	1143	5MW	IWUMD
12	KATAIK DAM	69075	2007	40.84	1585		IWUMD
13	KIN MON DAUNG DAM	12976	1990	24.99	487.66		IWUMD
14	KINDA DAM	1077545	1990	71.9	620	56MW	IWUMD
15	KYEEON-KYEEWA DAM	373375	2010	50	999.7	74MW	IWUMD
16	KYET MAUK TAUNG DAM	90168	1968	34.3	2590.8		IWUMD
17	LAIVA DAM	2410	1995	22.9	213.4		IWUMD
18	LOWER PAUNGLAUNG DAM	677700	2005	131.1	944.9	280MW	IWUMD
19	MA MYA DAM	86344	2015	45.7	3596.6		IWUMD
20	MALA NAT TAUNG DAM	62871	2008	21.9	3611.9		IWUMD
21	MANN CHAUNG DAM	148018	1999	41.1	1365.5		IWUMD
22	MOBYE	900000	1972	18.3	2438.4		DHPI
23	MONE CHAUNG DAM	765269	2005	61	1978	75MW	IWUMD
24	MYITTHA DAM	465763	2016	62.5	792.5	40MW	IWUMD
25	MYO GYI DAM	443498	2016	78.6	750.1	30MW	IWUMD
26	NATMOUK DAM	124582	1996	30.5	1341.1		IWUMD
27	NGALAIK DAM	92511	1987	25	1213.1		IWUMD
28	NGAMOEYEIK	222027	1995	22.9	4724.4		IWUMD
29	NORTH NAWIN DAM	359745	1982	35.1	1615.4		IWUMD
30	NORTH YAMAR	17339	1998	19.8	3169.9		IWUMD
31	PATHI DAM	37621	1997	27.4	762	2MW	IWUMD
32	PHUGYI	104000	1990	38			YCDC
33	PHYU CHAUNG DAM	780214	2016	74.7	310.9	40MW	IWUMD
34	SALIN DAM	164053	2002	67.1	844.3		IWUMD
35	SE TAW GYI DAM	447569	1987	40.5	1255.8	25MW	IWUMD
36	SHWEGYIN	2080000	2011	56.4	1100	75MW	DHPI
37	SHWELI 1	24110	2009	47	162	600MW	DHPI
38	SINTHE DAM	176499	1999	33.2	411.5		IWUMD
39	SUNCHAUNG	37893	2002	39.9	2865.1		IWUMD
40	SWA CHAUNG	266864	2002	29.6	2011.7		IWUMD
41	TABUHLA	240036	1996	29	397.8		IWUMD
42	TAUNGNAWIN	354009	1995	43	5082.2		IWUMD
43	THAPHAN SEIK DAM	3552428	1997	32.9	6884.5	30MW	IWUMD
44	THAUK YEGAT (2) DAM	400300	2012	93.8	382	120MW	DHPI
45	THIT SON	49296	1962	24.4	1103.4		IWUMD
46	THONESE DAM	292977	2003	45.7	402.3		IWUMD
47	UPPER PAUNGLAUNG	1700000	2015	98	515	140MW	DHPI
48	WABAR DAM	5119	1994	21.5	629.1		IWUMD
49	WE GYI DAM	310837	2001	35.1	1271		IWUMD
50	YAZAGYO DAM	64141	2015	50.3	1452.4	4MW	IWUMD
51	YENWE DAM	1149358	2007	76.5	320	25MW	IWUMD
52	YEYWA	2611000	2010	132	690	790MW	DHPI
53	YEZIN DAM	90044	1976	33.5	2468.9		IWUMD
54	ZAUNG TU DAM	407049	2000	44.8	1797	20MW	DHPI
55	ZAWGYI DAM	638775	1998	44.2	777.2	12MW	IWUMD

5 Recent Flooding in Japan

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1. Introduction

In recent years, climate change has heightened flood risks in Japan, leading to significant flooding each year.

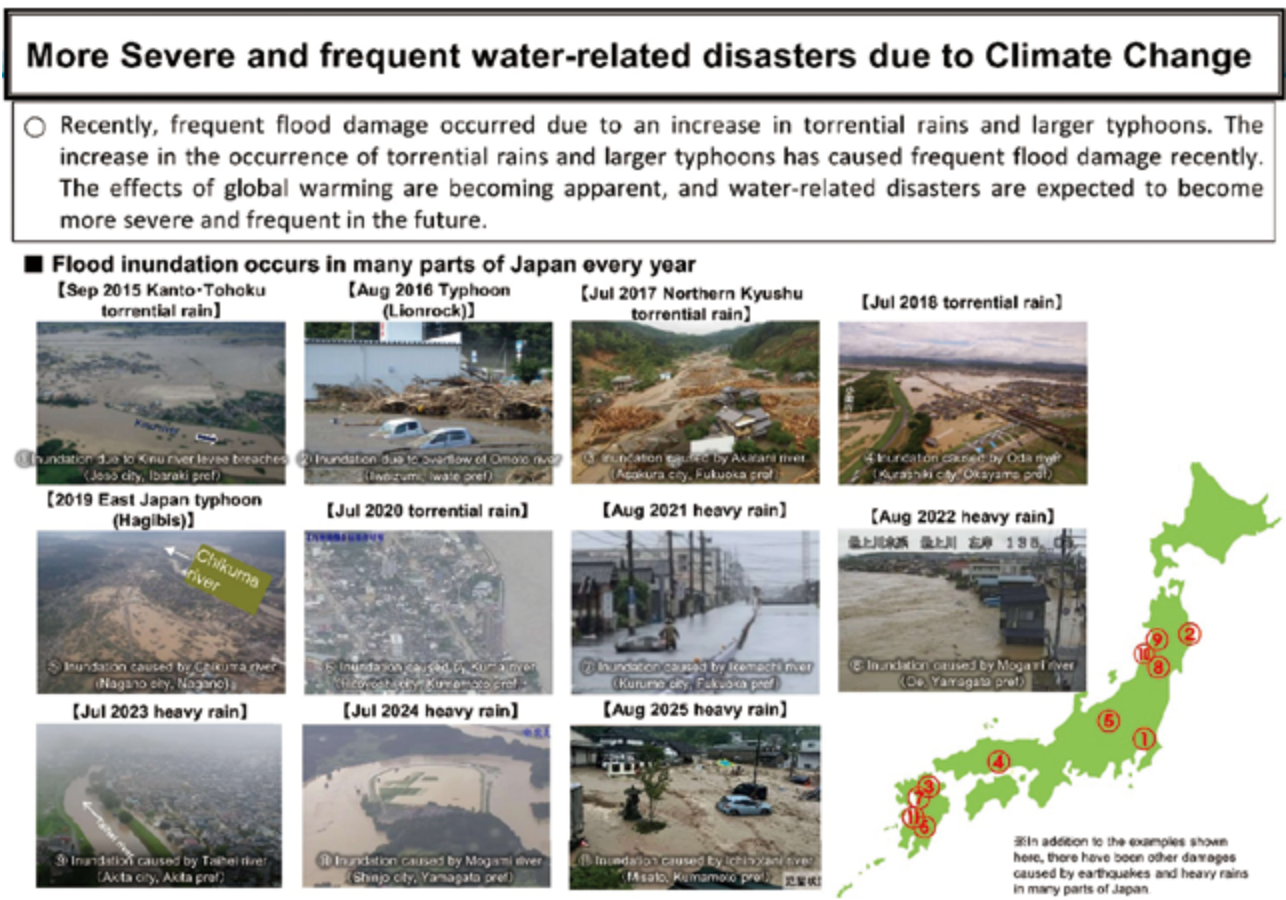


Figure 1. Recent Flood Damage Cases in Japan

This paper discusses recent flooding events in Japan, focusing on two significant occurrences: the heavy rainfall that began on 20 September 2024 and the heavy rainfall that began on 6 August 2025. It also presents examples of the effectiveness of flood control measures observed during the heavy rainfall on 6 August 2025.

2. Recent Flooding in Japan

(1) Heavy Rainfall Beginning on 20 September 2024

This section discusses the damage and various aspects of the heavy rainfall that began on 20 September 2024.

(a) Weather Conditions Based on the Japan Meteorological Agency Reports

Around 20 September 2024, a weather front stalled over the Sea of Japan near the Tohoku region. On 21 September 2024, a low-pressure system along this front moved eastward across the Sea of Japan. Additionally, on 22 September 2024, a low-pressure system that had developed from Typhoon No. 14 moved from the Sea of Japan toward the Sanriku coast. The influx of warm, moist air toward this low-pressure system and the stalled front created highly unstable atmospheric conditions, resulting in heavy rain and thunderstorms across a wide area, spanning from the Tohoku region to western Japan.

In particular, a linear precipitation zone developed in Akita Prefecture around dawn on 20 September 2024 and affected Ishikawa Prefecture during the morning of 21 September 2024. In Noto, Ishikawa Prefecture, the risk of heavy rain disasters significantly increased due to this precipitation zone. As a result, a Heavy Rain Special Warning was issued for Wajima City, Suzu City, and Noto Town on 21 September 2024. From 21 to 22 September 2024, total precipitation in parts of Ishikawa Prefecture exceeded 500 mm, more than double the average monthly rainfall for September. This led to record-breaking heavy rain along the Sea of Japan coast in the Hokuriku and Tohoku regions.

(b) Damage Situation Overview

- **Casualties:** A total of 17 fatalities and 47 injuries (including both serious and minor injuries).
- **Residential Damage:** A total of 1,849 residential buildings were affected.
- **Flooding:** Flooding impacted 28 rivers across 21 river systems managed by the prefecture, with levee breaches confirmed at two locations.
- **Landslides:** There were 272 incidents of landslides and debris flows.
- **Water Supply:** Water supply facilities experienced outages that affected approximately 5,216 households.
- **Road Closures:** 48 locations on prefectural roads and higher were closed due to damage.
- **Others:** Port facilities and urban parks also sustained damage.

General Damage Information

As of 13:00, 21 November 2024, the Fire and Disaster Management Agency website reported the following:

- **Human Casualties:** 16 deaths (15 in Ishikawa, 1 in Kumamoto).
- **Residential Damage:** 108 buildings completely destroyed (all in Ishikawa); 565 buildings partially destroyed (all in Ishikawa); 285 buildings with water above floor level (270 in Ishikawa and 15 in Nagasaki); and 1,284 buildings with water below floor level (26 in Yamagata, 3 in Niigata, 1,166 in Ishikawa, 1 in Kagawa, and 88 in Nagasaki).

(c) Response to the Damage

MLIT responded as follows:

- (i) Ministerial Directive (Issued at 12:26 on 21 September 2024).
- (ii) MLIT Disaster Countermeasures Liaison and Coordination Meeting (The meetings were held on 20, 21, 22, 23, and 25 September 2024).
- (iii) Press Conferences (A joint press conference was held with relevant ministries and agencies on 21 September 2024).
- (iv) Hotline¹ Establishment Status (Established with 53 municipalities nationwide, comprising 27 cities, 20 towns, and six villages).
- (v) TEC-FORCE² Dispatch Status (A total of 3,469 person-days dispatched) (Status: Completed).



Figure 2. Surveying the Damage in Affected Areas Using a Disaster Response Helicopter



Figure 3. Emergency Drainage Using a Drainage Pump Truck

¹ The hotline provides information to assist in decisions about issuing evacuation advisories. In addition to information from flood forecasts, river office directors directly contact local government heads via mobile phone to relay updates on river conditions, water level changes, and future projections.

² TEC-FORCE was established in April 2008 to offer rapid support for local governments in disaster preparedness. It comprises personnel from Regional Development Bureaus nationwide. TEC-FORCE assists disaster-affected municipalities by assessing damage, preventing further harm, and promoting early recovery. To address concerns about large-scale disasters, including the Nankai Trough mega-earthquake, the number of personnel was increased to approximately 18,000 in April 2025, up from around 2,500 at its founding.



Figure 4. Assessment of Disaster Damage



Figure 5. Dispatch of Liaison Officers to Municipalities



Figure 6. Technical Advice to Local Authorities



Figure 7. Technical Advice for Search Operations

(vi) Disaster Assessment by Disaster-Prevention Helicopters

- The disaster prevention helicopter (*Mannaka-go*) surveyed Ishikawa Prefecture on 23 September 2024
- The disaster prevention helicopter (*Hokuriku-go*) surveyed Ishikawa Prefecture on 23, 24, and 25 September 2024, and on 1 and 10 October 2024
- The disaster prevention helicopter (*Kinki-go*) surveyed Ishikawa Prefecture on 25 September 2024

(vii) Disaster Situation Survey Using Car-SAT³

Surveys were conducted in Ishikawa Prefecture on 25, 26, 27, 28, 29, and 30 September 2024 and on 1, 2, 3, 4, 5, and 6 October 2024.



Figure 8. Car-SAT

(viii) Deployment of Disaster Response Equipment (4 units dispatched at present) (Total: 981 units/days)

- Lighting Vehicles (Disaster Response): 3 units dispatched
- Car-SAT: 1 unit dispatched

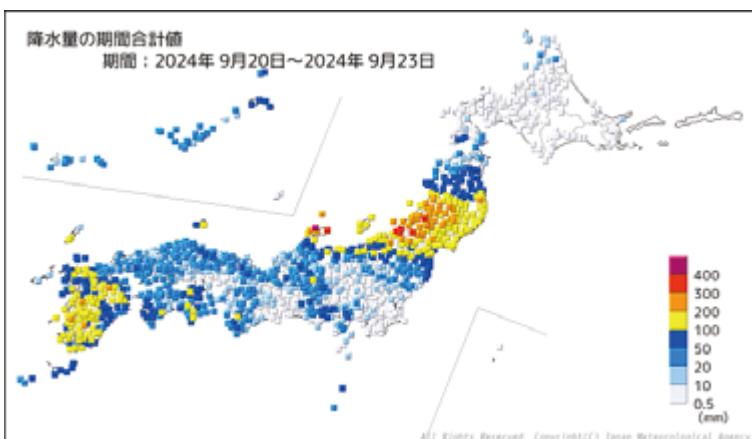


Figure 9. Distribution Map of Cumulative Precipitation Totals (20-23 September 2024)

Source: Japan Meteorological Agency website

³ * Car-SAT refers to mobile satellite communication equipment that enables vehicles to transmit footage of disaster damage in real-time via satellite communication while in motion. This capability allows disaster response headquarters to monitor damage conditions as they occur. Damage footage in real time via satellite communication while in motion. This allows disaster response headquarters to monitor damage conditions in real-time.

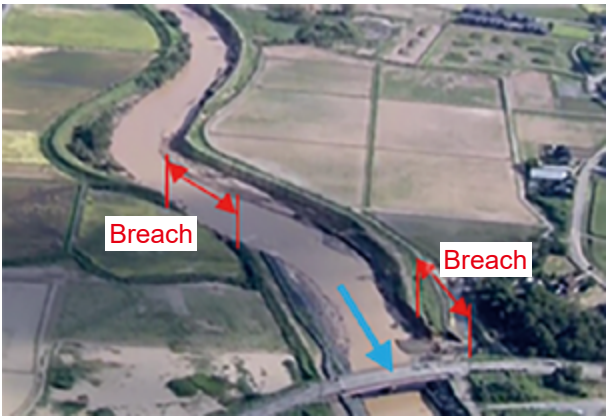


Figure 10. Breach of the Machinogawa River system's embankment (Wajima City, Ishikawa Prefecture)



Figure 11. Sediment and driftwood accumulate in the Tsukada River system (Wajima City, Ishikawa Prefecture)



Figure 12. Debris Flows and Other Related Incidents in Kute River Town, Wajima City, Ishikawa Prefecture



Figure 13. Survey of River Damage

(2) Heavy Rainfall Beginning on 6 August 2025

(a) Weather Conditions Based on the Japan Meteorological Agency Report (as of 10:00 on 25 August 2025)

From 6 to 12 August 2025, warm, moist air flowed toward a stationary front and a low-pressure system near Japan, creating highly unstable atmospheric conditions across a wide area extending from northern to western Japan. In Ishikawa Prefecture, a linear precipitation zone formed in the early morning of 7 August 2025, resulting in record-breaking rainfall with over 300 mm of precipitation within 24 hours. In Kagoshima Prefecture, a similar zone formed repeatedly from the early hours until dawn on 8 August 2025, leading to extreme heavy rainfall, with over 500 mm recorded in 24 hours. This significantly raised the risk of landslides, prompting the issuance of a Heavy Rain Special Warning for Kirishima City, Kagoshima Prefecture, in the early hours of the 8th. In the northern Kyushu region, a linear precipitation zone continued to develop from late 9 August 2025 through 11 August 2025, yielding over 400 mm of rainfall in some areas of Fukuoka and Kumamoto Prefectures within 24 hours. Consequently, another Heavy Rain Special Warning was issued for five cities and two towns in Kumamoto Prefecture (Tamana City, Nagasu Town, Yatsushiro City, Uki City, Hikawa Town, Kamikamigata City, and Amakusa City) from the early hours of the 11th until around noon.

Total precipitation from 6 to 12 August 2025 exceeded 600 mm in Kumamoto and Fukuoka Prefectures. It also exceeded 500 mm in Kagoshima, Niigata, Nagasaki, Nagano, Ishikawa, and Yamaguchi Prefectures, reaching over three times the average monthly August rainfall in some areas.

(b) Damage Situation Overview

The heavy rainfall beginning on 6 August 2025 resulted in 8 fatalities, four serious injuries, and damage to 7,914 residential buildings, primarily in Ishikawa, Fukuoka, Kumamoto, and Kagoshima Prefectures. Flooding was confirmed in 78 rivers across 58 water systems managed by prefectural governments. Additionally, 142 landslides were reported, and the water supply was disrupted for approximately 42,343 households.

Transportation infrastructure experienced significant disruptions, including highway closures and the suspension or cancellation of rail, air, and passenger ship services. MLIT provided support with its own drainage pump trucks, water sprinkler trucks (equipped with water supply devices), satellite internet equipment, and more. They also assisted in alleviating isolation in Kumamoto Prefecture by conducting situational surveys from disaster-prevention helicopters, providing technical support for road-clearing operations, and deploying TEC-FORCE personnel, for a total of 1,023 person-days. Emergency repairs were conducted on two breached rivers to secure the necessary levee cross-section and prevent secondary disasters. Road clearance operations were initiated, and isolated areas have been reopened. Emergency repairs are progressing sequentially, including in other damaged areas. For example: Kibegawa River (Kikuchi River system), embankment completion is expected by 29 August 2025; Sakuraigawa River (Sakuraigawa River system), emergency repairs were completed on 12 August 2025; National Route 249 (Suzu City, Ishikawa Prefecture), emergency vehicles have been able to pass since 15 August 2025; and work is underway to resume operations on three conventional railway lines operated by two companies, with replacement buses running or scheduled to run on suspended sections. To assess the damage accurately and provide technical advice and guidance on emergency measures and restoration methods for damaged public civil engineering facilities, disaster assessment officers from the Ministry were dispatched to Kagoshima Prefecture on 25-26 August 2025 for an emergency disaster survey.

(c) Response to the Damage

MLIT responded as follows (as of 05:30 on 18 August 2025):

- (i) MLIT Disaster Response Coordination Meeting (6 and 11 August 2025)
- (ii) Hotline Establishment Status: Established with 64 cities, 28 towns, and two villages
- (iii) TEC-FORCE Response: Currently planning to dispatch 42 personnel, totalling 974 person-days
- (iv) Disaster Situation Surveys via Disaster-Prevention Helicopters
 - Conducted by Kinki-go: 8 August 2025
 - Conducted by Harukaze-go: 9, 10, 11, 12, 13, 14, and 16 August 2025
- (v) Deployment of Disaster Response Equipment
 - Currently 2 units dispatched (total 89 units/days)
 - Drainage Pump Trucks: None dispatched to date.
 - Lighting Trucks: 2 units dispatched so far.
 - Water Sprinkler Trucks (with water supply function): None dispatched to date.
 - Water Sprinkler Trucks: None dispatched to date.
 - Satellite Internet Devices: None dispatched to date.
 - Drones: None dispatched to date.



Figure 14. Restoration Works for the Kiba River within the Kikuchi River System (Tamato Town, Kumamoto Prefecture)



Figure 15. Drainage Support Using Drainage Pump Vehicles for Inland Water Removal (Kanagawa City, Ishikawa Prefecture)



Figure 16. Aerial Survey Conducted by a TEC-FORCE Advisor (Kirishima City, Kagoshima Prefecture)



**Figure 17. Emergency Disaster Survey by Disaster Assessment Officer
(Aira City, Kagoshima Prefecture)**

3. Maintenance Effects

From 7 to 11 August 2025, heavy rain fell extensively across the Kyushu region. The Kashi Rainfall Observatory in Kumamoto Prefecture reported an extraordinary 362 mm of rainfall over 24 hours in the Kikuchi River system's Kashi River basin. In response to this situation, significant reconstruction efforts were carried out on the Kashi River, including the Yamashiro Weir and the Hirashima Weir, as well as channel dredging that removed approximately 440,000 m³ of sediment. These actions were part of the "Three-Year Emergency Measures for Disaster Prevention, Mitigation, and National Resilience" and the "Five-Year Accelerated Measures for Disaster Prevention, Mitigation, and National Resilience." The improvements led to a reduction in water levels by approximately 2 meters at the Hirashima Weir location (near 5k400). If these river enhancements had not been made, overflow would likely have occurred, potentially resulting in extensive flooding damage similar to that of the July 2012 flood, which affected 103 households and occurred during rain of comparable intensity.

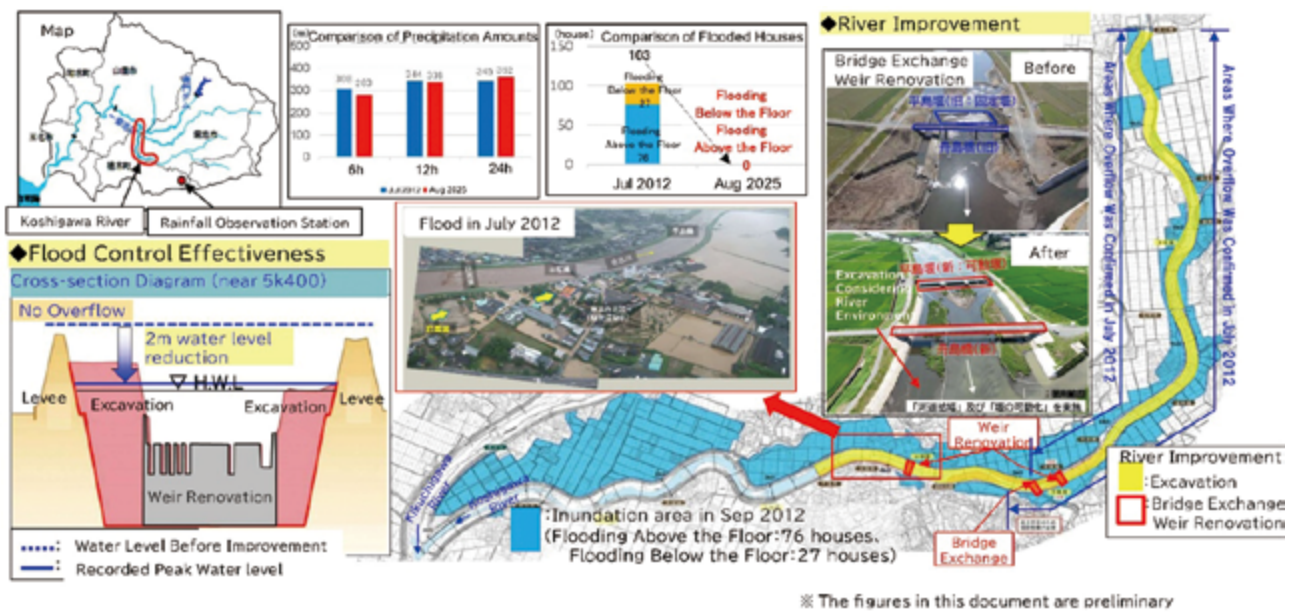


Figure 18. Maintenance Effects Demonstrated During the August 2025 Floods

4. Conclusion

In Japan, climate change has increased the risks of flooding, leading to significant flooding events every year. Notable recent floods occurred due to heavy rains starting on 20 September 2024 and again on 6 August 2025. The flood control measures that were implemented proved effective during the August 2025 floods. Given the ongoing impacts of climate change, it is crucial to promote proactive disaster prevention strategies.

6

Understanding Extreme Cryospheric Disasters in the Nepal Himalaya: Case Studies from the Thame Valley GLOF and Other Recent Events

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Abstract

The Nepal Himalayas have experienced a significant increase in the frequency, intensity, and complexity of cryosphere-related hazards in recent years. Accelerated glacier melt, the expansion of glacial and thermokarst lakes, and widespread permafrost degradation are increasingly destabilizing the region's high-mountain terrain. These evolving cryospheric processes have elevated the risk of Glacial Lake Outburst Floods (GLOFs) and related cascading hazards, making them one of the most destructive and unpredictable environmental threats in the Himalaya. Such disasters commonly arise from cascading interactions among geological, hydro-meteorological and climatic processes. As a result, high altitude communities, critical infrastructures and downstream ecosystems are facing increasing levels of risk and vulnerability.

This chapter provides a comprehensive overview of recent cryospheric disasters in Nepal and its transboundary regions, with particular focus on the 2024 GLOF event in the Everest (Thame) region and the three significant disasters of 2025 viz. the drainage of thermokarst lakes upstream of Til Village in Limi, Humla; the sudden outburst of a rapidly formed ice-dammed glacial lake at the confluence of two glaciers above Chumjung in Lo Manthang, Mustang; and the drainage of a rapidly expanding supraglacial lake on the Perupu Glacier at the headwaters of the Lhende River catchment in Kerung, Tibet, China. These events are identified as some of the most complex cascading hazards recorded in the region in recent years. Through an integrated analysis of satellite imagery and field observations, the study examines underlying physical mechanisms, associated geomorphic transformations, socio-environmental impacts, and emerging opportunities for improved risk mitigation and disaster management.

1. Introduction

Cryospheric disasters can be defined as events that have or can threaten human life, infrastructure or their welfare and are caused by or related to cryospheric processes (Ding et al., 2021). These cryosphere disasters include ice and snow avalanches, glacial lake outburst floods (GLOFs), debris flows, rock avalanches, freezing and thawing processes, snowmelt floods, snowdrifts, and water resource shortages. Among these, GLOFs represent one of the most severe threats (Chen et al., 2025; Wang et al 2025; Allen et al., 2022). GLOFs have also become increasingly frequent at a global scale, with a marked increase since the 1980s, with the average annual frequency rising from 5.2 events during 1981–1990 to 15.2 during 2011–2020 (Zhang et al., 2025). They occur when a natural dam composed of fragile glacier ice or unconsolidated moraine material suddenly

breaches or collapses, releasing large volumes of water and debris. Such floods generate high-energy waves capable of transporting debris over long distances, causing extensive damage to downstream communities, infrastructure, and agricultural land.

The Nepal Himalaya represents one of the most critical sub-regions within the HKH. While Nepal covers only over 6% of the total glacier area in the HKH (**Bajracharya et al., 2014**), it encompasses the major river basins of the Karnali, Gandaki, and Koshi, which drain southward into Nepal from the Tibetan Plateau of China and, in part, from India. Together, these basins contain more than 10% of the total glacier area of the HKH region (**Bajracharya and Shrestha 2011; Bajracharya et al., 2020**). However, glacier area loss within these basins has been significantly higher than in many other parts of the HKH. Evidence indicates that the Nepal Himalaya has already lost more than 24% (**Bajracharya et al., 2014**) of its glacier area over the past three decades, with the rate of loss accelerating in recent years. This accelerated glacier retreat has led to dramatic proliferation of glacial lakes. For instance, since the 1980s, the number of glacial lakes in the Koshi Basin has increased by 86% with total area has expanded by 47% (**Shrestha et al., 2017**). These pronounced increases in glacial lake extent and abundance have significantly heightened the risk of GLOF events across the region.

Larger proglacial lakes and their associated hazards have been relatively well studied (**Racoviteanu et al., 2022; Watanabe et al., 2009; Wilson et al., 2019**) and the assessment of these prominent glacial lakes in Koshi, Gandaki and Karnali basins had identified 47 potentially dangerous glacial lakes (PDGL) including 25 in Tibet, China; 21 in Nepal and one in India (**Bajracharya et al., 2020**). However, seasonally expanding supraglacial and ice-dammed glacial lakes remain comparatively less understood (**Miles et al., 2018b**). In recent years, these lakes have increasingly been recognized as significant hazards in high-mountain regions (**Watson et al., 2016; Sakai et al., 2010**). Supraglacial lakes develop rapidly on glacier surfaces, particularly on debris-covered glaciers, and may drain suddenly through crevasses or englacial channels, triggering localized floods and debris flows (**Miles et al., 2018a; Sakai and Fujita, 2010**). Although these lakes are often smaller in size, their abrupt drainage can impact downstream areas with little or no warning, making them difficult to monitor.

A critical emerging challenge in cryospheric hazards in recent decades is the increasing impact of such newly developed and smaller glacial lakes as well as permafrost thaw, the drainage of thermokarst lakes, shifts in precipitation patterns, and rapid snowmelt events. The impacts of these drainage events are often amplified by cascading processes, including the geological and geomorphological characteristics of the drainage pathways. Additionally, the destabilization and mobilization of moraine deposits have significantly amplified downstream disaster risks.

In particular, the frequency of breaches involving small and newly formed glacial lakes has increased, often resulting in high-impact events that propagate over long distances downstream. A notable example is the 2016 GLOF from Gongbatongsha Co, a lake with a surface area of only 0.01 km². Despite its small size, the outburst destroyed strategic friendship bridge at Kodari (Nepal -China border) disrupting trade between two countries for longer period, completely washout the 50 MW Bhoite koshi hydropower dam in Nepal locating 40km

downstream from the lake (**Cook et. al. 2018; Chen et. al. 2023, Wang et. al. 2024**). This incident underscores the necessity for a comprehensive assessment strategy that evaluates not only the physical dimensions of glacial lakes but also their inherent fragility and the vulnerability of the downstream socio-economic landscape.

Furthermore, cryosphere-related hazards in Nepal frequently manifest as cascading events where compound climatic and geomorphic processes overlap. These disasters are rarely isolated; instead, they trigger a chain of failures that amplify the total impact. The 2021 Melamchi flood serves as a prime example, where intense high-elevation rainfall and rapid snowmelt catalysed a glacial lake breach, moraine failure, and the subsequent collapse of multiple landslide dams (**Maharjan et. al. 2021**). These cascading interactions resulted in a disaster magnitude far exceeding that of the initial breach. Consequently, there is an urgent need to refine our understanding of these multi-hazard chains, ranging from the outbursts of seemingly insignificant lakes to large-scale cascading floods, to enhance disaster resilience in the Himalaya.

The urgency of this threat is further underscored by a surge in cryospheric disasters in recent years. This report provides a detailed understanding of these recent events, which have demonstrated increasingly complex and cascading characteristics. Notable among these is the August 2024 GLOF in Thame valley, where a rock avalanche triggered a chain reaction between two glacial lakes, destroying a high-altitude Thame village (**Maharjan et. al. 2025a**). Other significant recent events include the August 2023 Kagbeni flash flood in Mustang, driven by intense high-altitude precipitation and upstream dam breaching (**Khadka, 2023**), and the July 2025 supraglacial lake burst in the Lende River, which destroyed cross-border infrastructure (**Liu et. al. 2025, NDRRMA, 2025**). These events signify a shift toward compound disasters where climatic triggers and geomorphic failures coincide.

Ultimately, this study aims to synthesize past disaster data with a detail analysis of the recent 2024–2025 events, specifically focusing on the three major transboundary river basins, the Karnali, Gandaki, and Koshi in Nepal Himalaya. By examining the transboundary nature of these basins, the report seeks to bridge the gap between cryospheric science and disaster risk reduction. The goal is to develop a comprehensive understanding of how even "insignificant" cryospheric changes can trigger catastrophic results, providing a scientific basis for protecting the communities and infrastructure that depend on these volatile mountain ecosystems.

2. Historical records and Trend of Cryospheric disaster

Over the past century, GLOFs have repeatedly caused devastation across the region. Since 1921, 499 GLOF events have been recorded across the HKH, of which more than 96 GLOFs have occurred in the three major river basins of Nepal Himalaya viz. the Koshi, Gandaki, and Karnali (**Shrestha et al., 2023; ICIMOD, 2023**). These basins originate from the Tibetan Plateau in China and parts of northern India and together account for over 21% of all recorded GLOF events in the HKH (Figure 1). In recent years, a notable acceleration in GLOF occurrence has been observed. Between 2016 to 2025, 13 GLOF events were recorded within these three basins of Nepal Himalayas, representing nearly 14% of all recorded events in these basins, and approximately 3 % of the total GLOF events across the entire HKH. In 2025 alone, three lake draining events were recorded

in these three major basins of the Nepal Himalaya, underscoring the growing immediacy of the risk to local communities and infrastructure.

This rising trend of GLOF events reflects rapid changes in the high-mountain cryosphere, driven by accelerated glacier retreat, expanding glacial lakes, and increasing thermal and hydrological instability. The trend underscores the growing urgency of GLOF hazards and highlights climate change as a key driver intensifying cryospheric disaster risk in the HKH.

Figure 2 below shows the significant increase of GLOF events in the Nepal Himalaya over the past century. Between 1920 and 1959, events were rare or unrecorded, but the events began to pick up in the 1960s, with 8 events recorded. Subsequent decades showed fluctuating events, while marked increase occurred during 2010–2019, with 11 events, which is the highest recorded in any decade. From 2020 onward, seven events have already been recorded, reflecting continued rise of risk. This trend reflects accelerated glacier retreat, expanding glacial lakes, and growing thermal and hydrological instability, highlighting the rising risk of GLOFs to downstream communities, infrastructure, and agriculture.

Avalanches are another most significant and dynamic cryosphere hazard in the high mountains of the region. They occur across a wide range of elevations and seasons and are closely related to the interaction between glaciers, snow fall and cover, steep topography and permafrost conditions. Avalanches can occur in various forms depending on the materials involved and the dominant processes, including snow, ice, Rock or mixed of ice-rock avalanches. Thawing of permafrost plays a critical role in increasing avalanche activity by reducing mechanical strength that binds rock and ice on steep slopes. Combined with slope instability and disturbance in geological structures induced by seismic activity, making the rock and ice masses increasingly prone to collapse. These processes elevate the risk of large, high-impact avalanche events in mountain environments.

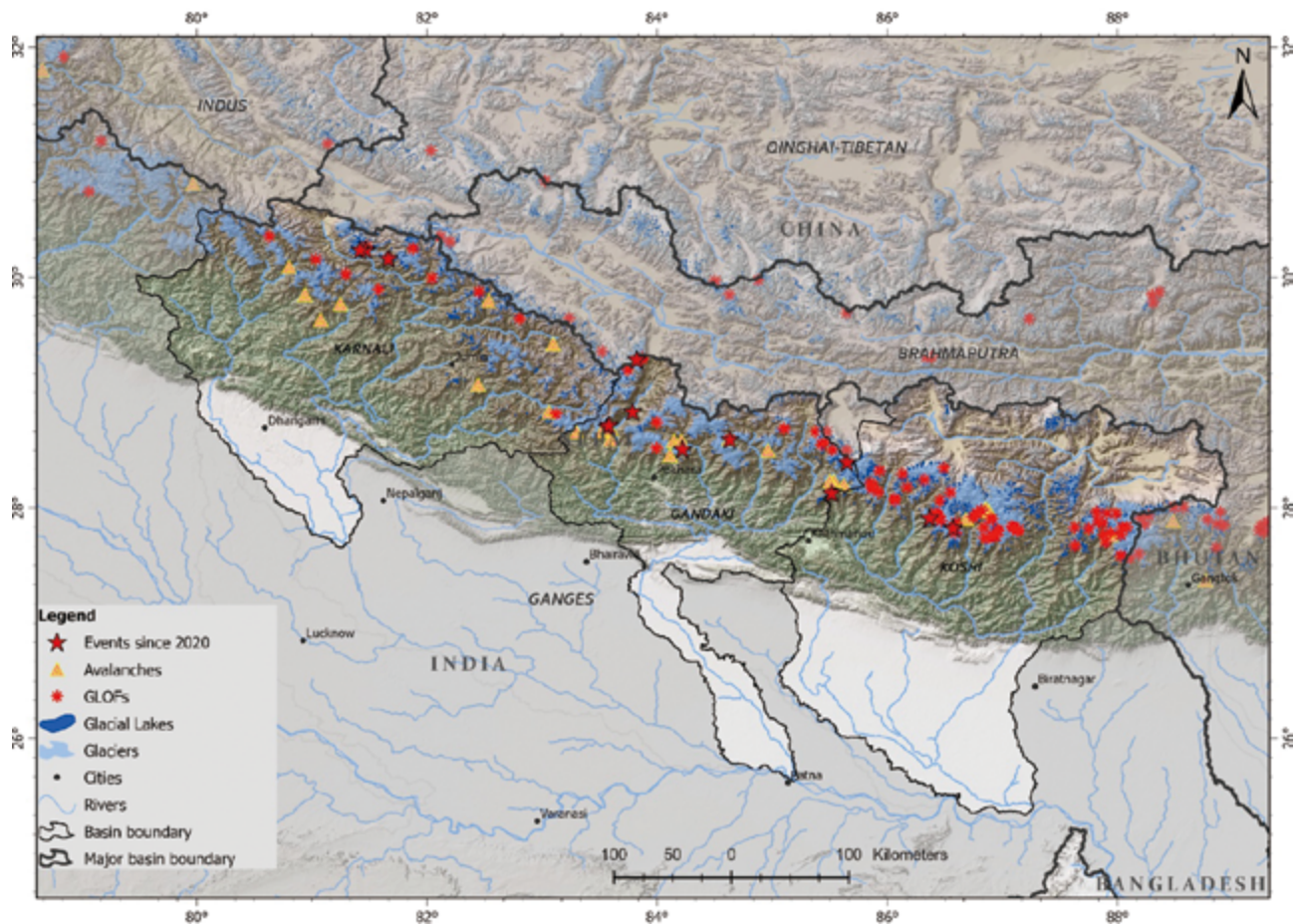


Figure 1: Map showing the study area and the distribution of recorded cryospheric disaster events highlighting the recent events from 2020.

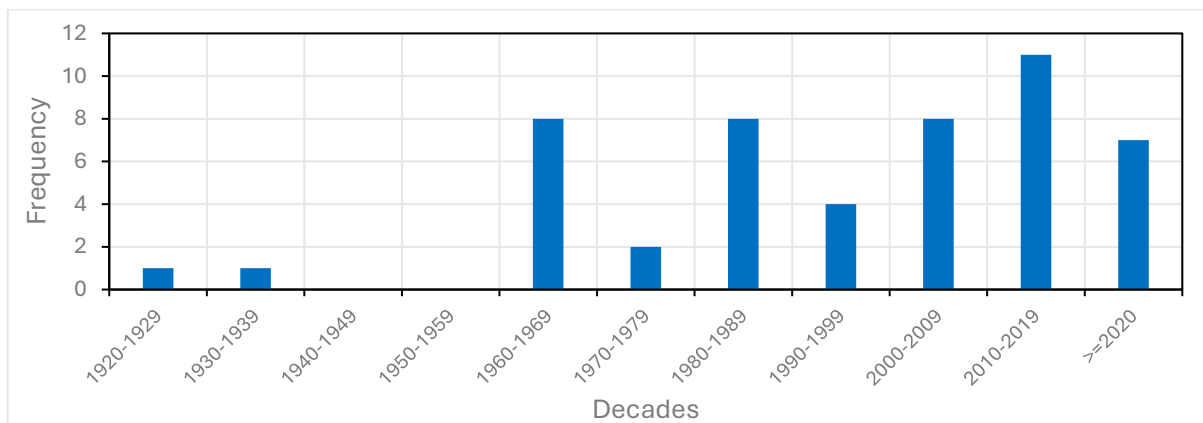


Figure 2: Decadal trend of recorded GLOF events in the Nepal Himalaya.

A striking example is the 2012 Seti Flood, triggered by a massive rock–ice avalanche from the southern flank of Annapurna IV, which vertically fell nearly 1,500 meters, releasing enormous potential energy that pulverized glacial moraines and ancient lake sediments in the Sabche Cirque (**Dwivedi & Neupane, 2013, Gurung et. al. 2015**). The avalanche rapidly mobilized the debris through the deep gorge valley, causing subsequent damming and breaching processes that led to catastrophic downstream impacts. The disaster resulted in significant loss of life, injuries, and extensive damage to houses, infrastructure, farmland, and water supply systems, highlighting

the high destructive potential of mountain avalanches, particularly for vulnerable downstream communities.

Similarly, ice avalanches generally originate from unstable hanging glaciers, ice cliffs or glacier termini located in steep slopes. The presence of crevasses and fractured ice masses further contributes to instability. Rapid glacier thinning and melting, combined with increased meltwater infiltration, weaken ice–bedrock interfaces, making glacier ice masses more prone to collapse. Ice avalanches can quickly transform into high-energy ice–rock–debris flows as they entrain loose material along their path. Further, when such avalanches impact downstream glacial lakes, they can trigger sudden breaching, greatly increasing the risk of downstream flooding. In 2024, a sudden flood in the Budi Gandaki River in central western part of the Nepal awoke peoples in downstream, although no casualties happened except disruption of trekking route for few days. This event is an example of ice avalanches occur from the termini of the Manaslu glacier and impacted downstream glacier lake (Birendra tal) **(Maharjan et. al. 2024)**.

Another major form of avalanche is the snow avalanche, which occur when accumulated snow on a slope becomes unstable and detaches. Often triggered by a combination of factors such as overloading of snow, weak bonding between snow layers, change in snow density or structures, vibrations from sound, seismic activity, or human-induced blasts. Climatic and environmental changes such as changes in snowfall patterns, rising snowlines, increased frequency and intensity rain-on-snow events accelerate snow melt all alter snowpack instability and further increase avalanche risk. Snow avalanches can take the form of slab, loose-snow, or wet-snow flows, and their speed and volume and runout distance are highly depended on terrain features and slope, and snow conditions, often cause severe damage to settlements, trekking routes, and infrastructure. Notable examples in the Nepal Himalaya include avalanches in the Annapurna region and the Everest region, which have repeatedly affected villages, mountaineers and trekking trails, causing fatalities and property damage **(Thakuri et. al. 2020, Acharya et. al. 2023)**.

On 14 October 2014, a severe snowstorm associated with Cyclone Hudhud deposited nearly 1.8 meters of snow within 12 hours in the high mountains, triggering a series of snow avalanches across the Annapurna and Dhaulagiri regions in Nepal's Manang and Mustang districts. The event resulted in at least 43 fatalities of various nationalities, including at least 21 trekkers **(Wang et. al. 2015)**. Similarly, the 7.8-magnitude Gorkha earthquake on 25 April 2015 triggered multiple avalanches, trapping climbers and trekkers at Everest Base Camp and in other high-mountain areas. These avalanches caused at least 23 deaths and injured 61 people. In addition, earthquake-induced avalanches, landslides, and rockfalls in the Langtang Valley completely destroyed Langtang village, claiming the lives of more than 350 people **(Fujita et. al. 2017, Thakuri et. al. 2020, Zhuang et. al. 2024)**.

More recently, in early November 2025, severe snowstorms associated with a Montha cyclonic system triggered numerous snow avalanches across Nepal's high-mountain region. The event killed at least nine people, including five Italian climbers, while many climbers, trekkers, and researchers were stranded at high elevations. Large-scale rescue operations were undertaken, with several individuals successfully evacuated by air, underscoring the continued and evolving avalanche risk in the Nepal Himalaya **(AFP/RSS, 2025)**.

These are just a few examples of the events. Historical records show that out of 615 avalanche events across the entire HKH region, 68 occurred in Nepal's three major basins—Koshi, Gandaki, and Karnal, resulting in 823 fatalities since 1922. Long-term data show an increase in both avalanche occurrence and associated fatalities in the Nepal Himalaya (Acharya et. al. 2023, Thakuri et. al. 2020). Between 1920 and the 1960s, avalanches were rare and largely undocumented, reflecting lower exposure and limited systematic reporting rather than absence of events. From the 1970s onward, avalanche activity became more prominent, likely due to increased human activities in high mountains through mountaineering, trekking, and infrastructure development. Records since the 1990s show a marked rise in avalanche frequency and fatalities. The most striking is in 2010–2019 decade, which records the highest number of avalanches and an exceptionally high fatality count (Figure 3). This spike is largely associated with the earthquake-triggered avalanches in the Langtang Valley. Since 2020, 12 avalanche events have been recorded within a five-year period. This overall trend reflects a transition from rare, localized avalanche events to more frequent and high-impact disasters, driven by increasing exposure and a rapidly changing cryospheric and climatic environment.

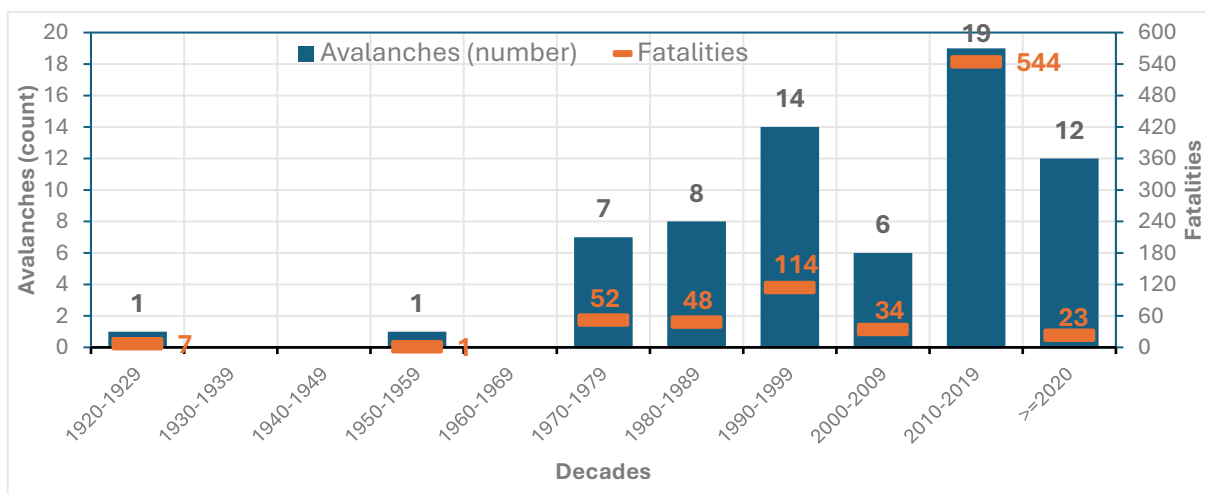


Figure 3: Decadal trend of recorded avalanches and fatalities in the Nepal Himalaya

3. Case Studies of Recent Events

Within just two years (2024 and 2025), Nepal experienced six cryosphere-related disaster events originating from glacier-influenced high-mountain regions. Several of these events caused significant downstream impacts, including loss of life, damage to infrastructure, disruption of livelihoods, and extensive sediment deposition along river corridors, underscoring the increasing linkage between high-altitude cryospheric processes and downstream vulnerability.

Figure 4 illustrates the spatial distribution of these events across Nepal's three major river basins. These events reflect the prevalence of rapidly retreating glaciers, expanding glacial lakes, degradation of permafrost and unstable geomorphic conditions in the headwater regions. The following sections provide a detailed discussion of the causes, triggering mechanisms, and impacts of each event, offering insight into the evolving nature of glacier and permafrost related hazards and the growing risks posed under a warming climate.

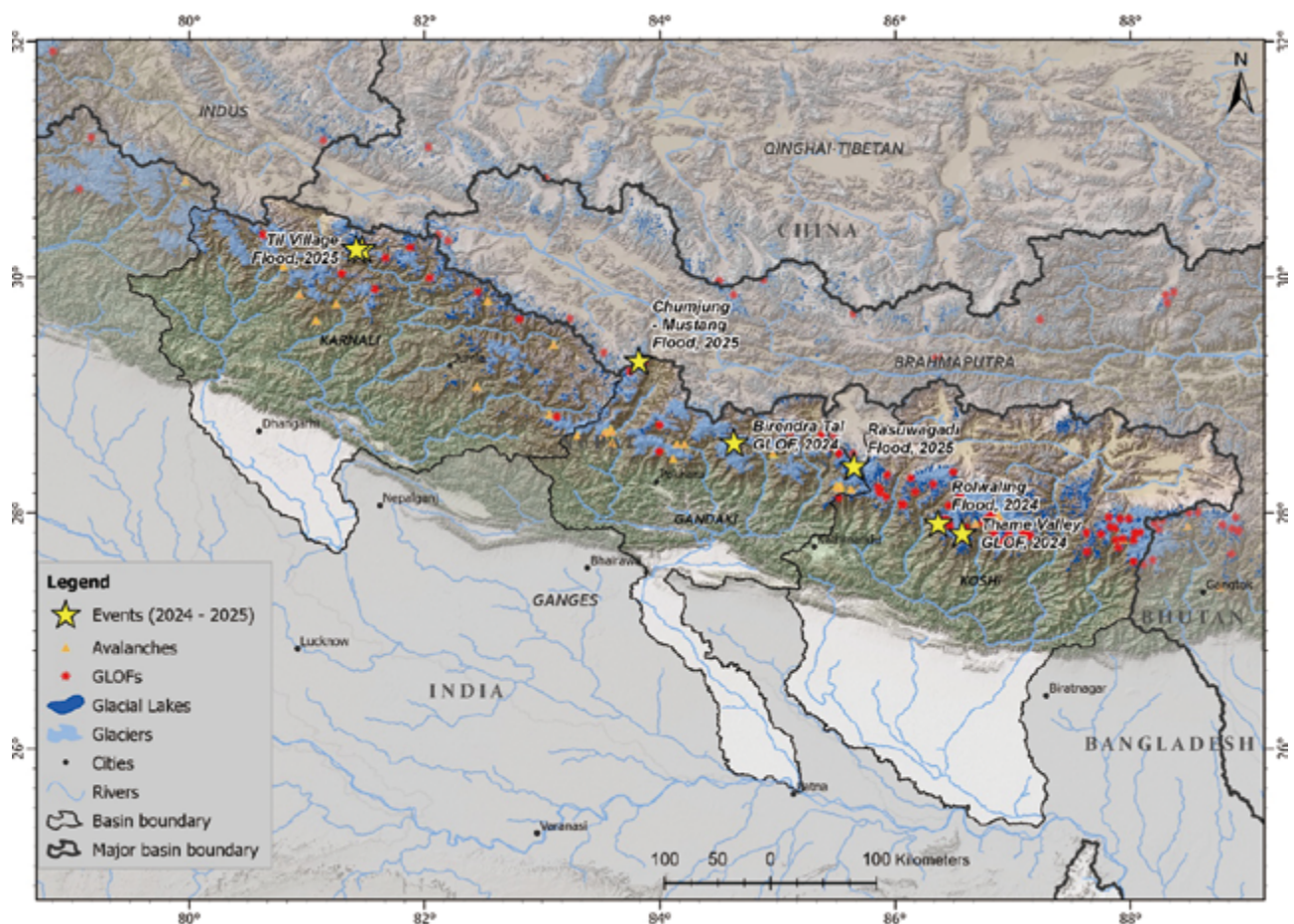


Figure 4: Location of major cryospheric disaster case study sites from 2024 to 2025.

A. Birendra Tal GLOF, 2024

Birendra Tal is an end-moraine dammed glacial lake located at 3600 masl at the northeastern base of the Mount Manaslu (8,163 m) in Chumanubri Rural Municipality, Gorkha District, western Nepal. On 21 April 2024, an ice avalanche from the steep, heavily crevassed Manaslu Glacier stuck the lake, causing a surge of lake water to flow through its outlet channel (Figure 5). The Sudden overflow temporarily disrupted the local trekking route by washing away a wooden bridge. However, no major damage to lives and infrastructure was reported (**Maharjan et. al. 2024**).

Detailed analysis of remote sensing data indicates that such events are frequent, as reflected by recurring fluctuations in the lake surface area over time and influenced by the glacier's position on the steep slope and presences of dense crevasses throughout the glacier surface. The most recent event involved only the overflow of surged lake water, which drained through a pre-existing open channel in the end-moraine dam, without causing any additional structural damage.

However, the hazard remains substantial. The analysis shows a persistent risk of debris flows as well as ice and snow avalanches from the adjacent left valley. Ongoing temperature rise and continued glacier retreat are likely to further destabilize the area, increasing the probability of similar events in the future. These future events may be more intense and could cause impacts greater than the moderate effects observed during the most recent incident.

To better understand and anticipate such future events, a detailed study of glacier dynamics, including crevasse development and ice-detachment processes, is essential. This can be achieved through remote-sensing techniques and field-based monitoring tools, such as Ground based Interferometric Synthetic Aperture Radar (GB-InSAR) and time-lapse cameras. Continuous observation using satellite imagery, in-situ lake-level sensors, and time-lapse monitoring, combined with the establishment of a flood early warning system, is necessary to improve preparedness and reduce risks in the valley.

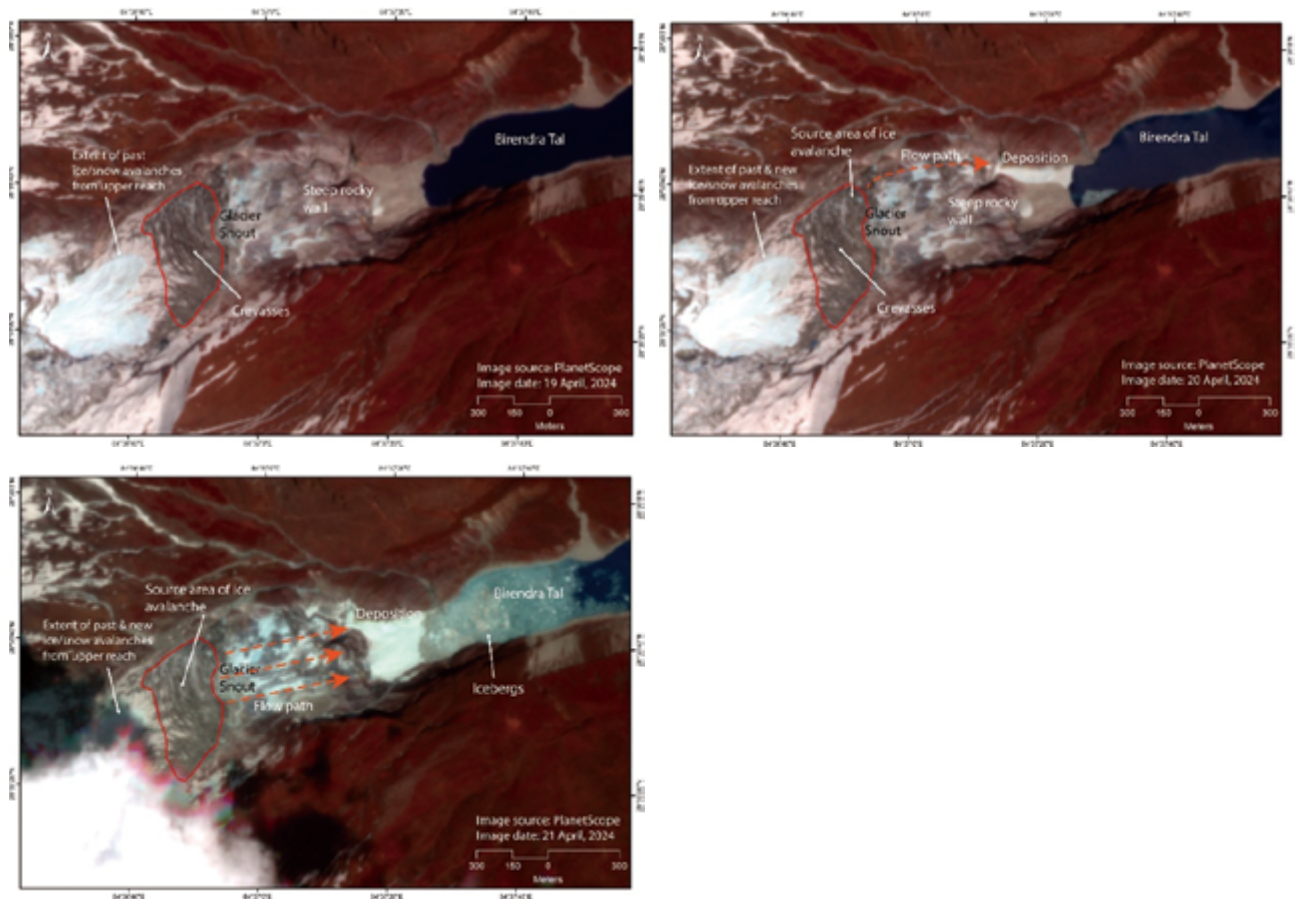


Figure 5: Sequential satellite images from 19 to 21 April 2024 illustrating ice avalanche activity from the Manaslu Glacier snout to Birendra Tal in April 2024.

B. The Thame valley GLOF, 2024

On 16 August 2024, the Thame Valley experienced a devastating glacial lake outburst flood (GLOF), caused by the sequential failure of two cascading glacial lakes. The disaster had significant impacts on Thame village and other downstream settlements, with Thame bearing the brunt of the damage. Located at 3,800 meters above sea level (masl) in Ward No. 5 of Khumbu Pasang Lhamu Rural Municipality (KPLRM), Solukhumbu district, Thame is a culturally significant Sherpa village and is also known to be among one of the earliest settlements in the Khumbu region. Beyond its cultural importance, it is also a historic mountaineering village, home to many renowned mountaineers (**Maharjan et. al. 2025a**).

Geomorphologically, Thame sits on gently sloping paleo-glaciolacustrine deposits, flanked on three sides by the lateral and end-moraine complexes which reflect its glacial past. Recent high-resolution satellite imagery

identifies eight glacial lakes within the watershed, ranging from 0.001 km² to 0.12 km², of which some are locally named while others remain unnamed. Among these, the Upper Ngole Cho and Lower Ngole Cho lakes which lie around 10 km above the Thame village were the ones that failed, setting off the chain of events leading to the flood (Figure 6).

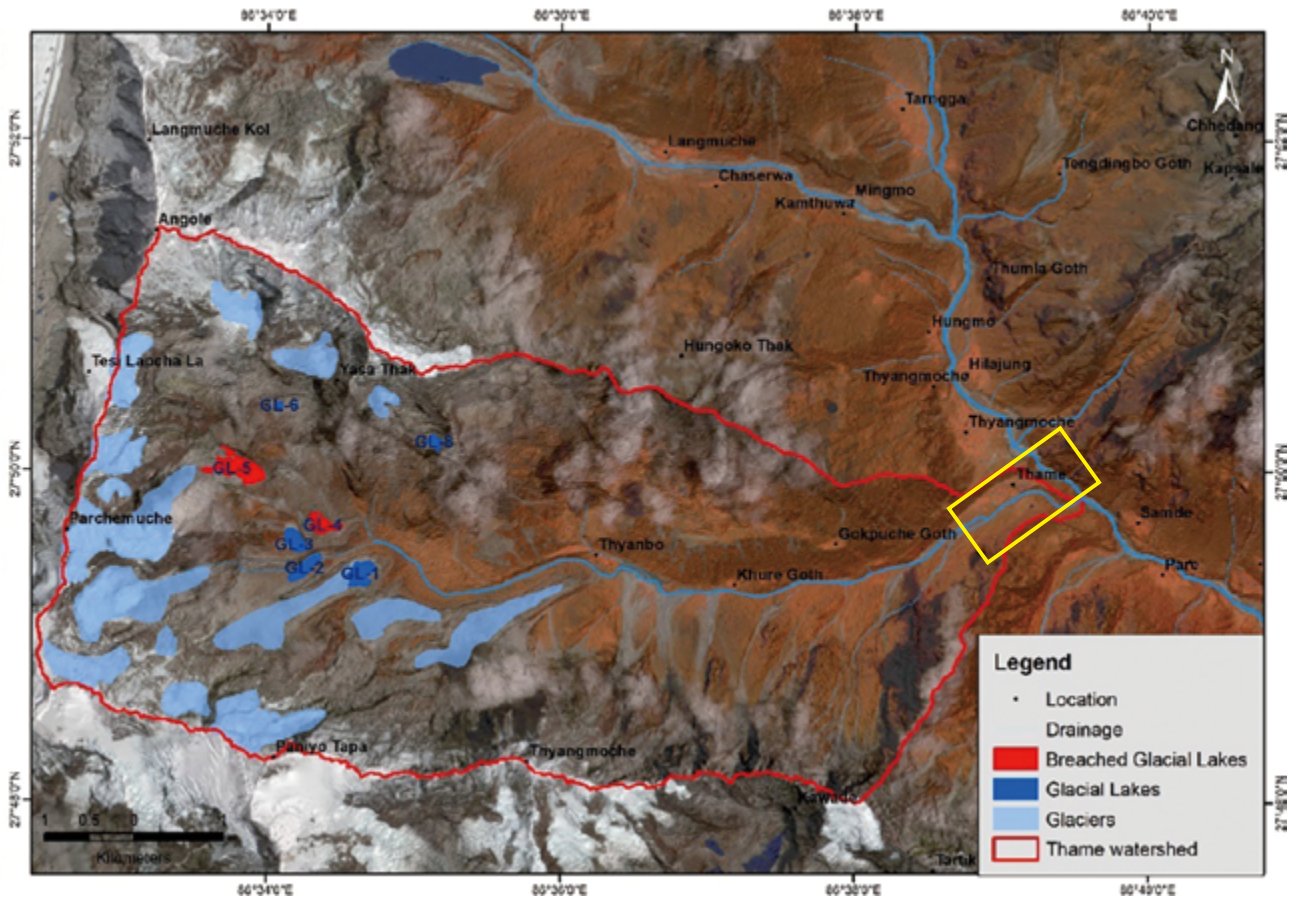


Figure 6: Map (background Image source: Planet) of the Thame valley showing glaciers and glacial lake with two breached glacial lake highlighted by red polygon (GL-5 in the mid-left is Upper Ngole Cho and GL-4 is Lower Ngole Cho) (Top) . Uncrewed Aerial Vehicle (UAV) captured image (Yellow rectangular mark in top image) showing the impact of GLOF in Thame village (Bottom).

Field investigations, coupled with remote sensing analyses, indicate that a rock avalanche from the left flank of Upper Ngole Cho triggered the initial breach. The avalanche, with an approximately 200-meter fall, generated a high-energy displacement wave that overflowed through the lake's outlet causing significant erosion of the moraine deposits atop of the bedrock. The section of the dam eroded measures 4.5 meters in thickness and 20.7 meters in width (Figure 7). This failure released approximately $1.56 \times 10^5 \text{ m}^3$ of water from the lake and a 20% reduction in its surface area (Maharjan et. al. 2025a).

The overflowing water then descended roughly 120 meters and gained tremendous erosive power and surged towards the downstream Lower Ngole Cho. This increased pressure, combined with the erosive force of the high-velocity flow, rapidly weakened the structurally unconsolidated moraine of Lower Ngole Cho. As the floodwater continued to erode the moraine, it eventually failed, resulting in a breach measuring 21.6 meters in depth and approximately 51 meters in width (Figure 7). This led to the release of roughly $3.03 \times 10^5 \text{ m}^3$ of water leading to a substantial decrease of around 60 % of the lake's total surface area.

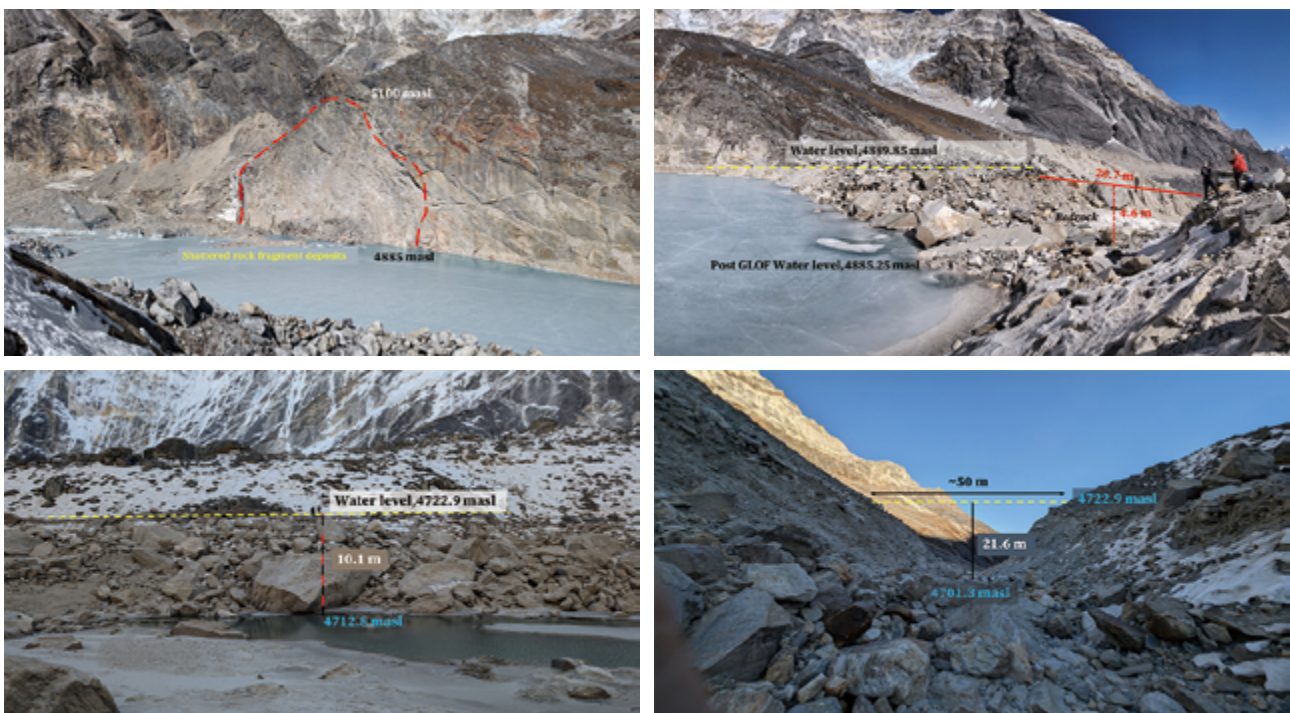


Figure 7: Field photo showing the rock avalanche scar and deposits on the left side of Upper Ngole Cho, approximately 200m above the current lake level(Top left); Field photo of the breached moraine at Upper Ngole Cho, with red text/lines indicating breach dimensions (Top Right); Field photographs showing the breached moraine and opened outlet of the Lower Ngole Cho (Bottom left); Field photograph showing the remaining portion of Lower Ngole Cho (GL-4) with changes in lake level before and after the flood (Bottom right). (photos: Sudan Bikash Maharjan)

Impacts on Thame Village

However, the most severe impacts were observed in Thame village. Detailed geomorphological analysis along the Thame River shows that the damage was not solely due to the surge of lake water. As the GLOF progressed downstream, the highly concentrated flood reshaped the river channel by mobilizing and deposition of larger boulders on its course, eroding riverbank, scouring and deepening the riverbed.

The redistribution of sediment and debris caused localized deposition zones, altering the natural course of the river in some sections. The main check point is observed at 3 km downstream from the lake up to where majority of the course materials accumulated upstream and about 2m thick layer of finer sediments was deposited over 100 – 200 m wide and 650 m long outwash plain, indicating temporary ponding. Beyond this section, the flow triggered secondary geomorphic processes, including bank collapse, deep riverbed scouring, and mobilization of larger sediments, which were deposited in the upper part of Thame village. The flood spread across the full width of the valley and diverted into an old seasonal channel running through the middle of the village. In the mid and lower sections, the river became deeply incised, and bank slumping, collapse, and widening tension cracks further destabilized the area.

These processes caused severe destruction in the village: 24 households were completely damaged, 14 were partially damaged, and 16 experienced minor damage. Among the damaged houses were eight hotels and lodges and several small businesses. A total of 9.51 hectares of agricultural land was heavily affected. Thame School, the village's only school was destroyed (Figure 8 and Figure 9). The intake of the hydropower operated by the Khumbu Electricity Company, which supplies electricity to Thame, Namche, Khunde and Khumjung was severely damaged, along with transformers, and electricity poles.

Continuing Hazards and Post-GLOF Instability

The risk to Thame village is no longer confined to this event. The GLOF caused extensive alteration of river morphology, including riverbed aggradation and incision and widespread riverbank destabilization, creating conditions that can bring forth ongoing geomorphic instability. As a result, elevated hazard levels are more likely to persist for several years following the GLOF.

Concurrent to that, During the 2025 monsoon season, increased river discharge extensively eroded the sandy riverbank near the settlement. A section of the riverbank toward the settlement collapsed, temporarily blocking the channel before rapidly breaching and draining. This avulsion event swept away additional five houses that had survived the 2024 GLOF, underscoring the prolonged vulnerability of the area and the continuing impacts. At the same time, tension cracks along both riverbanks have continued to widen and deepen, causing progressive subsidence and the collapse of several bank sections. These failures are slowly encroaching toward the remaining parts of the village, placing what is left of Thame at persistent and increasing risk (Figure 10).



Figure 8: Time lapse photographs showing development of Thame village over time and impact by the 2024 GLOF.



Figure 9: Post-GLOF landscape of Thame village, showing extensive boulder deposition, sediment accumulation, and active tension cracks. Photo: Tenzing Chogyal Sherpa

The instability extends beyond the settlement itself. The expanding cracks now threaten the Thame Hydropower facility, which supplies electricity to many of the major villages in the region, including Namche, Khumjung, Khunde, and Thame. If the cracks continue to migrate upslope, the surge pond of the hydropower system could eventually be lost entirely. In this sense, while the GLOF caused immediate destruction, its more enduring impact has been the destabilisation of the entire valley. Bank erosion, slumping, and landslides have increased in both frequency and magnitude, leaving Thame in a fragile and evolving post-disaster landscape.



Figure 10: Overlooking the current state of Thame village as of November 2025.
(Photo by: Mingma Nuru Sherpa)

Above the village, the situation remains equally concerning. The lake that initiated the 2024 cascade viz. The Upper Ngole Cho still remains highly vulnerable to future hazards, including rock avalanches, debris flows, and ice avalanches. Any renewed displacement wave or overtopping could once again trigger similar type of floods. Based on their morphology and surrounding terrain, two additional lakes in the basin viz. Rindhi Cho (GL-1) and Homey Cho (GL-2) are also classified as moderate to high risk. These sites require further field investigations, including detailed geophysical surveys, to better understand subsurface conditions and potential failure mechanisms.

Response

Despite the extensive structural damage on the Thame, it was fortunate that there was no loss of life. However, the event served as a stark wake-up call for the people living in the Everest region. Communities that had long been warned about the possibility of GLOFs but had grown increasingly desensitized suddenly found themselves confronting the reality of such a disaster. The aftermath has led to a noticeable shift in local awareness. People have become more receptive to scientific assessments and more willing to engage with ongoing hazard studies.

Following the GLOF, the Sagarmatha Pollution Control Committee (SPCC), together with the Khumbu Pasang Lhamu Rural Municipality (KPLRM), took significant initiative. Recognising the urgency of improved preparedness, they began working closely with Sherpa researchers and technical professionals from the community. Through this collaboration, they secured funding for a flood early warning system for Thame Valley and the downstream settlements. The project is now underway and is expected to be completed within the next two years. Importantly, it stands to become one of the first early warning systems in the region that is locally initiated, locally led, and locally managed. Figure 11 and Figure 12 shows the location of selected sites for the installation of early warning systems including hydrological stations and automatic weather stations in Thame valley and beyond.

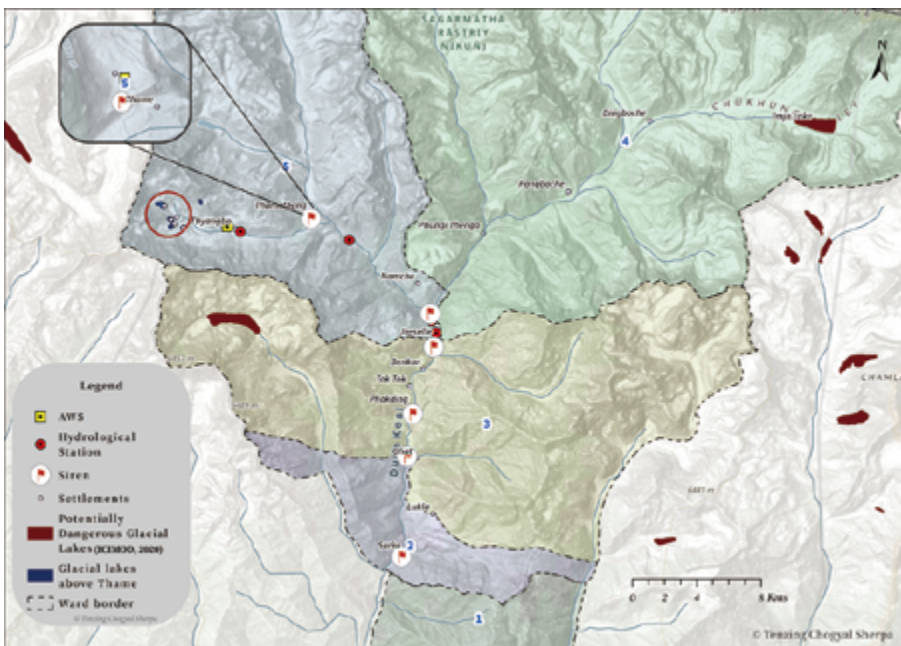


Figure 11: Map showing the locations of early warning systems, including hydrological monitoring stations and automatic weather stations, along the Thame River and downstream areas of the Bhoté Koshi and Dudh Koshi rivers.

In many ways, the story of the Thame GLOF is a difficult one. Yet it also demonstrates how a destructive event can generate a chain of awareness, motivation, and tangible action even from a local scale. The tragedy has, in its own way, set in motion a more resilient future for the people of Thame and the Khumbu region.



Figure 12: Field photograph of Thame village showing the proposed siren installation site, marked with a blue crossed circle on the upper left terrace of the village. (Photo: Tenzing Chogyal Sherpa)

C. Flood in Rolwaling valley, June 2024

In 2024, another disaster occurred in a catchment immediately west of the Thame Valley, taking place about two months prior to the Thame event. On the night of 22 June 2024, a devastating flood from the headwaters of Chhesugolchha Khola struck the lower part of Beding, impacting the Rolwaling Valley (**Shiwakoti, 2024**). Despite the scale and severity of its impacts, this event received limited national and international attention compared to the Thame GLOF. Nevertheless, the magnitude of damage and disruption was comparable, underscoring the need for greater recognition of flood-related hazards beyond high-profile glacial lake outburst events.

The flood caused extensive damage in Dogang, located about 7.5 km downstream from the confluence of the Chhesugolchha Khola and the Rolwaling Khola near Beding. Eight small hotels were completely swept away. Critical infrastructure, including foot trails, bridges, and electricity poles along the national transmission line in Beding, sustained significant damage. The total economic loss is estimated to exceed 50 million Nepalese rupees (**Shiwakoti, 2024, Himalayan News Service, 2024**). In addition, a landslide-induced blockage was reported along the course of the Rolwaling River, temporarily obstructing river flow.

The disaster left numerous domestic and international tourists stranded in the valley for more than a week. In response, the Nepal Army, in coordination with the District Administration Office, conducted rescue operations and delivered food and essential supplies to villages that had lost access due to disrupted access routes.

Initial reports in the news media attributed the event is due to the breaching of small ice lakes located at approximately 4,300 masl within the valley. However, our analysis of pre- and post-event satellite imagery indicates a different mechanism. The event was primarily triggered by landslides and the mobilization of moraine and talus deposits due to heavy rainfall in the upper slopes at elevations of approximately 4,800–5,000 masl. These materials were funnelled into a centrally located, deep cirque valley around 4,300 masl, where they temporarily dammed the valley floor. The subsequent breach of this transient dam generated the flood observed downstream (Figure 13).

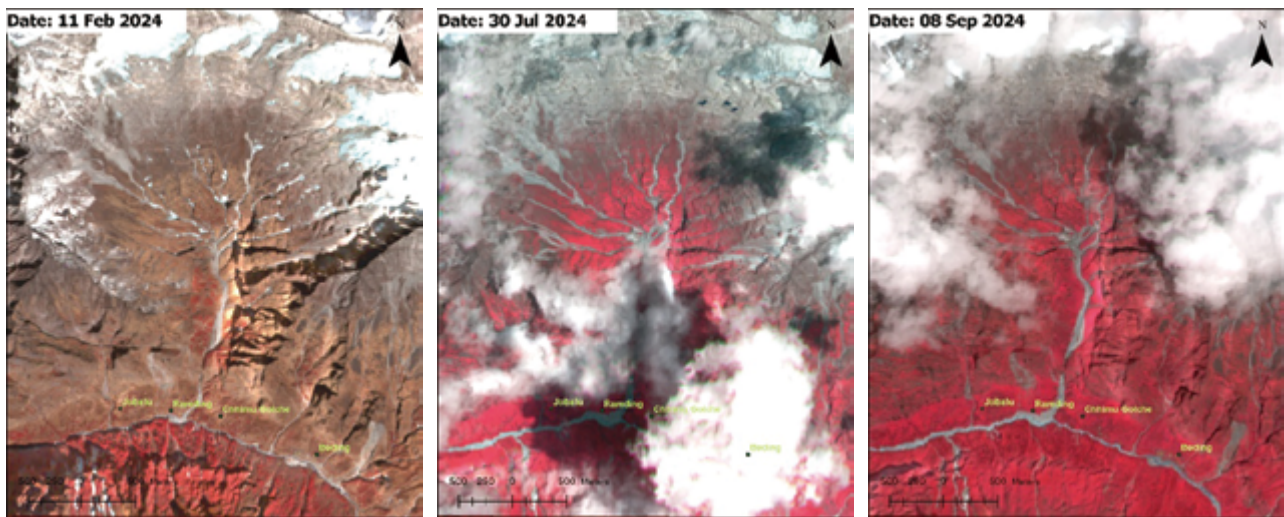


Figure 13: Pre- and post-event satellite images reveal a centripetal debris flow originating from glacial moraine deposits on the surrounding steep slopes. The flow was funneled into the centrally located deep cirque valley, temporarily blocked, and then discharged through a single outlet to the south.

D. Flood in Til village, Limi, Humla, June 2025

Til village, with a population of around 126 and 22 household, is the last settlement in the Limi Valley, located in the northernmost part of Humla District in north-western Nepal, directly bordering Tibet, China. The village is located at the left bank of the Til river, a tributary of the Limi river.

On 15 June 2025, at around 10 PM, a loud rattling sound accompanied by ground vibrations alarmed and frightened the residents of Til village (**Rai, 2025, Baskota et. al. 2025**). Immediately the villagers left their house and sought shelter in open areas and in the Shree Himsikhar Basic School building, located other side of the Til River. This unexpected flood with high concentrated debris occurred in a small, steep drainage on the eastern side of the village, known as Tiljung Khola. The Tiljung Khola exhibits moderate to high longitudinal gradients with numerous waterfalls and rapids along its path before joining the Til River in the southeastern part of the settlement. The Tiljung Khola catchment covers approximately 2.6 km² and is dominated by rock glaciers and permafrost in its headwater area. Hydrologically, the catchment is primarily sustained by snowmelt and permafrost thaw.

To better understand the complex processes behind the flood and its potential future impacts, the ICIMOD team carried out a comprehensive field investigation in June 2025. Remote sensing and field investigations indicate the presence of three distinct cascading rock glaciers in the headwaters of Tiljung Khola. Two thermokarst lakes are located on the uppermost glacial rock glacier depression surfaces at an elevation of 5347 masl (Figure 14). These lakes are 17m apart and blocked by more than 10 to 20 m high rock glacier features formed on a cirque valley that was carved by past glacial activity (Figure 15). These rock glaciers are primarily composed of boulder size rock fragments with little to no finer materials, and the interstitial spaces between these boulders and rock fragments are filled with ice and snow.

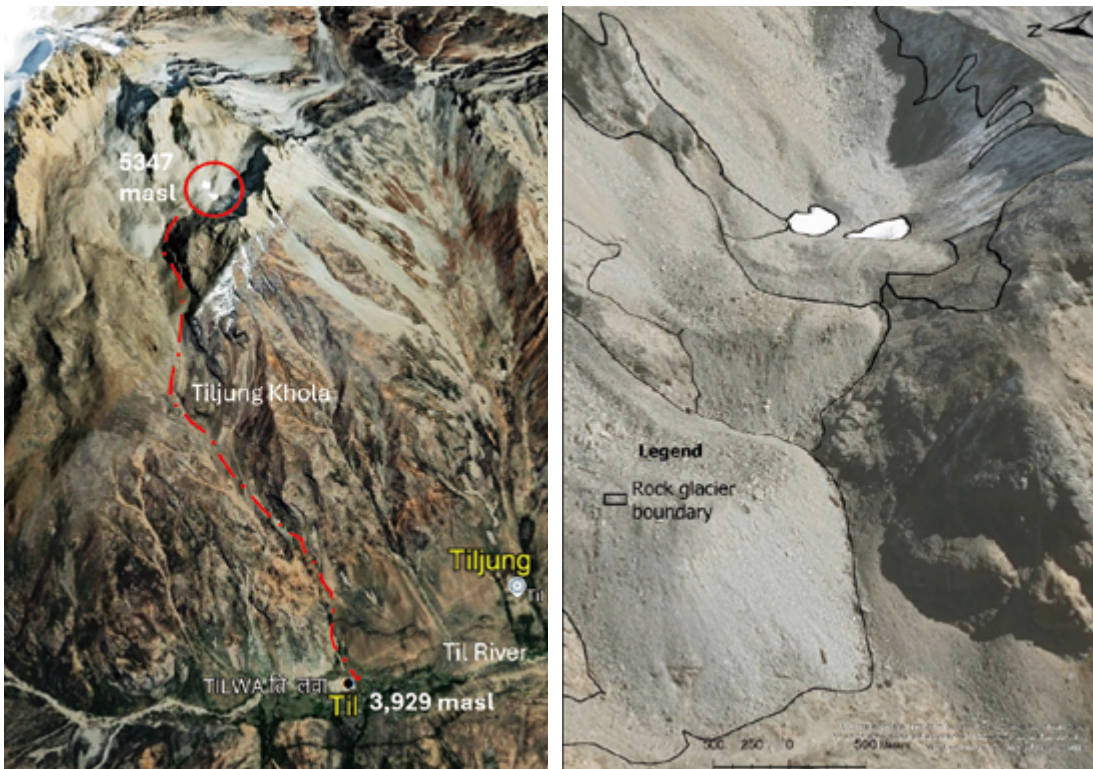


Figure 14: 3D images from Google earth showing the Til village, source area (Red circle) of Flood and flow path (Dash red line) along the Tiljung Khola (Left). Three cascading rock glaciers (marked by solid black polygons) and two thermokarst lakes on the top glaciogenic rock glacier in the headwaters of Tiljung Khola – source area (Right)

Field photographs indicate that the surfaces of both lakes were frozen and had collapsed inward at their centers, confirming that the lakes had completely drained (Figure 15). During the field investigation, numerous subsurface drainage channels were observed carrying meltwater from snow and ice into the lake basins, as well as through the adjacent rock glaciers, accompanied by audible water flow. These observations suggest that, with the onset of the thawing season, melting snow and ice percolate into the porous rock debris, and their thermal influence accelerates the thawing of interstitial ice within the rock glaciers. This process channels lake water internally through the cascading rock glacier and results in its discharge was observed at 300m downstream from the lake near the base of the second rock glacier.



Figure 15: Field photograph showing two lakes with their frozen surfaces collapsed inward at the center, indicating that both lakes had fully drained. (photo by Sudan Bikash Maharjan)

The sudden drainage of the lake released a rapid surge of water downstream. However, this outflow did not trigger a collapse of the rock debris nor mobilize significant sediment from the moraine itself. Erosional activity began approximately 500 m downstream from the lake and evolved into a high-energy flow around 800 m downstream, where temporary ponding was more likely and the channel gradient increased. Beyond this point, the flow intensified further as it passed through a steep, high-gradient channel with numerous waterfalls and rapids, resulting in pronounced vertical and lateral erosion along its course.

The most significant and severe vertical erosion occurred near Til village, where the flow dropped abruptly from intact bedrock terrain onto the talus-fan deposits in the village area. Here, the riverbed was scoured to a depth exceeding 20 m, causing progressive bank failures and extending tension cracks that placed three residential houses, an animal shed, and a drinking-water tap at high risk (Figure 16 and Figure 17). It also washed out the village's drinking-water and irrigation systems, the trail connection between the village and the monastery, and the water-supply system for the local micro-hydropower plant. Additionally, the powerhouse of the under-construction 15 kW hydropower located further downstream was washout (Figure 18).

The risk remains ongoing. During the forthcoming freezing season, interstitial spaces within the rocky debris of the rock glacier are likely to freeze, potentially blocking subsurface flow channels through the refreezing of ice and snow. The drained lake may also partially refill from surrounding meltwater and snowfall, which subsequently refreezes. During the thawing season in the following year, these ice-blocked pathways may reopen, resulting in renewed drainage and associated flood hazards (Qin et. al. 2023). Moreover, the recent flood has extensively altered the flow pathways, causing significant erosion and destabilization of the steep drainage channel, which could further amplify the impacts of future lake drainages, depending on the triggering processes and the volume of water released.



Figure 16: An aerial view captured by an Uncrewed Aerial Vehicle (UAV) shows a deeply incised drainage channel cutting through the rocky steep terrain in the upper section, with pronounced vertical and lateral erosion on the talus fan deposits in the middle and lower sections. Til village is visible in the lower left corner of the image.



Figure 17: Field photographs showing deep vertical incision and erosion on the talus fan deposits, along with progressive bank failures to the east of Til village. (photo by Sudan Bikash Maharjan)

During this mission, a micro-weather station was installed near the flood source area at N30.24372 E81.46115, at an elevation of 5,279 m (Figure 19). This is the first instrument installed in the valley, as there are currently no existing monitoring stations in the area. The station measures relative humidity, air temperature, solar radiation, soil moisture, and soil temperature, capturing conditions from 20 cm below the ground up to 2 m above the surface.

The data from this station will provide critical insights into the thermal and climatic conditions of high-altitude permafrost and rock glaciers in the Til Valley. It will help understand freeze-thaw cycles, snowmelt dynamics, and potential triggers for the formation and draining of thermokarst lakes. Over time, the information will allow researchers to quantify permafrost degradation rates, assess slope stability, and model snow and ice melt processes. Ultimately, these information and knowledge can also serve as a vital input for early warning systems and hazard preparedness, supporting local communities and authorities in the district to better manage and mitigate cryosphere-related risks.



Figure 18: Pre- and post-event field photographs show the 15 kW hydropower station, which was under construction, completely washed out by the flood. (Left photo by Penpa Dhondup, Ward Member of Limi Rural Municipality; Right photo by Sudan Bikash Maharjan).



Figure 19: Micro-weather station installed near the lake drained area at 5,270 m asl, measuring relative humidity, air temperature, solar radiation, soil moisture, and soil temperature from 20 cm below ground up to 2 m above the surface in stable terrain.

In addition to the immediate source area, the broader Til Valley remains at risk from other parts of the catchment. The headwaters of the main river and its tributaries contain numerous glaciers, glacial lakes, permafrost zones, and rock glaciers, all of which are increasingly susceptible to destabilization under continued climatic warming. During the monsoon season (28 July 2025), another flood already struck the village (Figure 20). This flood originated approximately 5 km upstream from Til village, from one of the main tributaries of the Til River (**Republica, 2025**). The event washed away the main bridge over the Til River, cutting off the village from the primary trail connecting it to the administrative center of Namka Rural Municipality and the district office. Analysis of pre- and post-event satellite imagery indicates that the flood originated in a glacier area, where meltwater had accumulated on a small, relatively flat surface that normally stores glacier meltwater. Accumulated monsoonal rainfall caused this rain and water pool to overflow, triggering massive landslides and

mobilizing glacial sediments and causing the downstream flood. This event further underscores the elevated and valley wide flood risk.

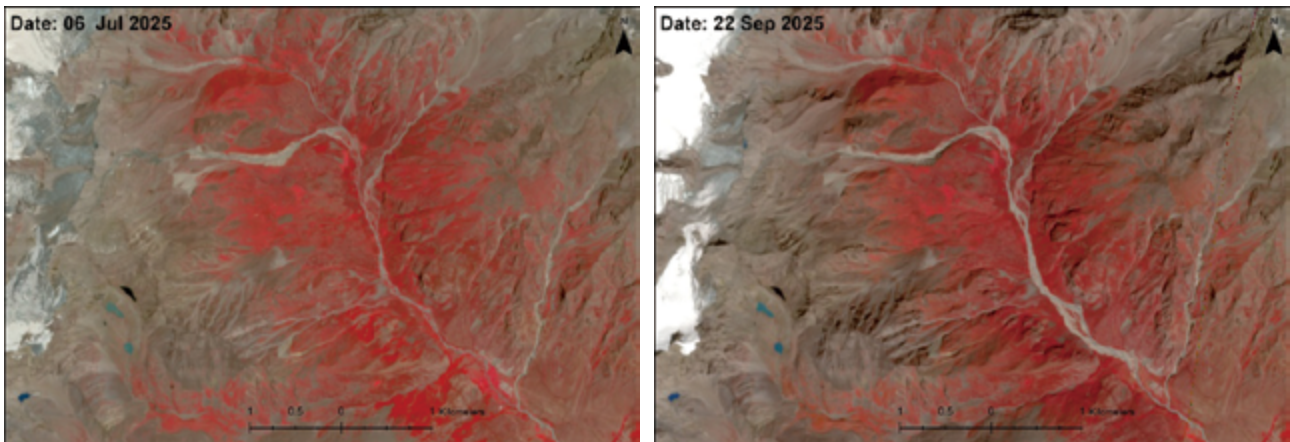


Figure 20: Pre and post satellite image showing the flood path of 28 July 2025 event in Til valley. (Image source: Sentinel 2).

E. Chumjung Flood event, Lo-Manthang Rural Municipality, Mustang - July 2025

On 8 July 2025, at around 5:00 PM local time, an unexpected flood occurred in the Chhauma River upstream of Chumjung and Lo Manthang in Upper Mustang. The flood extensively damaged four bridges, including two motorable bridges—one at Chumjung and another under construction at Samjung in Lo Manthang–2. No casualties were reported. Immediately after the event, people living near the flood-affected area, including residents and hotel occupants in Nyamdo village, were relocated to safer locations. Timely communication with downstream settlements helped prevent further impacts and reduced the potential for major damage (**Khadka, 2025, Thapa and Steiner, 2025**).

The flood was caused by the sudden drainage of a glacial lake that had formed approximately one month prior to the event. The lake began forming at the end of May 2025, at an elevation of around 5,900 masl. It was developed at the confluence of two simple basin-type clean-ice glaciers, which merge to form a compound glacier of the Nhubine Himal, located near the northern border with Tibet, China and around 25 km upstream from the Lo Manthang. Analysis of a time series of satellite images indicates that, with the onset of the melt season, meltwater from fresh snow and glacier ice accumulated in a topographic depression at the glacier confluence. The lake expanded rapidly, increasing nearly 5-fold from 0.0038 km² on 31 May 2025 to 0.019 km² by 8 July 2025, and was impounded by clean glacier ice (Figure 21). Although relatively small, with an area of approximately 0.019 km² just six hours before drainage, continued melting, lake enlargement, and the thermal influence of the stored meltwater accelerated internal ice melting (**Thapa & Steiner, 2025**). This process led to the development of englacial and/or subglacial drainage channels, ultimately resulting in the sudden release of water from the glacier snout.

The released water significantly mobilized glacier-deposited sediments near the glacier snout, while extensive erosion and landslides along the flow path contributed large volumes of fine sediment. The resulting highly

turbid, sediment-laden flood caused substantial downstream impacts, with visible sediment deposition observed along the main river (Kali Gandaki) for distances of up to approximately 35 km downstream.

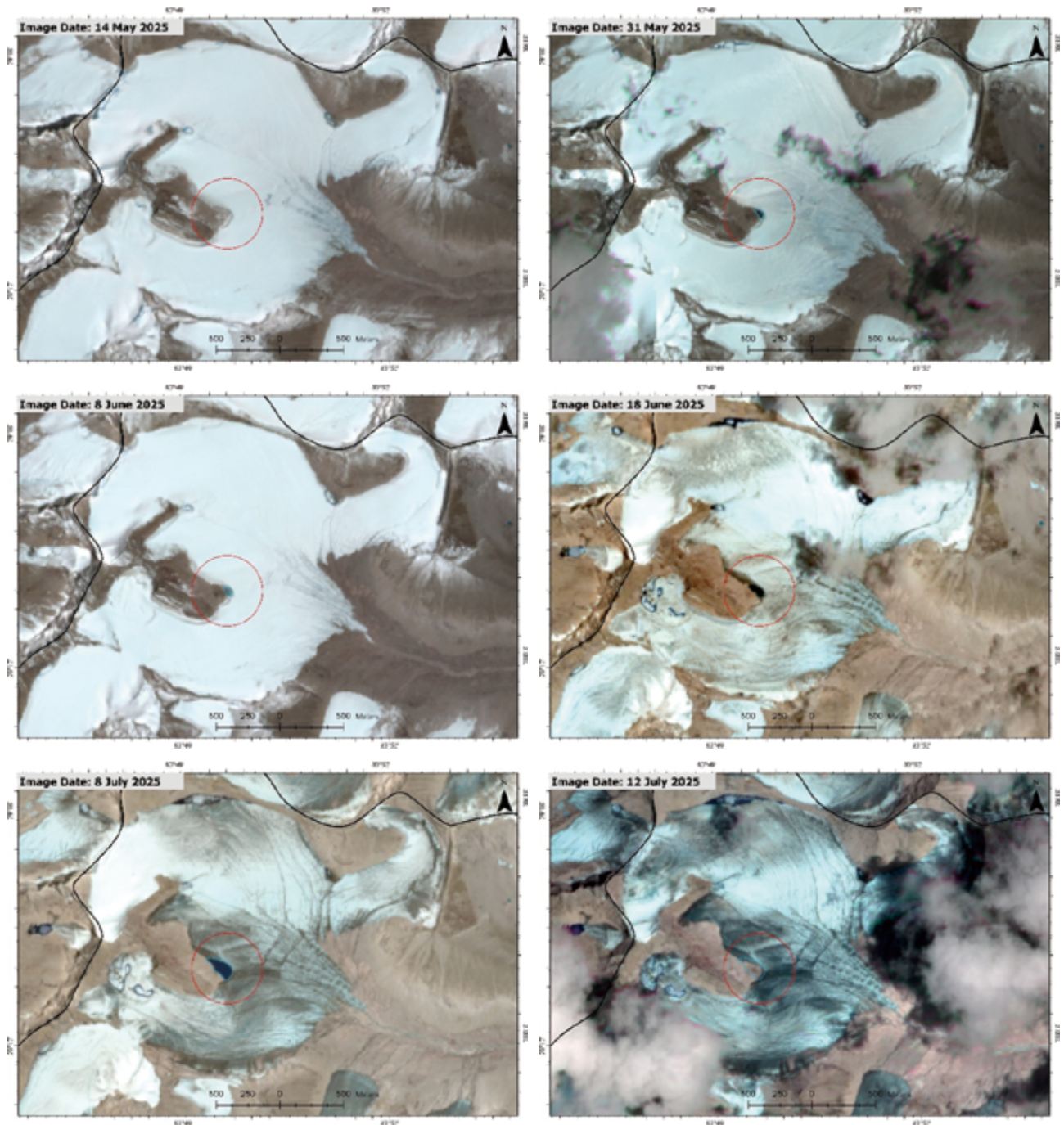


Figure 21: Sequential Sentinel-2 MSI satellite images showing the rapid formation of a glacial lake at the confluence of two simple basin-type glaciers (marked by red circle) and its subsequent disappearance after 8 July 2025.

F. Rasuwagadi Flood, July 2025

The most destructive flood of 2025 in Nepal occurred on 8 July and stands out as a striking example of a transboundary cryospheric disaster. An unexpected torrential flood originated from the Perupu glacier in the Lhende River watershed in Kerung, Tibet, China, crossed the international boundary and travelled more than 100 km downstream, severely affecting people and communities in Nepal. The flood caused extensive damage

to critical cross-border infrastructure, including the complete washout of the Strategic Friendship Bridge, thereby disrupting the Nepal–China trade route (Figure 22). On the Nepalese side, more than 1–1.5 km of the road section between Syaphrubesi and Rasuwagadhi was destroyed, isolating communities, businessman and tourists and hindering emergency response (NDRRMA, 2025).

This disaster had profound impacts on energy and public infrastructure. Almost, seven Hydropower projects along the Trishuli River in Nepal were severely affected, reducing nearly 250 MW of operational capacity, which is equivalent to 8% of Nepal’s national power supply. The Rasuwagadhi Hydropower Project sustained severe damage to its dam, headworks (Figure 23), and labour camps, while floodwaters entered the tunnel of the Chilime Hydropower Project, interrupting electricity generation. In addition, construction activities at the 216 MW Upper Trishuli project were impacted, and floodwaters undermined a recently completed transmission substation responsible for evacuating power from the basin. The flood also devastated logistics and customs facilities, with the customs office and dry port washed away, along with numerous vehicles, including 23 cargo trucks, 47 new electric vehicles, and 6 Chinese trucks; the electric vehicle charging station was also damaged. Eight units of heavy equipment and multiple machinery assets were impacted. Overall, the disaster resulted in 11 fatalities, 18 people reported missing, and one person injured, underscoring the severe human, economic, and infrastructure consequences of transboundary cryospheric hazards (NDRRMA, 2025).

The flood was caused by the sudden drainage of a rapidly formed supraglacial lake situated at approximately 5,160 masl on the mid-section of the debris-covered portion of the compound-valley Perupu Glacier (Figure 24). This glacier, covering an area of around 17.5 km², forms the headwaters of the Lhende River watershed and lies about 35 km upstream of Rasuwagadhi at the Nepal–China border.

Supraglacial lakes form on the glaciers when meltwater accumulates in surface depressions, particularly on debris-covered sections where uneven ice melt creates ponds. These lakes are highly dynamic, often forming, expanding, merging, and draining within a single melt season, and can evolve into larger moraine-dammed glacial lakes. Their natural dams, composed of ice and moraine material, make them vulnerable to sudden breaching, posing significant hazards to downstream communities and infrastructure in high-mountain regions.



Figure 22: Before (November, 2024) and after (9 July 2025) photographs showing the Nepal-China Friendship bridge was completely wash out by GLOF. (Photo by Sudan Bikash Maharjan{left} and Online{right})



Figure 23: Before (November, 2024) and after (9 July 2025) photographs showing the Hydropower dam was completely collapse. (Photo by Sudan Bikash Maharjan (left) and online sources (right).)

Satellite image analysis shows that numerous small ponds on the debris-covered glacier surface had been forming, merging, and disappearing over time, which is a normal process of ice melting in debris-covered glaciers. However, after May 2025, rising temperatures and accelerated melting led to the formation, expansion and merging of multiple ponds, resulting to form larger supraglacial lake. The increased hydrostatic pressure from the growing water volume, coupled with thermal interaction between the lake water and the dammed ice, weakened the ice dam, ultimately triggering the sudden drainage of the lake. This drainage also affected several other supraglacial ponds downstream on the glacier surface.

Rapid assessments indicate that the ponds began to grow from March 2025 and continued expanding until mid-May 2025, reaching a combined area of 525,000 m² by 28 June 2025. Multiple ponds then coalesced to form a single larger lake of 638,000 m² on 7 July 2025. Satellite imagery from 8 July 2025 shows that the lake had suddenly reduced in size by about one-third (435,000 m²), indicating the release of a significant volume of water (Figure 25) (Lui et. al. 2025). The event is further evidenced by the formation of a visible channel on the glacier surface, impacts on downstream ponds, and sediment erosion at the glacier snout.

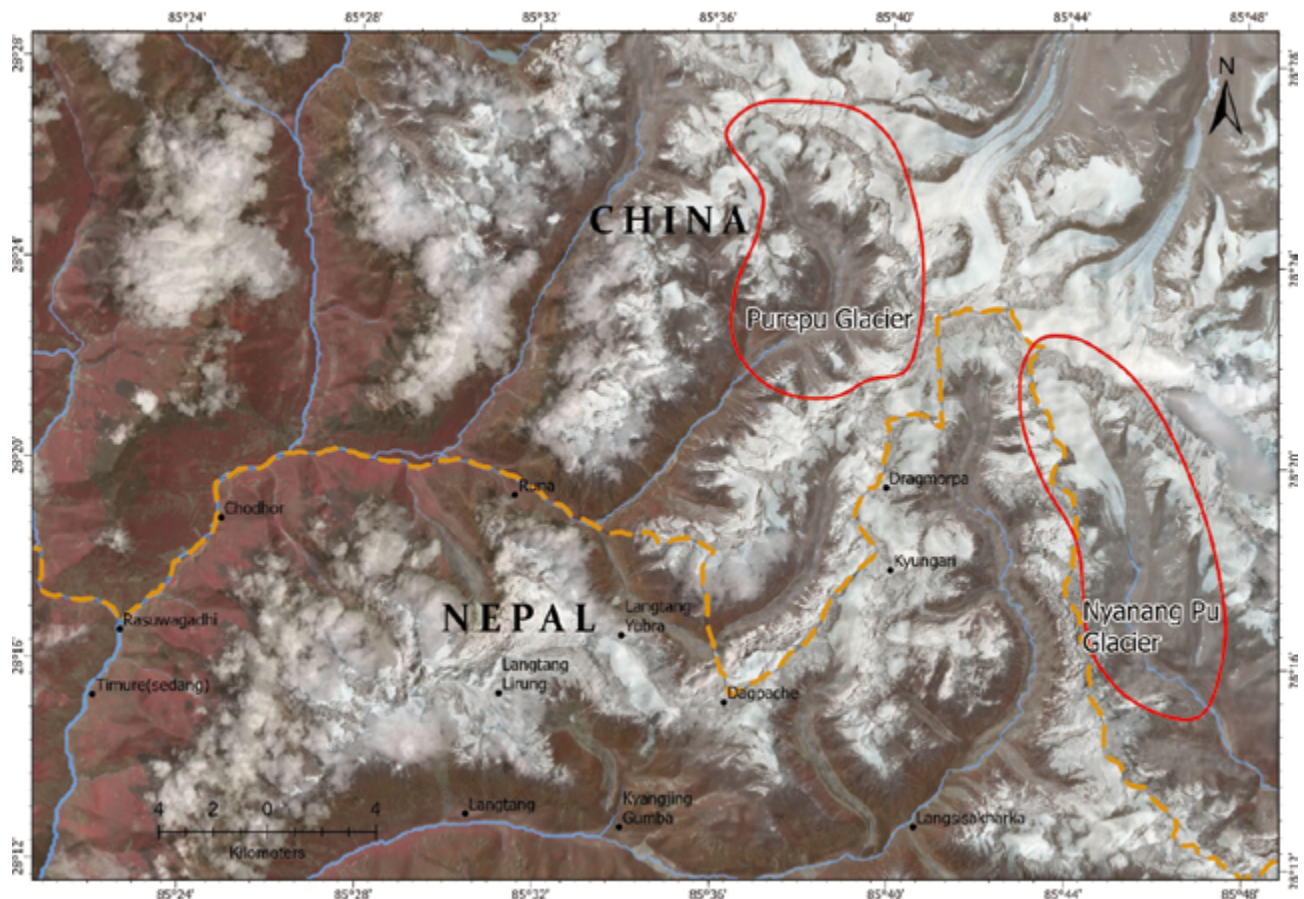


Figure 24: Location map of the Purepu Glacier, the source area of the 8 July 2025 flood, and the Nyanang Pu Glacier, where a similar supraglacial lake formed and slowly drain without major impact in downstream.

Time-series analysis of satellite imagery, along with observable morphological changes in the downstream river valley, indicates that a similar lake-draining event also occurred in 2023 (Figure 26). However, during that event, the floodwaters extended only about 10 km downstream from the glacier. In contrast, the 2025 flood caused far greater destruction over a much longer distance. The magnitude and spatial extent of the impact along the downstream path suggest that the damage was not solely the result of the single lake-draining event. Rather, it is likely that multiple cascading processes were involved, influenced by previous events, as well as the geological and morphological characteristics of the river valley along its course. These conditions may have amplified the flood's force and extent, leading to widespread downstream impacts that highlight the complex and cascading nature of transboundary glacial hazards.

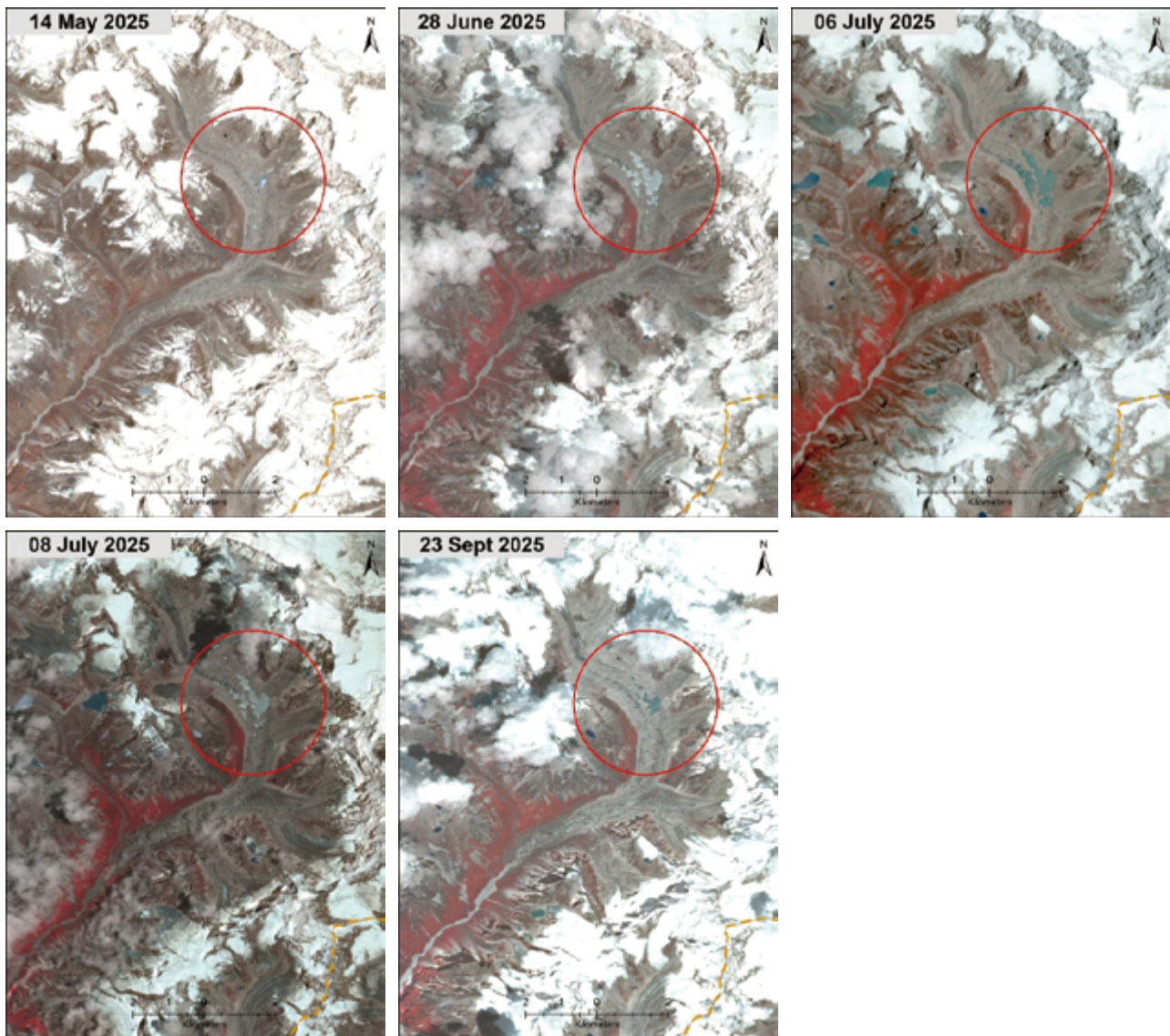


Figure 25: Time series of Sentinel-2 MSI imagery illustrating the rapid formation of a supraglacial lake on Perupu Glacier beginning in mid-May 2025 and drained on 8 July 2025. The 23 September 2025 image shows size of the lake had reduced significantly.

Similarly, around the same timing and nature, a rapidly developing and expanding supraglacial lake was observed on the Nyanang Pu Glacier, located on the eastern slope of Shishapangma Peak in Nyalam District, Tibet, China. The meltwater from this glacier and lake flows toward the Nepal–China border trade route at Kodari in Sindhupalchok District, northeast of Kathmandu Valley, Nepal. On 7 July, one day before the Rasuwagadi flood, a minor draining event occurred from this lake. The event caused only limited impacts in Nyalam town, located 26 km downstream, with minor debris deposition on the roads, which has since been cleared, and did not result in significant downstream damage.

The Nyanang Pu Glacier itself is a compound valley glacier covering about 26 km² and extending 16 km from 7,000 to 4,965 masl. Formed by multiple tributaries converging into a predominantly debris-covered trunk, the glacier has a clean ice accumulation zone in the upper section and highly hydrologically active middle and lower sections, featuring numerous supraglacial lakes, ice cliffs, and meltwater channels. Steep descents and undulating surfaces, combined with large supraglacial lakes near the terminus, make the mid-to-lower glacier

particularly vulnerable to climate-driven melt and the potential formation of moraine-dammed lakes, posing downstream glacial lake outburst flood (GLOF) risks.

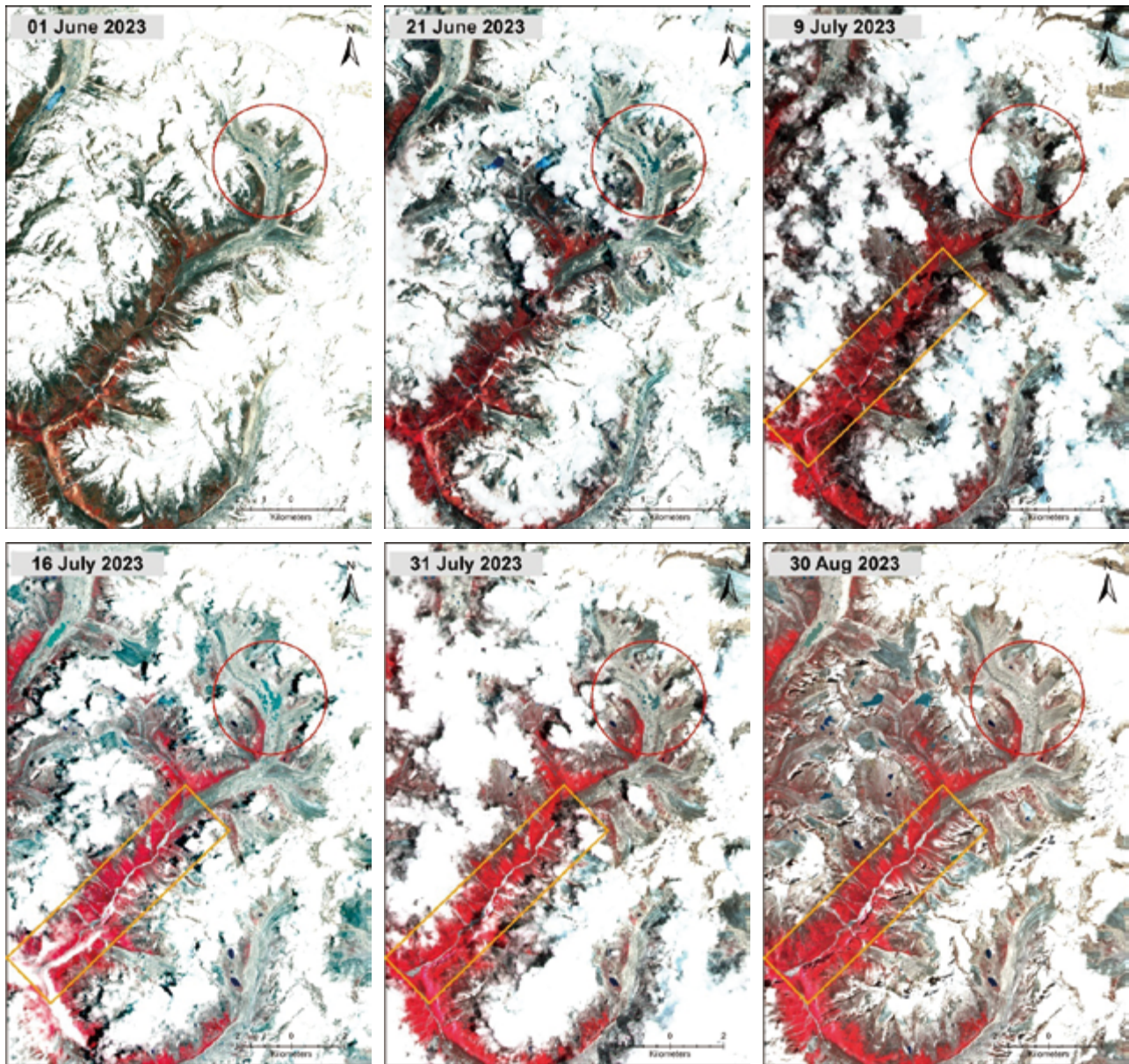


Figure 26: Time series of Sentinel-2 MSI imagery illustrating the rapid formation of a supraglacial lake on Perupu Glacier beginning in June 2023 and its drainage between 9 and 16 July 2023. (marked in red circle) The 16 July image shows extensive sediment deposition extending up to ~10 km downstream from the glacier snout. (marked by orange rectangular box) By 30 August 2023, the lake had completely disappeared.

Analysis of the Supra glacial lake development in the mid-section of Nyanang Pu Glacier using satellite imagery from 2016 to 2025 shows a consistent pattern of seasonal lake formation and drainage. By 2023, over ten small supraglacial ponds had formed, expanded, and partially drained during the summer melt season, with similar trends in 2024. In 2025, these ponds coalesced into a single large lake, reaching 0.58 km² by 7 July, and gradually reducing to 0.39 km² by 13 July, indicating partial and slow drainage (Figure 27 and Figure 28). While the immediate risk has decreased, the lake remains sizeable, highlighting the need for ongoing monitoring due to its potential hazard to downstream areas. Below figure shows the dynamics of supraglacial lake development

in the mid-section of the Nyanang Pu Glacier (Maharjan et. al. 2025b).

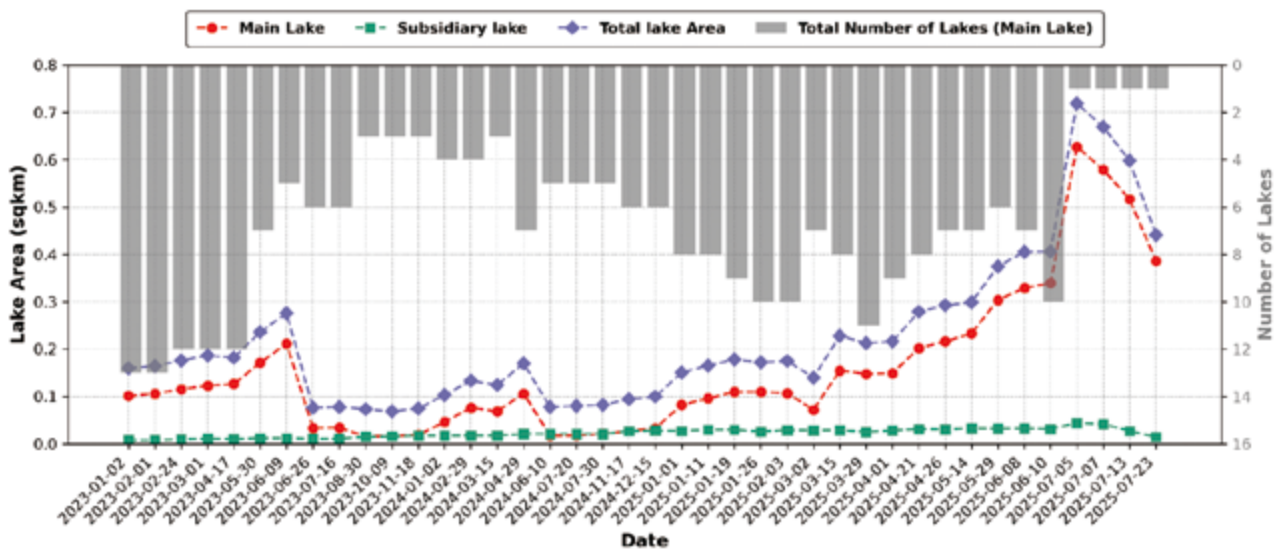


Figure 27: The figure illustrates the development of supraglacial lakes in the mid-section of the Nyanang pu glacier from 2023 to present, with a particular focus on the main, larger supraglacial lake. The accompanying bar chart depicts the number of supraglacial ponds that formed within the eventual boundary of this main lake. The red line indicates the main supraglacial lake's area expansion over time, the green line highlights a persistent subsidiary supraglacial lake along the left lateral moraine, and the purple line represents the total supraglacial lake area within the mid-glacier region.

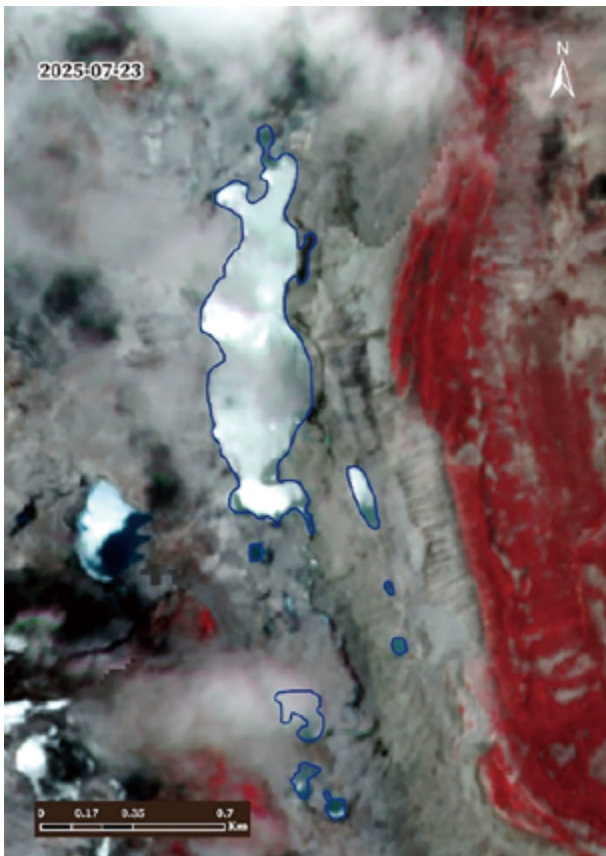


Figure 28: Sentinel-2 imagery of 23 July 2025 shows a reduction in the supraglacial lake's size in Nyanang pu glacier, with a clearly visible channel at its frontal section, indicating gradual drainage.

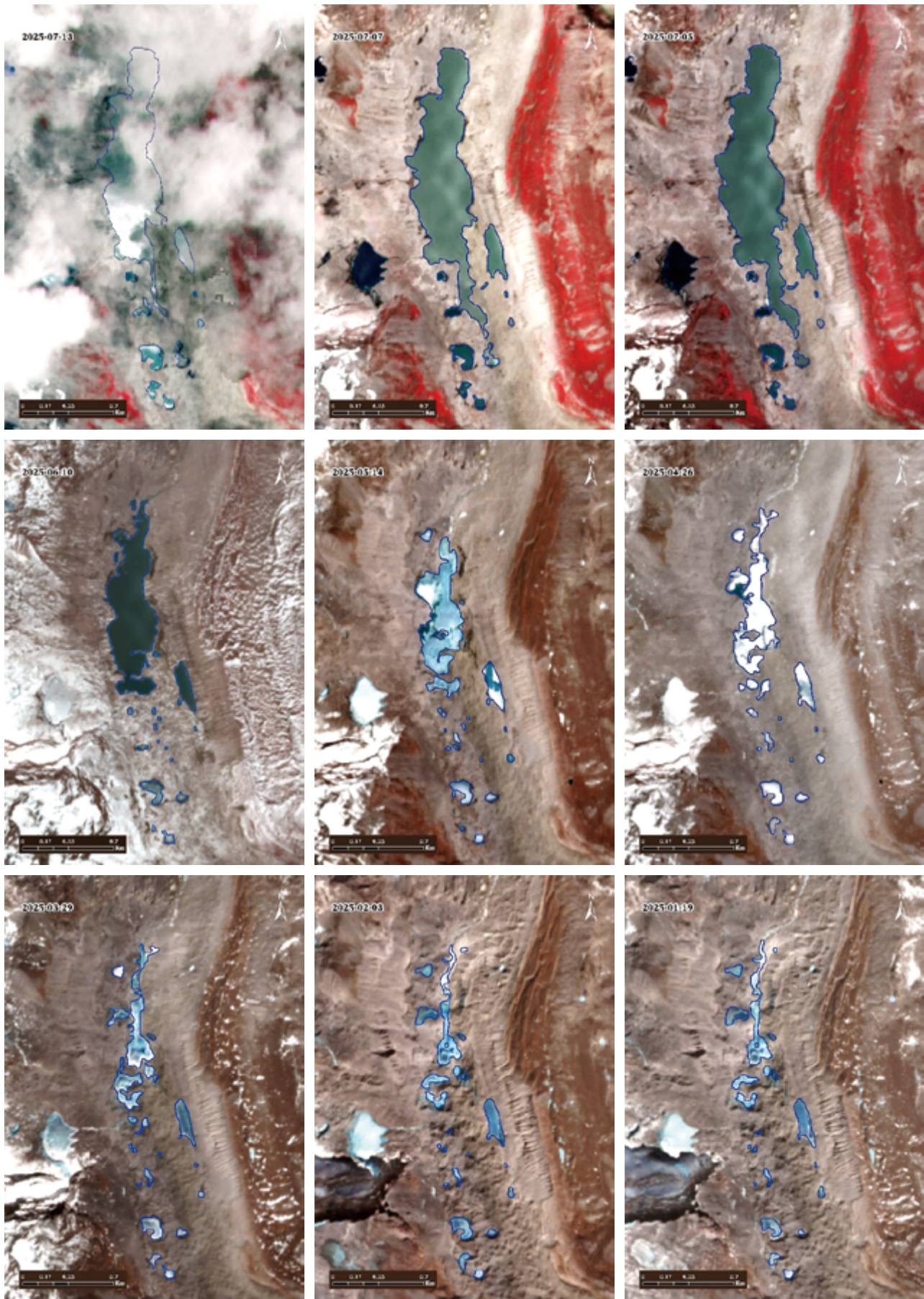


Figure 29: Monthly Sentinel-2 images of 2025 illustrate the development of supraglacial lakes in the mid-section of the Nyanang Pu Glacier.

4. Way Forward

The study demonstrates that cryospheric disasters in the Nepal Himalaya are undergoing a transformation in frequency, magnitude and complexity under rapidly changing climatic conditions. Recent events indicate that hazards such as GLOFs are no longer dominated solely by large, prominent moraine dammed glacial lake alone. Instead, smaller, newly formed supraglacial lakes, thermokarst lakes on rock glaciers and transient ice or sediment laden/dammed features are increasingly responsible for destructive floods. Despite their limited size, these features have triggered disproportionate downstream impacts, as seen in the Gongbatongsha Co event in 2016, Melamchi Flood in 2021 and recent Rasuwagadhi flood, and Til village disasters. These cases highlight that lake area or volume alone are insufficient indicators of such disasters; factors such as lake stability, surrounding slope instability, glacier dynamics, geological and geomorphological conditions along the flow path, and downstream exposure are equally critical.

The recent events also underscore the complex and cascading nature of high-mountain hazards. Sequential failures of upstream glacial lakes can amplify downstream impacts, generating geomorphic, infrastructural, and socio-economic consequences that extend well beyond the immediate flood zone. Understanding these cascading mechanisms is critical for hazard assessment and mitigation planning in high-altitude regions. Avalanches, landslides, and other secondary processes are increasingly coupled with permafrost degradation, rapid glacier melt, intense snowstorms, and geomorphological controls in downstream valleys, further amplifying the magnitude and spatial extent of disasters. Many recent events have demonstrated that high mountain hazards are rarely isolated failures, instead, they result from chains of interacting processes, including ice or rock avalanches, lake overtopping, moraine erosion, transient damming and channel avulsions. The Thame Valley GLOF, for instance, clearly exemplifies how sequential lake failures and post-event geomorphic instability can magnify impacts far beyond the initial trigger and prolong risk for years after the main event. In addition, rainfall- and snow and ice melt driven floods in Rolwaling, Mustang, and Humla underline the convergence of cryospheric change with monsoonal and extreme weather events.

The rapid and unpredictable evolution of new glacial lakes and downstream impacts observed recent years underscores the urgent need of near real time monitoring systems. A comprehensive, integrated hazard and risk analysis should identify hotspots glaciers and vulnerable areas for continuous monitoring. This involves satellite-based surveillance complemented by in-situ observations such as automatic weather stations, lake level monitoring, time-lapse camera monitoring and ground temperature probes. At a same time, locally led flood early warning systems such as the initiative currently being undertaken in the Thame valley should be upscale and replicated in other vulnerable catchments to ensure timely warnings and effective community response.

High-mountain hazards often have transboundary implications, making cross-border information exchange essential. The Rasuwagadi Flood underscores the transboundary dimension of cryospheric hazards. Timely information shared by the Chinese partners proved critical for situational awareness in Nepal. Such coordination allows prompt communication with national authorities and proactive planning for potentially affected downstream

communities. Historically, many of these most damaging events originated upstream in Tibet-China, causing extensive damages, loss of life and economic disruption in Nepal. This demonstrates that cryospheric disasters are not confined by the political boundaries and the downstream vulnerability is tightly coupled with upstream cryospheric dynamics beyond national jurisdiction. Therefore, stronger transboundary cooperation and data sharing mechanisms are very much essential, to substantially reduce downstream losses by timely sharing the hydrometeorological information and early warnings. Regional platforms and institutions like ICIMOD should facilitate joint monitoring, coordinated risk assessment and harmonized response mechanisms.

The rapidly growing risk of cryosphere-related disasters in the region emphasizes the need to move beyond predominantly reactive or post-event responses toward an anticipatory, integrated, and transboundary risk management approach. Hazard and risk assessment are necessary to expand beyond the traditional focus on single larger and well identified glacial lakes. It should incorporate the multi criteria approaches that integrate lake dynamics including all forms of the glacial lakes, glacier dynamics, slope instability, permafrost conditions as well as moraine or sediment laden deposits including other geological and geomorphological conditions along flow paths and downstream exposures. Scenario-based modelling of cascading events can help anticipate worst-case outcomes, identify critical thresholds, and support robust preparedness and contingency planning.

Once the natural systems are disrupted by such disasters, hazard levels often remain elevated for several years due to persistent alterations in river morphology, increased slope instability, and progressive erosion, as clearly illustrated by the Thame Valley and Melamchi flood cases. Therefore, post-disaster risk management and recovery planning must be strengthened to address long-term and residual risks. This may include sustained monitoring, informed land-use planning, and, where necessary, relocation or structural mitigation measures, supported by the integration of detailed geomorphic stability assessments rather than focusing solely on immediate reconstruction.

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