Interreg
Co-funded by the European Union
Alpine Space

X-RISK-CC

PILOT DOSSIER

GARMISCH-PARTENKIRCHEN IN BAVARIA

HOW TO ADAPT TO CHANGING WEATHER EXTREMES AND ASSOCIATED COMPOUND RISKS IN THE CONTEXT OF CLIMATE CHANGE

LEAD PARTNER

eurac research

PROJECT PARTNERS

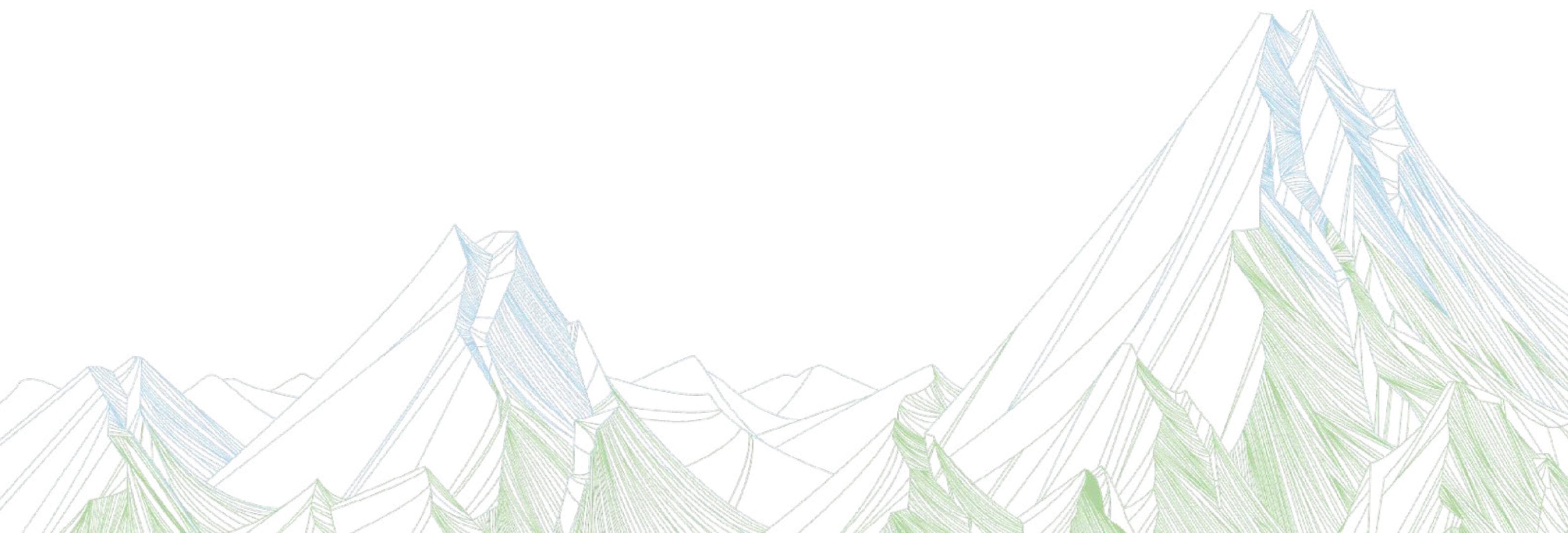
Wildbach- und Lawinenverbauung Forsttechnischer Dienst
umweltbundesamt
GeoSphere Austria
Technische Universität München TUM
Auvergne Rhône-Alpes Énergie Environnement
Republic of Slovenia Ministry of the Environment, Climate and Energy Slovenian Environment Agency
Razvojna agencija Sora d.o.o.

GARMISCH-PARTENKIRCHEN IN BAVARIA

HOW TO ADAPT TO CHANGING WEATHER EXTREMES AND ASSOCIATED COMPOUND RISKS IN THE CONTEXT OF CLIMATE CHANGE

THIS DOSSIER

The dossier focuses on Garmisch-Partenkirchen district in Bavaria (Germany) used as a pilot area in the X-RISK-CC project. The dossier is designed to make the local knowledge developed by the project accessible to the general public. It provides information on past and future weather extremes, associated hazards and risks, and proposed actions to improve the future risk management in the area.



Author List:

Technical University of Munich

Eurac Research

Civil Protection Agency, Autonomous Province of Bolzano

GeoSphere Austria

Autonomous Province of Trento

Slovenian Environment Agency

Development Agency Sora

Auvergne Rhône-Alpes Energy Environment Agency

Forest-technical service for torrent and avalanche control, Section Tyrol

Environment Agency Austria

Reference Contact:

Prof. Dr.sc.tech. Daniel Straub
Chair of Risk Analysis and Reliability
www.cee.ed.tum.de/era

Prof. Dr. rer. nat. Michael Krautblatter
Chair of Landslide Research
www.cee.ed.tum.de/landslides

Technische Universität München
Arcisstr. 21
80333 München

Publication Date:

December 2025

This publication is available on the project website under the "Outcomes" section:

X-RISK-CC - Alpine Space Programme

INTRODUCTION

THE BACKGROUND

In recent years, the Alps have experienced unprecedented weather extremes such as heatwaves and droughts, heavy rains and storms, which have had severe impacts on the environment, society and the economy. These events have challenged the risk management capacities of the affected Alpine regions. The scale (*magnitude*) and local severity (*intensity*) of such extremes can lead to multiple simultaneous (*compound*) impacts and cascading effects, resulting in complex, long-lasting or even irreversible consequences.

Recent scientific evidence indicates that climate change (CC) is increasing both the intensity and frequency of extreme meteorological events. However, the understanding of their compound and cascading impacts—and how to manage them—remains limited. On the regional level, these events are not adequately addressed within current Disaster Risk Reduction (DRR) frameworks. Similarly, where Climate Change Adaptation (CCA) plans exist, they often underestimate the severity of extreme events and associated risks, and frequently lack concrete, actionable measures.

THE PROJECT AND ITS GOALS

The **X-RISK-CC** project (full title: "*How to adapt to changing weather e***X***tremes and associated compound and cascading* **RISK***s in the context of* ***C****limate* ***C****hange*") is funded by the European Union and aims to improve the management of risks related to extreme weather and natural hazard events under climate change in Alpine regions. This goal is pursued through the collaboration of scientists, risk managers and policy makers on local, national and international levels.

In X-RISK-CC, risks are defined as the adverse consequences caused by weather extremes (e.g., heavy rainfall) triggering natural hazards (e.g., flooding), which in turn affect human systems (e.g., loss of private property). Risk is therefore not determined by weather and natural hazards alone, but by their interaction with exposure (e.g., buildings located in flood-prone areas) and vulnerability (e.g., lack of flood protection infrastructure) within socio-economic systems (***FIGURE 1***).

Understanding and managing current and future risks requires not only the analysis of weather extremes and resulting hazards, but also a consideration of the evolution of human systems and potential risk management solutions. Since weather cannot be controlled, risk reduction must focus on measures that decrease vulnerabilities, reduce exposure or, where possible, mitigate the hazard itself.

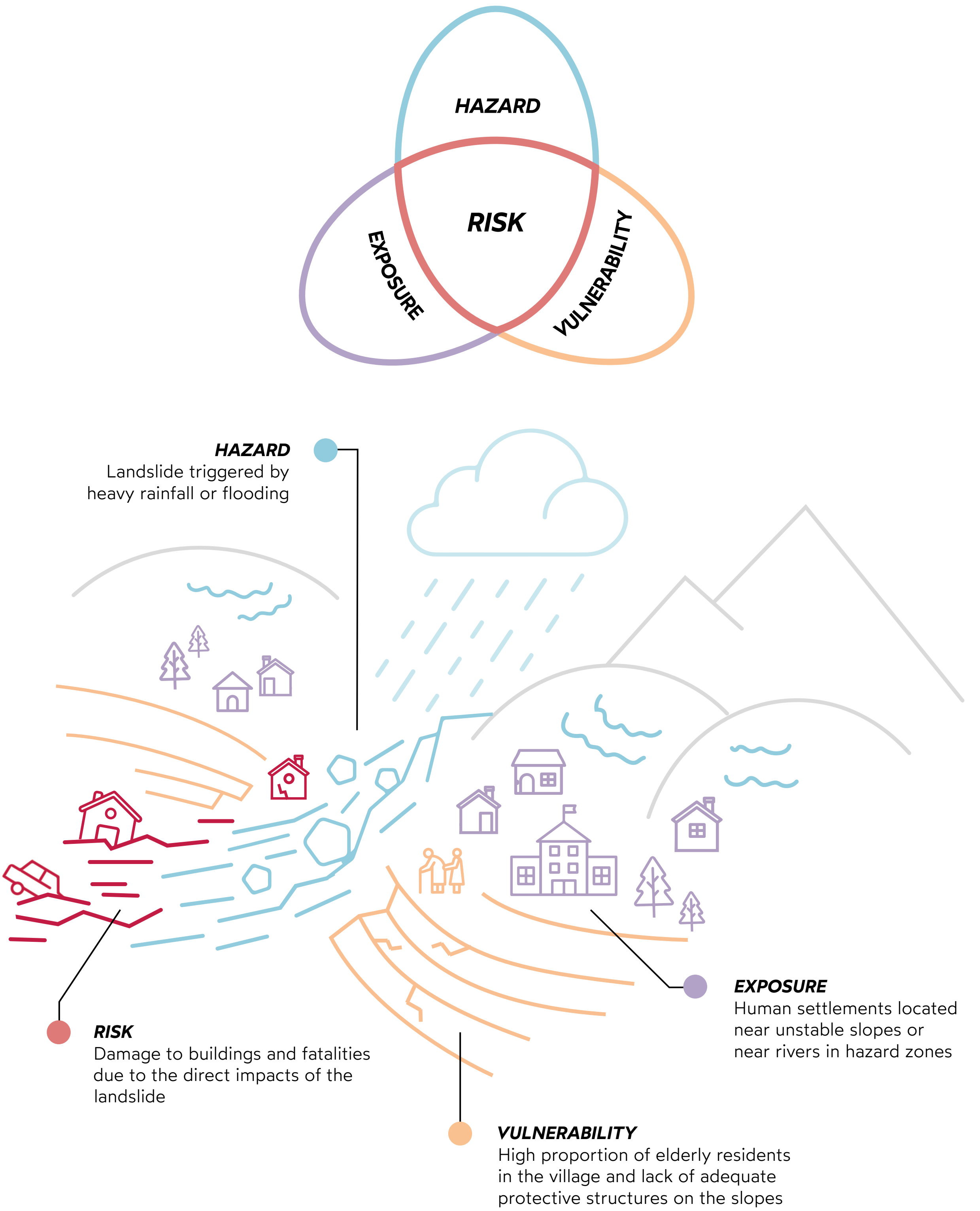


FIGURE 1: *Illustrative examples of hazard, exposure and vulnerability contributing to risk (the concept of risk is based on the framework developed by the Intergovernmental Panel on Climate Change - IPCC).*

The main questions guiding the X-RISK-CC project are:

→ Are we adequately prepared to cope with extreme weather events?

→ What gaps exist in current risk management practices, based on recent experiences?

→ How will weather extremes and related risks evolve in the Alps?

→ How can local risk management practices be improved to address future weather extremes?

The project begins with an analysis of past extreme weather events and their projected future trends, assessing the hazards they trigger and integrating these with data on exposure, vulnerability and impacts. This approach is used to evaluate existing risk management practices and to develop concrete measures that strengthen resilience to future risks.

In a complex system like the Alpine region, which is particularly prone to weather extremes and natural hazards, risk arises from multiple, often interconnected factors. Identifying effective points of intervention requires a thorough understanding of local conditions.

Recovery from impacts caused by heavy rainfall in July 2021 (Photo: Rudi Achtner).

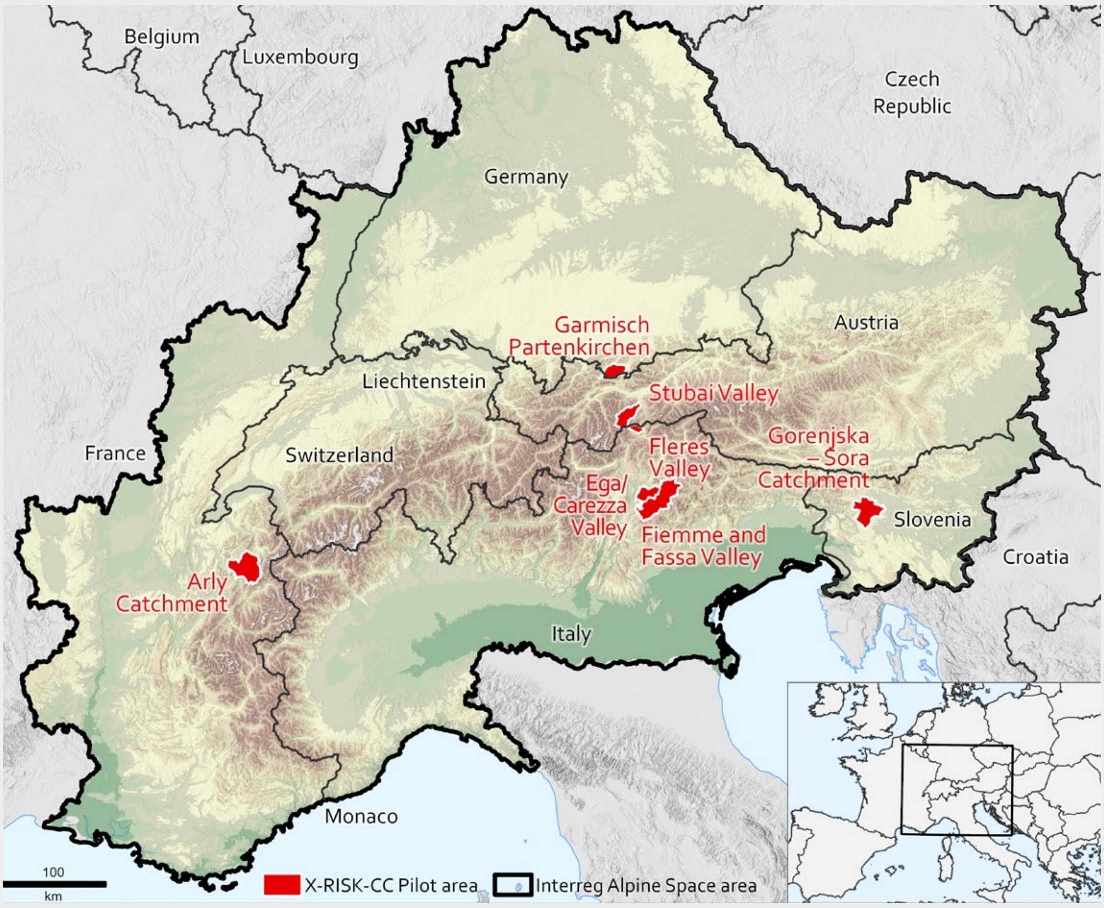


FIGURE 2: *Map illustrating the pilot areas (shown in red) of the X-RISK-CC project.*

To this end, specific pilot areas across the Alps (***FIGURE 2***) have been selected as representative case studies for detailed analyses and the development of tailored risk management solutions. In these areas, progress is driven by close collaboration with local risk managers and stakeholders. Their active involvement is essential both for identifying effective measures and for translating local knowledge into transnational recommendations.

PILOT AREA: GARMISCH-PARTENKIRCHEN (BAVARIA, GERMANY)

GEOGRAPHICAL AND ENVIRONMENTAL SETTING

The Garmisch-Partenkirchen district is located in southern Germany, in the administrative region of Upper Bavaria, and within the Northern Calcareous Alps (***FIGURE 3***). It spans approximately 223 km², with elevations ranging from about 680 to 2,900 m above mean sea level (a. m. s. l.). The main city is Garmisch-Partenkirchen, with a population of about 28,400 people.

The Garmisch-Partenkirchen district is a renowned tourist destination in both summer and winter. It offers ski areas, several hiking trails and natural attractions, in particular the Partnach Gorge, which is visited by more than 400,000 people each year, primarily during the summer season. The area is also traversed by major north-south transalpine routes leading to Innsbruck and the Fern Pass. The Partnach Gorge is located along the Partnach River, which is approximately 18 km long and whose catchment covers an area of about 130 km². The Partnach River originates at an altitude of 1,440 m a. m. s. l. on the Zugspitze massif and flows down the Reintal Valley. Downstream of the Partnach Gorge until its confluence with the Loisach River, the Partnach River passes through densely populated areas where its banks are widely reinforced with stone and boulder riprap.

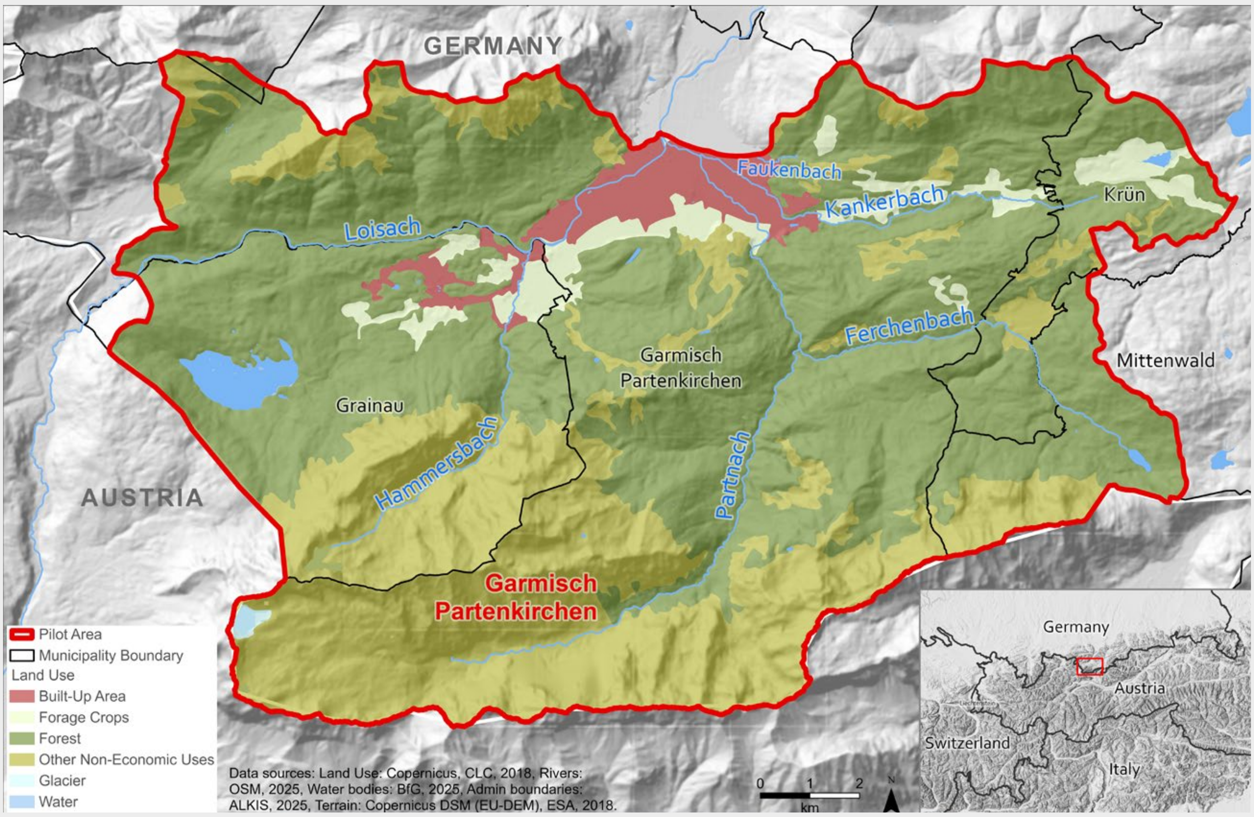


FIGURE 3: *Map of the Garmisch-Partenkirchen district in Bavaria, Germany (in red).*

The upstream areas of Garmisch-Partenkirchen, including the Partnach and the Hammersbach Catchments (the latter covering 10 km^2), are located in one of the wettest parts of Bavaria. Annual precipitation totals are around 1,350 mm in the town of Garmisch-Partenkirchen and exceeds 2,000 mm at the Zugspitze summit. Due to its mountainous terrain, the area is prone to natural hazards - particularly debris flows, rockfalls and floods – typically triggered by heavy rainfall (***FIGURE 4***).

In the city of Garmisch-Partenkirchen, the Loisach and Partnach rivers, fed by multiple tributaries such as Kanker and Fauken, have experienced several flood events in the past causing significant damage to the town and surrounding areas. The Partnach Gorge is also frequently affected by flooding events, usually characterised by relatively low sediment concentrations. However, landslides and debris flows originating in the upstream tributary catchments are constant sources of high sediment supply. Driftwood mobilised on the lower slopes of the Ferchenbach sub-catchment poses a major issue, having caused logjams in the narrow Partnach Gorge. In some cases, this has led to logjams, dam breaks and outburst floods – such as the 2018 flash flood, during which approximately 1,000 m^3 of driftwood was recorded..

Within the X-RISK-CC project, we analysed how risks related to the effects of **heavy precipitation events on natural hazards** may evolve **in the Garmisch-Partenkirchen area** in the future.

FIGURE 4: *Mass movement processes in the Garmisch-Partenkirchen pilot area. Left: Sediment supply from the steep slopes in the Hammersbach catchment, which facilitates the transition from water flow to sediment-rich, hyperconcentrated flow. Right: Landslide on the south side of the Ferchenbach in July 2025 (Photos by Benjamin Jacobs and Amelie Hoffmann).*

PAST AND FUTURE WEATHER EXTREMES

Heavy precipitation events—particularly short-duration rainfall during the summer months—are the most relevant meteorological drivers of natural hazards such as debris flows, landslides and floods. Changes in extreme precipitation in a warming climate, can alter the probability of occurrence of these phenomena.

Based on data collected from weather stations, the Garmisch-Partenkirchen area has already experienced a mean annual temperature increase of approximately 1.5 °C since 1951, along with a general shift in the precipitation regime (i.e., how precipitation is distributed throughout the year). Dry periods (i.e., days without rain) have increased, especially in spring and early summer, while extreme precipitation events have become more intense and frequent. Observations from 1950 to 2022 show an increase in the annual maxima of daily precipitation. Short-duration heavy rainfall episodes (one hour) are now more frequent than in the early 2000s, particularly in summer. In Garmisch-Partenkirchen, data show an overall increase in extreme one-hour rainfall episodes by four events per decade since 2000.

⚠ Dealing with uncertainties

Climate projections are produced by different models, each yielding different results. For simplicity, these projections are often averaged, even though they represent a range of plausible outcomes, the width of which depends on the uncertainty in how models simulate the future evolution of specific processes. Moreover, projected values should be interpreted as estimates of the magnitude of change, not as exact predictions for specific places and times (e.g., rainfall on a given day in July 2050).

Nevertheless, the consistent signal of increasing precipitation extremes conveys an important message for risk managers: the likelihood of natural hazards and cascading impacts is rising.

The **return period**, also known as the recurrence interval, is the estimated average time between events of a given magnitude. It is expressed in years and derived from statistical analysis. For example, a 100-year return period for a flood means there is a 1/100 (or 1 %) chance of such a flood being exceeded in any given year.

Looking into the future, more intense and frequent precipitation events are projected for the coming decades in the pilot area. Up to 25 additional extreme precipitation days per year could occur by the end of the century if the global warming reaches + 4 °C. The return period of annual one-day precipitation extremes is expected to shorten: a 100-year event—currently corresponding to approximately 165 mm per day in Garmisch-Partenkirchen—could become up to 40 % more intense, exceeding 200 mm per day in the future. Extreme one-hour precipitation events are also projected to intensify, as higher temperatures lead to more water vapour in the atmosphere that can be converted into rainfall. Humidity in the atmosphere, and consequently rainfall intensity, increases approximately by 7 % per degree of warming. Based on this relationship, a one-hour precipitation event—currently yielding ~ 8 mm per hour—will be four times as high by 2100 under the highest global warming scenarios.

In parallel with more intense and frequent heavy rainfall events, drier summer conditions are also projected as a result of rising temperatures and a general decrease in summer precipitation totals.

Global warming levels are used to illustrate future scenarios where specific increases in mean global temperature with respect to the preindustrial period (1850-1900) are reached. A global warming level of + 3 °C indicates a world 3 °C warmer than in 1850-1900.

HAZARDS IN PRESENT AND FUTURE CLIMATE

The Garmisch-Partenkirchen area is exposed to multiple natural hazards, including debris flows, rock slope failures, landslides, river floods and flash floods. Several of these processes—typically triggered by extreme precipitation events—have been recorded over the past decades, for example in 1999, 2005, 2013, 2018, 2020, and 2021. These events have affected popular touristic destinations such as the Partnach and Höllental Gorges, as well as the town of Garmisch-Partenkirchen.

The Partnach Gorge is frequently impacted by flood events with relatively low sediment concentrations but with driftwood log jams as a major concern. Discharge records at the Partnach measuring station (1920-2020) indicate that flood events have occurred more frequently since the 1970s. The largest discharge was recorded on 23rd August 2005, corresponding to an event with a return period of 100 years.

Debris flows and landslides originating in upstream areas can deliver significant sediment to both the Partnach and Höllental Gorges (***FIGURE 5***). In the Ferchenbach Valley, heavy precipitation in early summer 2024 reactivated eight large landslides, which can potentially increase the sediment supply to the Partnach Gorge. Debris flows in the upper Reintal

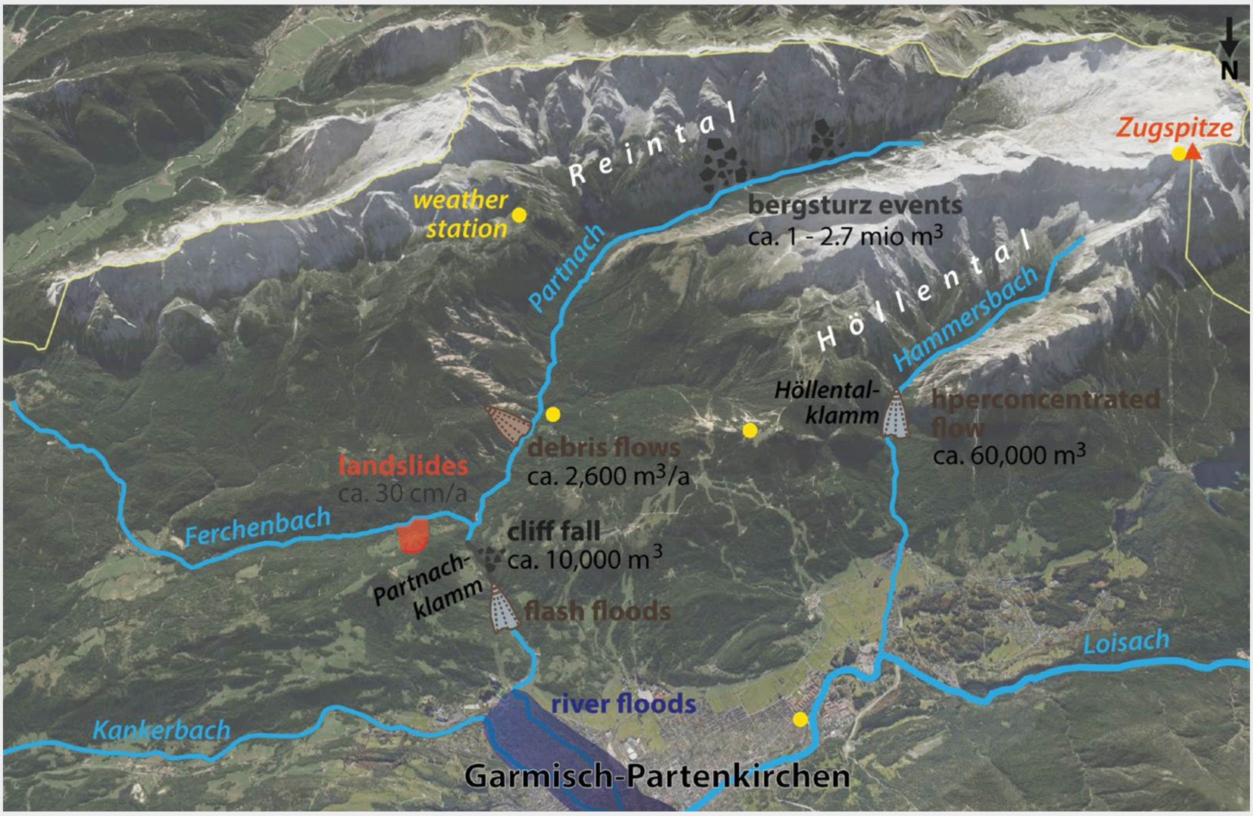


FIGURE 5: *Main rivers, valleys and hazards in the Garmisch-Partenkirchen pilot area (Source: Theresa Frimberger).*

Valley reached volumes of 50,000-100,000 m^3 in 2005, while in the Höllental Gorge approximately 60,000 m^3 of sediment were mobilized during the 2020 event.

Due to the limited availability of documented historical records, it is not possible to analyse recent trends in the magnitude or frequency of these hazards in detail. However, more frequent and intense precipitation extremes projected for the future could increase the likelihood of flooding along both main and secondary rivers draining into the valley. Large landslides and debris flows may also become more frequent, acting as additional sediment sources for events in the lower Partnach Catchment. Flash floods in the gorge are expected to become more frequent as a result of the intensification of short-duration (one to a few hours) rainfall extremes.

In a warmer climate and with more prolonged dry periods during summer wildfires can become more likely in the area and, in turn, increase the likelihood of debris flows. Previous studies have shown that the erosion rates can be up to ten times higher on burnt slopes even decades after a wildfire event.

Driftwood in the Partnach Gorge in December 2023. Even small accumulations of wood can block the discharge and increase the risk of log jams in the event of extreme rainfall (Photo: Theresa Frimberger).

CURRENT AND FUTURE IMPACTS AND RISKS

The Garmisch-Partenkirchen district is a popular tourist destination. The Partnach Gorge alone attracts more than 400,000 visitors annually, primarily during the summer months (May to October). Tourists and hikers are among the directly exposed groups in the event of flooding in and around the gorge, which may be triggered by heavy rainfall or blockages. Flash floods that cause a sudden rise in water levels pose a particular threat as they are difficult to anticipate and can leave little time to close gorges to visitors or evacuate.

Natural hazards can physically damage tourism-related infrastructure, including hiking paths and accommodations, leading to economic losses in the tourism sector. For instance, in summer 2018, the Partnach Gorge was closed for nearly two months due to flood damage, which destroyed paths and bridges and caused significant driftwood blockages in the tunnels.

Flood events can also have serious consequences for the town of Garmisch-Partenkirchen. In addition to endangering residents and damaging private property, floods can severely impact businesses and public infrastructure affecting them directly or indirectly by interrupting physical access to the region. This was the case in 2019 and again in 2024, when road networks were disrupted and train services interrupted. In the future, the construction of bypass tunnels-either planned or already underway-can be expected to reduce inner-city traffic volumes on major roads, thereby also reducing the impacts of flood events to transit traffic.

⚠ What is a Hazard Map?

A hazard map illustrates areas potentially affected by a specific natural hazard. It uses colour coding to represent the **likelihood and intensity** of a hazard occurring in each location. Hazard maps are essential tools for **disaster risk management** and **spatial planning**, as they help guide land use decisions, infrastructure development, and emergency preparedness.

According to current hazard zone maps, up to 110 hectares of urban and semi-urban areas could be flooded during an extreme flood event affecting the Partnach or Kanker Rivers. If current trends in population growth and tourism continue, the number of people exposed to natural hazards is likely to increase. This may create demand for new buildings and infrastructure, which must be carefully planned in areas of low or no hazard risk. Given the projected intensification of extreme weather events, existing hazard zones may expand in the future. Therefore, updating hazard zone maps to account for future climate conditions will be essential to guide the safe placement of new developments.

THE ROLE OF VULNERABILITY IN RISK

The impacts of a hazard event can be exacerbated not only by the event's intensity or the number of exposed elements, but also by other factors such as social characteristics (e.g., an ageing population, low risk perception, or lack of awareness), and the condition and maintenance of buildings and infrastructure. Tourists— particularly international visitors—are expected to be especially vulnerable, as they often lack the same level of risk awareness and familiarity with local emergency procedures.

Greater impacts are more likely when risk management practices are inadequate—for example, in the absence of protective measures such as rockfall barriers—or when preparedness for responding to multiple simultaneous or cascading hazards is low.

Due to regular exposure to natural hazards, local organizations responsible for prevention, preparedness, and response are well-trained in dealing with these types of events, but continuous efforts are needed to improve the ability to cope with arising challenges. New structural and technological measures, such as the rake installation at Ferchenbach and a gauging station upstream of the Partnach Gorge, are being implemented to mitigate hazard impacts and enhance preparedness, particularly for flash floods events. These events pose challenges due to their rapid onset and the sudden rise in water levels within the gorge.

In this context, a thorough evaluation of current risk management measures and their adaptation to changing conditions is crucial for the safety of people and their activities.

Visiting the construction site of a innovative S-shaped rake in Ferchenbach upstream of the Partnach River confluence during the third Stakeholder Meeting in July 2025 (Photo: Amelie Hoffmann).

RISK MANAGEMENT

RISK MANAGEMENT CYCLE

Effective management of natural hazard risks requires systematic planning and coordination. Risk management provides a structured and iterative process aimed at minimizing risks and enhancing community resilience. This process involves a continuous cycle of interconnected actions, as illustrated in the infographic.

The main phases of the **risk management cycle** include:

PREVENTION	PREPAREDNESS
RESPONSE	RECOVERY

The interphases —the transitions between phases— are critical components of the risk management, as they involve shifts in responsibilities, resources, and attention. These interphases (Prevention-Preparedness, Preparedness-Response, Response-Recovery, and Recovery-Prevention) require particular attention to ensure smooth transitions, clear communication across phase boundaries and to avoid potential gaps in risk management.

Second stakeholder meeting in January 2025 in Garmisch-Partenkirchen (Photo: Theresa Frimberger).

Activities and measures taken in advance to ensure effective response.

Early warning systems, emergency planning, training and exercises, resource pre-positioning, public awareness campaigns, and establishment of coordination mechanisms.

Capacity to act and prepare before a hazardous event strikes.

Actions taken during and immediately after an event to save lives, reduce impacts, protect the environment and meet basic subsistence needs.

This includes effective coordination, emergency operations, search and rescue, evacuation, emergency communications, and immediate humanitarian assistance.

Emergency response requires the coordinated intervention of all civil protection actors.

Measures taken to mitigate the risk. This includes structural measures and non-structural measures.

STRUCTURAL MEASURES
protective structures, nature-based solutions, retention areas, asset protection measures

NON-STRUCTURAL MEASURES
land-use planning, hazard zone maps, education, communication and legislative frameworks

Supports acceptable levels of risk society is willing to live with.

Actions taken after a disaster to overcome the event and enhance resilience through build back better principles.

This includes restoration of infrastructure and services, economic recovery, psychosocial support,participative reconstruction planning, and implementing lessons learned.

Integrates adaptive actions and long-term thinking.

*Key actions and measures associated with each phase of the risk management cycle, including both **structural** and **non-structural** measures that support prevention, preparedness, response, and recovery.*

STAKEHOLDER INVOLVEMENT APPROACH

In the pilot area, three participatory workshops were held to analyse and improve local risk management of natural hazards driven by weather extremes. Participants included different entities dealing with risk: municipalities, civil protection, torrent control authorities, technical experts, research institutions, and representatives from different levels of administration. During **the first workshop** the recent extreme events were reviewed to evaluate what worked well and what failed in terms of risk management so to identify entry points for future improvements; in **the second workshop** participants were invited to evaluate the current capacity and potential challenges in managing similar events but in a plausible future context, based on analysed climate projections and possible socio-economic evolution; **the third workshop** was focused on developing concrete action plans for improving the management of future risks related to climate extremes.

1. Workshop

ANALYSE THE PAST AND IDENTIFY GAPS

2. Workshop

IMAGINE THE FUTURE AND ANTICIPATE CHALLENGES

3. Workshop

DEVELOP ACTIONS TO BUILD CAPACITY

Participating organisations in (one or more of) the workshops in the Garmisch-Partenkirchen pilot area

- Bayerisches Landesamt für Umwelt (Representatives of flood control strategies and torrents)
- Wasserwirtschaftsamt Weilheim (Representatives of flood warning, flood protection and river management)
- Landratsamt Garmisch-Partenkirchen (Representatives of disaster protection and climate change management)
- Bergwacht Bayern (Representatives of disaster protection)
- Markt Garmisch-Partenkirchen (Representatives of the Gorge operation and civil construction authority)
- Gemeinde Grainau (Representatives of municipal maintenance and flood protection)

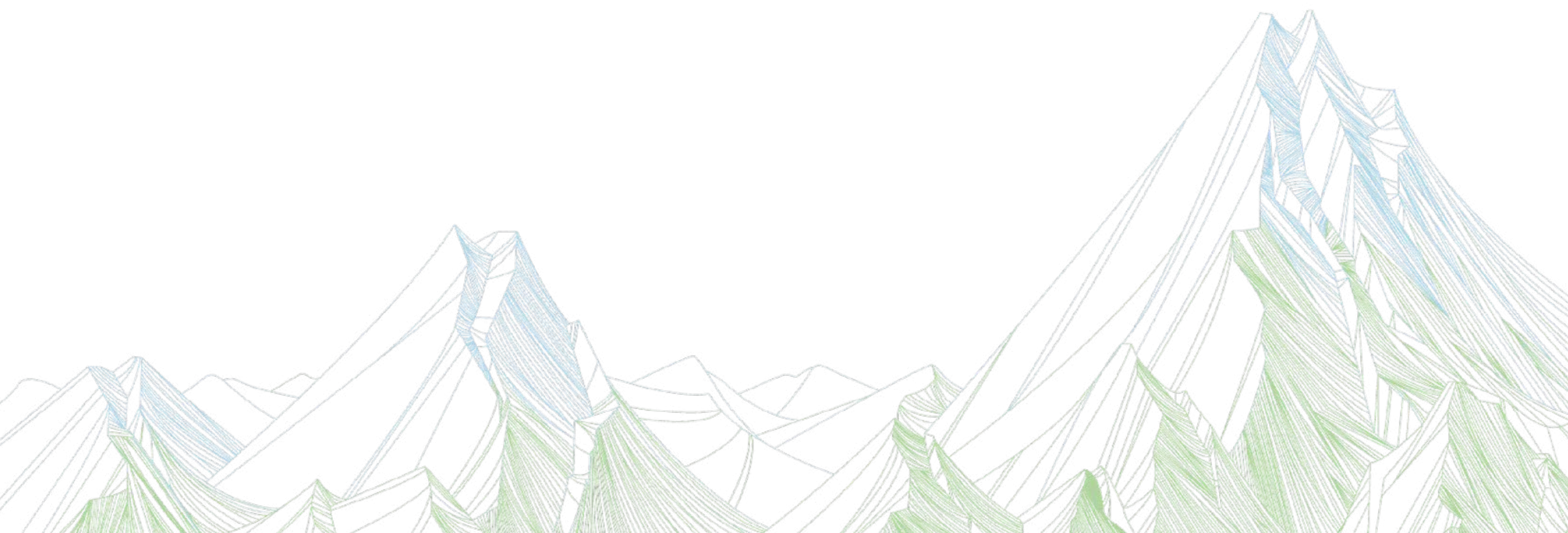
RISK MANAGEMENT GAPS

In the Garmisch-Partenkirchen pilot area, the first workshop brought together local and regional stakeholders to discuss existing strategies for managing natural hazards in the Partnach Gorge. Participants noted that while structural protections exist within and downstream of the gorge, the upstream area still lacks adequate measures—though improvements, such as a new rake, are being planned. Contingency plans are in place and, so far, recent events have remained within their expected range. A range of early warning and monitoring tools are available, including extensometers and visual monitoring systems. Additionally, the gorge is closed to visitors on critical days as a preventive safety measure. Roles and responsibilities in emergency response are generally well defined, with mountain rescue able to respond flexibly. Recovery processes inside the Partnach Gorge are supported by a master agreement for recurring works over three years, with no major funding difficulties; the city plays an important role in this context. However, limited documentation of smaller events hinders shared learning, long-term planning, and the broader consideration of new protection structures and mitigation strategies.

When looking at future scenarios for the Garmisch-Partenkirchen pilot area, participants identified several concrete challenges and needs. Existing protective structures are likely insufficient to cope with combined sediment and driftwood overload if extreme events intensify. The current legal framework for consideration of climate change in dimensioning of structures can limit flexibility in adapting structural and preparedness measures to local risk dynamics. To strengthen prevention and preparedness, stakeholders stressed the importance of improving flood models, regular sediment removal from channels, and maintaining small or dirt roads to ensure multiple access points to the middle part of the catchment. During the response phase, better support for decision-making is needed, including more explicit information on the effects of water levels and the structural condition of bridges—potentially through a dedicated cadastre. A closer involvement of the scientific community was identified as key to support understanding of evolving hazards and to justify future protection measures.

GAPS PER PHASE

The key gaps identified for past events and for the projections for the future through the participatory workshop process are reported in the following sections, first for each phase of the risk management cycle, then for the interphases between them.



GAPS PER PHASE

PREVENTION

- Structural protective measures and bridges are designed to account for raised water levels and driftwood transport, but the combined occurrence of rare sediment-laden flows and driftwood transport can exceed existing protection structures and block bridges leading to flooding and sediment deposition in places that would usually not be affected and are not indicated in the hazard maps.
- Legal foundations, such as the equality principle, do not allow for higher protection standards to be implemented in places where emerging climate-related hazards are expected to increase significantly, likely exceeding the current standard climate allowance of 15 %.
- The flood risk arising from Wamberger Graben is not sufficiently addressed. The hospital "Klinikum Garmisch-Partenkirchen" is located in the area at risk of extreme flood events from Kanker and Wamberger Graben.
- Wood transported from the upper and middle reaches of the Kanker accumulates in the retention basin and can lead to additional impacts (e.g., jamming) in the event of flooding.

PREPAREDNESS

- Local response organizations are missing access to information on bridge conditions and conditions of protective structures that may be jammed or damaged during extreme events, e.g., events with combined sediment and driftwood transport.

- As the Partnach Gorge cannot be accessed during critical water levels, there is little knowledge about flooding processes in the gorge. For past events it can only be estimated what maximum water levels occurred, or in what time logjams formed and breached. This makes it difficult to develop and validate accurate models on how the Partnach Gorge affects flood formation in downstream Garmisch-Partenkirchen.

- Currently the German Weather Service (DWD) does not issue warnings for convective rainfall events. Because these types of events are difficult to model, the predictions are highly uncertain and there is a risk of issuing warnings without an event occurring. On the downside, convective rainfall events can surprise local risk managers and response organizations if no warning is issued to these organizations.

- The model currently used to estimate flood areas and create flood maps by the water management agencies starts downstream of the Partnach Gorge and covers the Partnach River until its confluence with the Loisach River. Desirable improvements would be to better account for the effects of sediment and driftwood transport in the current modelled area and to extend flood modeling upstream to include the Gorge and its flood shaping characteristics.

- The Bavarian flood warning center (Hochwassernachrichtendienst Bayern) warns according to four warning levels that correspond with different severities of impacts based on real-time gauge measurements. Since the warning levels issued are based on the gauging station located close to the city of Garmisch Partenkirchen, the thresholds used are not representative of water level changes that can impact the Partnach Gorge. Independently of official warnings, the Gorge manager continuously monitors the water level at the same gauge to identify criticalities for the operation of the Gorge.

- Warnings reach local response organizations via various channels. DWD publicly warns in case of extreme weather and the Bavarian flood warning center in case of imminent flooding. Additionally, the district administration (civil protection) receives warnings and relays them to local response organisation. Not all warnings are tailored to the respective area of receiving organisations.

RESPONSE

- Warning levels issued by the Bavarian flood warning center do not necessarily correspond with the thresholds that will likely affect critical or vulnerable infrastructure, e.g., hospitals, schools or transportation infrastructure. There is a lack of information on which discharges or water levels at the gauge will lead to which assets being exposed.
- A pre-drafted and adaptable communication strategy for all involved response organizations, but especially for the spokespersons of the administrative district offices (Landratsamt), can ensure fast and accurate communication of hazard information and imminent threats to the public in case of an event and help avoid miscommunication.

RECOVERY

- Systematic documentation is compiled for catastrophic events but smaller events without major damages are dealt with and documented locally. There is a need for better documentation and quantification of all hazard and damage processes. Missing documentation of hazard events and damages mean there is less basis for modelling, validation and quantification of hazard and risk processes that can ultimately result in less economic decision making when defining new protection strategies and mitigation actions.

GAPS PER INTERPHASE

PREVENTION → PREPAREDNESS

- Conflicting interests in safety/operation of Partnach Gorge and upstream catchment and environmental concerns. These specifically relate to the topics of sediment and forest management which affect both the safety of visitors to the Gorge and upstream hiking paths and efforts in nature conservation.
- A closer involvement of the scientific community in the analysis and documentation of past event as well as preventing and preparing for future events. Deficits in documentation and limited availability of models make it difficult to reduce uncertainty in projections about future hazard and risk situations. As a result, new adaptation strategies and mitigation measures might be suboptimal.
- Quantitative methods such as benefit-cost analysis help assess the appropriate use of resources to maximize risk reduction. Although not all positive or negative impacts of adaptation or mitigation can be quantified, a positive benefit cost ratio is a useful starting point when having to decide between multiple measures.

UNDERSTANDING RISK TERMINOLOGY

What is the equality principle?

The principle of equality in flood protection requires that all citizens be treated equally. This means that no individual regions may be given preferential treatment or disadvantaged, but that protection measures, such as the construction of dikes, dams, or the designation of retention areas (e.g., flood polders), be implemented in endangered areas according to a uniform standard.

Why are convective rainfall events difficult to predict?

Convective rainfall occurs when locally the sun heating the ground causes warm air to rise and condense into clouds. The complex physical interactions are difficult to reproduce in models. Even small uncertainties in the model inputs can lead to widely different outcomes. Due to the small scale of the phenomenon, past data is often of insufficient quality to calibrate and validate models of convective rainfall.

Sediment supply into the Partnach River in the Reintal Valley (Photo: Benjamin Jacobs).

CO-DESIGNED TAILORED ACTIONS FOR THE PILOT AREA

Following the identification of gaps in risk management capacity through participatory workshops with local stakeholders and administrative authorities in the Garmisch-Partenkirchen pilot area, several actions have been identified to strengthen resilience. Participants prioritized the following gaps as the most crucial challenges:

1. Conflicting interests between safety/operation of the Partach Gorge and upstream catchment.
2. Warning levels do not necessarily correspond with the thresholds that affect critical or vulnerable infrastructure.
3. Dealing with and communicating uncertainties in risk to emergency services and the public.
4. Legal foundations do not allow for higher protection standards to be implemented in places where emerging climate hazards are expected to increase significantly.
5. Missing access to information on bridge conditions and conditions of embankment structures.

The complete list and details of the tailored action plan devised for the pilot area of Garmisch-Partenkirchen are published in a separate document called "Tailored Action Plan: Garmisch-Partenkirchen" which can be found at:

X-RISK-CC - Alpine Space Programme

https://www.alpine-space.eu/project/x-risk-cc/

The tailored action plan focusses on suggesting initiatives to tackle some of these most critical gaps.

CHALLENGES AND PERSPECTIVES

Organisations involved in the management of extreme weather events in the Garmisch-Partenkirchen pilot area bring to the table a large amount of knowledge and experience gained over the course of various extreme and more frequent weather events. Due to frequent occurrences, the involved organizations are already well equipped and experienced in coping with these types of events and continue to explore new measures, in particular structural and technological solutions, to some of the challenges posed by natural hazards in the region.

Over the course of the three stakeholder meetings, the circle of participating stakeholders has grown steadily. Nevertheless, some risk management or response organizations were not represented in one or more workshops. These include, for example, the offices of the mayors, the volunteer fire departments, as well as nature conservation authorities and associations. The gaps identified here thus provide a valid perspective on the challenges of dealing with natural hazards but cannot be considered complete or as the sole basis for prioritizing next steps.

The tailored action plan represents an initial proposal of activities for improving risk management in the pilot area developed within the X-RISK-CC project through the collaborative framework between research and practice. However, initiating further actions and implementing measures with regards to adaptation to future extreme weather events and the resulting risks remain main responsibilities of local and national authorities and are supposed to be realized after the project end. To do so, the local responsible organizations would have to recognize the need for action and independently push ahead with the implementation of such or similar actions.

Site visit during the third Stakeholder Meeting in July 2025. (Photo: Amelie Hoffmann).

USEFUL RESOURCES

X-RISK-CC – Alpine Space Programme

https://www.alpine-space.eu/project/x-risk-cc/

AlpHaz – Munich Alpine Hazards and Mitigation Cluster

https://www.cee.ed.tum.de/alphaz/

X-RISK-CC – Web GIS: information on intensity and frequency of weather extremes in the entire Alpine Space

https://cct.eurac.edu/x-risk-cc

ACKNOWLEDGMENTS

We extend our sincere gratitude to all participants who contributed their time, expertise and local knowledge throughout the project and the work-shop series in the Garmisch-Partenkirchen pilot area. Representatives of the municipal administrations, local and regional agencies as well as emergency organisations shared valuable insight from their direct experience in managing extreme events in this Alpine territory. Special thanks go to Mr. Achtner for providing us in-depth insights and access to the Partnach Gorge operation and the Bavarian environmental ministry for their contribution in funding our work on the X-RISK-CC project.

Landslide on the south side of the Ferchenbach stream in July 2025. There are several active slopes along the Ferchenbach stream which are monitored by a new early warning system. A landslide during a heavy rainfall event carries the risk of subsequent debris flows, in which large quantities of sediment would be transported downstream through the Ferchenbach stream (Photo: Amelie Hoffmann).

Technische Universität München
Arcisstr. 21
80333 München, Germany

Prof. Dr.sc.tech. Daniel Straub
Chair of Risk Analysis and Reliability
www.cee.ed.tum.de/era

Prof. Dr. rer. nat. Michael Krautblatter
Chair of Landslide Research
www.cee.ed.tum.de/landslides

LEAD PARTNER

PROJECT PARTNERS