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Landslide risk management: from hazard to disaster risk reduction

Abstract Integrated disaster risk management is crucial in reducing landslide risk. The International Consortium on Landslides has launched several initiatives to enhance research and practice in landslide risk management, including the Tokyo Action Plan 2006, the ISDR-ICL Sendai Partnerships 2015–2025, and the Kyoto Landslide Commitment 2020. This article presents a collection of papers covering various aspects of landslide research and disaster risk management across diverse scales and regions worldwide. To effectively manage landslide disaster risk, it is essential to have a solid understanding of disaster risk and foster a sustained collaboration between science and policy-making to strengthen disaster risk governance. The ICL is dedicated to this mission, and by working together, its members and partners can contribute to the comprehension, reduction, and mitigation of landslide disaster risk globally.

Keywords Landslide disaster risk management · Disaster risk reduction · International Consortium on Landslides · Sendai Framework for Disaster Risk Reduction

The collection of papers titled "Landslide risk management: from hazard to disaster risk reduction" is a virtual thematic issue covering various aspects of landslide research to manage disaster risks on diverse scales. This includes 20 articles published between 2005 and 2023 addressing global and specific concerns about managing landslide disaster risk. These include those issues of interest reflected by the International Consortium on Landslides' (ICL) key initiatives to reduce disaster risk.

There has been international consideration regarding the impact of landslides worldwide. Consequently, global landslide and avalanche hotspots were created to identify developing countries most at risk for landslides and avalanches, using climate, lithology, earthquake activity, and topography data. The resulting model scaled the hazard index into nine levels and used global population data to assess risk. However, their application may not accurately reflect local conditions, so further investigation is necessary before using or interpreting the results for specific national circumstances (Nadim et al. 2006). This has led to the developing of national strategies to understand disaster risk, which involve challenges associated with landslide occurrence at the national level, particularly in mountain regions.

In Switzerland, for example, approximately 6% of the land is susceptible to slope instability. Since a long time ago, the Swiss government has been working to manage natural hazards like avalanches, floods, and landslides. With population growth and climate change, the risk is increasing. Authorities use zoning laws and hazard maps to manage landslide disaster risk and prevent hazardous land development. These maps use colors to indicate restricted construction areas with safety requirements and areas without restrictions. Communication with locals may raise disagreements. Nonetheless, with community approval, strict policies can reduce landslide risks (Lateltin et al. 2005).

Similarly, although landslide disasters are rare in the UK, they cause over £10 million in financial losses annually. A management framework was built on managing small and larger landslides affecting urban areas. Case studies identified three key issues: lack of evidence, the need to evaluate guidance, and the significance of near misses. Local response effectively manages small landslides, while emergency services respond promptly and efficiently to larger landslides. However, it was possible to identify that a lack of data and understanding of near misses pose risks. Investment in geohazard databases, specific planning guidance, accounting for near misses, and more case studies are still needed (Gibson et al. 2013). This goes hand in hand with the availability and allocation of resources.

Klimeš et al. (2017) suggested a more comprehensive landslide risk assessment in the Czech Republic due to uneven government spending. They proposed using the term "low-risk environment" to understand public perception better. Additionally, they recommended calculating the frequency of potentially fatal landslides using near-miss events and raising public awareness of the risks. Accurately assessing the likelihood of landslides' impact on people or traffic is crucial for effective risk management.

Raška (2019) studied the history of community-based landslide disaster risk reduction in NW Czechia by analyzing a database of 230 events from 1531 to 2019. The study examined institutional and social conditions, the number of events, triggers, impacts, and recovery processes for five historical periods. From this analysis, a hybrid model was developed which combines traditional and newly established practices. This means that community engagement in landslide disaster risk reduction should consider the region's environmental, institutional, social, and technological factors, as well as the unique conceptualizations of the community that enable productive engagement. The study recommends further attention to community engagement approaches and regularly re-evaluating traditional perspectives. Furthermore, interdisciplinary studies should address long-term path dependencies and cross-cultural variations in community engagement within landslide disaster risk reduction in specific settings.

By understanding how hazards change over time, information from past events can be used to deal with current hazards. Sassa et al. (2016) created a numerical model that can simulate the development of tsunamis caused by landslides. This model was tested using data from the Unzen-Mayuyama disaster in Japan in 1792, and the simulated tsunami heights matched the recorded heights at the coast. This information was documented by "Tsunami-Dome-Ishi," a stone that marks where the tsunami reached and memorial stone pillars and can be applied to similar scenarios (Fig. 1).

Hong Kong is another country that faces landslide risk. Since the late 1940s, it has experienced over 470 deaths due to severe landslides. This is due to the city's hilly terrain, seasonal rainfall, and urban development. A holistic approach to risk management is required to address the impact of climate change. The slope safety system is an example of using engineering and non-engineering methods to manage landslide risk and build a smart city in Hong Kong. The strategy involves a central authority overseeing slope design and construction, research and development, geotechnical standards, slope upgrades, regular maintenance, a landslide warning system, public education, and innovation. These efforts have significantly decreased the number of landslide fatalities in Hong Kong. However, climate change and extreme rainfall remain challenges for the future (Cheung 2021).

The Geotechnical Engineering Office established a Slope Safety System in 1977 to address this. The system has effectively reduced landslide risk using various strategies and has been continuously improved to enhance emergency preparedness. Technical developments in landslide risk management, early warning, and emergency systems aim to improve the system's resilience against extreme rainfall events caused by climate change. The Slope Safety System in Hong Kong has successfully managed the risk of landslides for many years. Although it is impossible to eliminate this risk completely, proactive steps have taken place to enhance the system for the future (Pun et al. 2020). This includes Hong Kong's Landslip Warning System (LWS), which covers the entire territory and has been upgraded multiple times since its launch in 1977. The LWS continuously increases the number of rain gauges and uses the Internet of Things (IoT) and cloud computing to withstand extreme weather conditions. Along with slope upgrading and geotechnical control, the system has reduced injuries, loss of lives, and landslide damage. Accurate data and regular upgrades are necessary for reliable prediction models, and multi-level warning systems provide ample time for emergency preparedness. The LWS must remain resilient and use technological advancements (Kong et al. 2020).

ICL is focused on improving collaboration among its members, which is one of its most valuable contributions. In 2009, a catastrophic landslide occurred in the Peruvian Andes, and scientists and community members worked together on a disaster risk reduction project. Not only did they undertake hazard mapping and landslide monitoring but they also emphasized the importance of identifying stakeholder roles accurately and implementing effective risk communication strategies. To understand the community's needs and opinions, it was crucial to have effective communication between external experts and community leaders. Therefore, a cultural paradigm shift in DRR is necessary to build stakeholders' trust and ensure the project's scientific basis (Klimeš et al. 2019).

Along this vein, Czech Republic and Peru experts have long worked to monitor slope movements at Machu Picchu. They installed a network of instruments that adhered to site protection requirements and showed no major hazards. Tourist access to Intiwatana Hill has been limited since 2019. Historical photos from the 1940s were also analyzed, showing that Inca structures have not been affected by damaging processes. This successful collaboration between the Czech World Centre of Excellence on Landslide Risk Reduction and managers of the National Archaeological Park of Machu Picchu has led to low-cost and environmentally friendly hazard management, which comprised the use of portable extensometers and dilatometric measurements of low-impact and eco-friendly monitoring. These devices are strong, precise, and eliminate the need for permanent on-site installations. Sustained future cooperation between both parties will benefit research and conservation efforts (Vilímek et al. 2020).

Analysis of disaster drivers and hazard dynamics should be considered to reduce landslide disaster risk. In this regard, a study by Cui et al. (2019) expressed concern about a debris slide, flow, and flood that resulted in over 500 fatalities and the destruction of hundreds of homes in Freetown, Sierra Leone. The researchers emphasized that urbanization has led to hazardous conditions that cause loss of life, property damage, and environmental harm. The lack of proper risk assessment during urban planning has worsened the situation. Informal settlements and slums are particularly vulnerable due to low-quality buildings. Early warning systems, emergency plans, education, and community participation are necessary to minimize the risk of disasters.

On that note, Hostettler et al. (2019) evaluated the effectiveness of community-based soil-bioengineering techniques in mitigating shallow landslide events. The Red Cross worked with local communities in Honduras to stabilize 230 landslide hazard sites using bioengineering measures, a cost-effective technology that offers multiple benefits to landowners. Through this initiative, it was possible to recognize the importance of empowering communities to take responsibility for their own future by building self-confidence. Thus, participatory approaches are essential for sustainable, long-term transformative change and risk reduction.

In like manner, it should be noted that current efforts to reduce vulnerability to natural hazards like landslides are inadequate, and more investment in disaster risk reduction is needed. More investment in disaster risk reduction is necessary to mitigate the insufficient impact of natural disasters like landslides. Maes et al. (2019) proposed a social multi-criteria evaluation participatory methodology to identify effective DRR measures based on stakeholder groups' perceptions. Stakeholder acceptability is prioritized over cost, feasibility, and effectiveness. SMCE can facilitate discussions and aid in developing long-term strategies for reducing landslide risks closely tied to how landslides are perceived.

In their research, Hernández-Moreno and Alcántara-Ayala (2017) emphasized that understanding potential disaster risks is crucial for building resilient communities. Psychological numbness and effectively communicating hazards and risk management must be overcome to prevent future disasters. Likewise, disaster response plans must consider short, medium, and long-term impacts on affected populations and the environment. Furthermore, resilience can be built by promoting disaster risk management as an opportunity for community and family development. Evaluating risk perception and vulnerability can help improve future disaster risk management.

The participation of various actors should not be neglected to manage disaster risk from an integrated perspective. This is one of the endeavors that ICL has been supporting for a long time. For instance, experts from various countries gathered in Harbin City, China, for an academic conference on landslides. Transportation

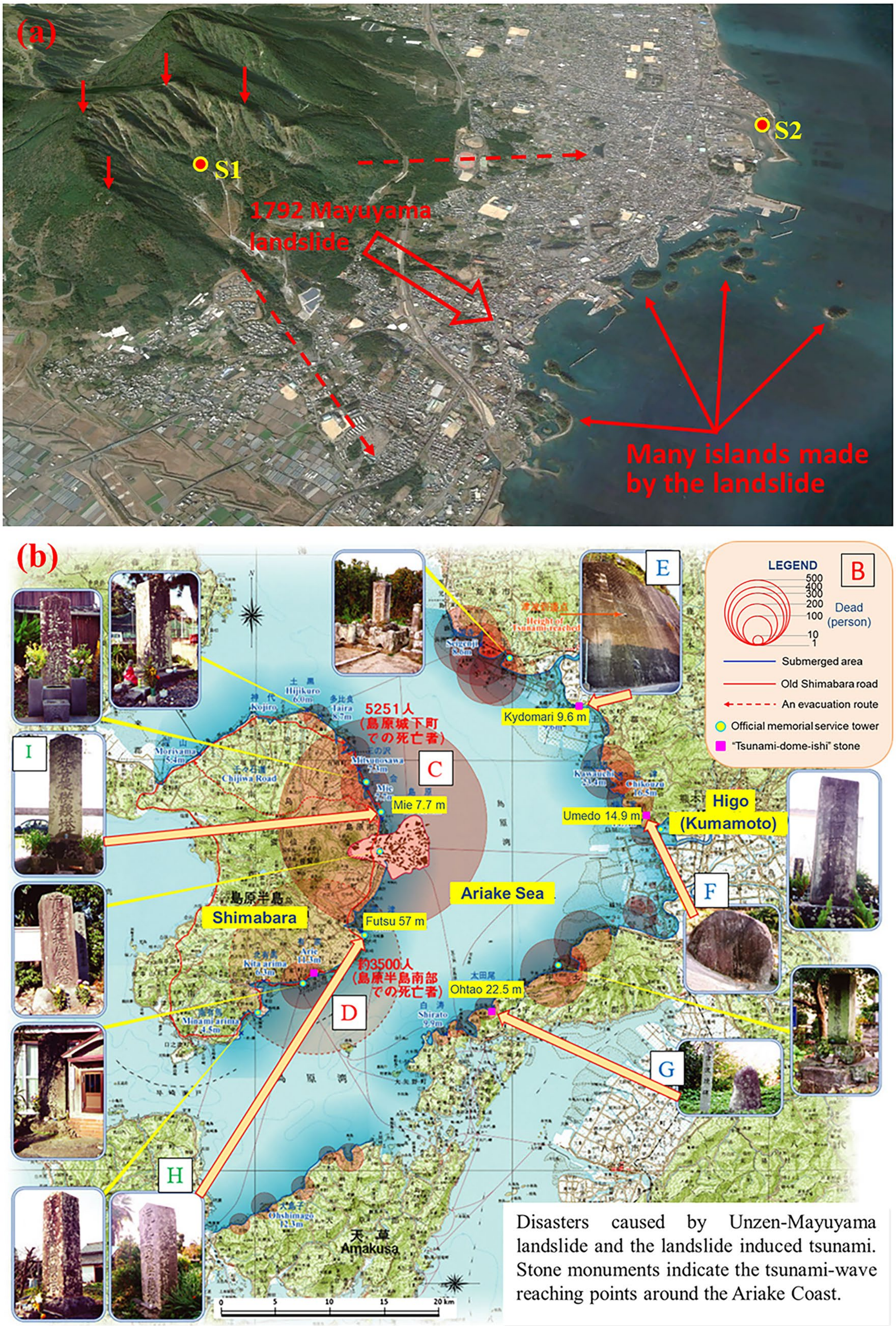

Fig. 1 Impact of Landslides-1792 Unzen-Mayuyama landslides and tsunami disaster (source: Sassa et al. 2016)

authorities, government officials from Heilongjiang Province and Inner Mongolia Autonomous Region, and teachers and students from Chinese universities and research institutes also attended. The event was co-organized by the Northeast Forestry University of China and the State Key Laboratory of Frozen Soil Engineering and co-sponsored by multiple organizations (Guo et al. 2019).

Cooperating with all parties is essential to effectively carry out the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) at all levels. Developing nations require improved training and education on reducing the risks of landslides. To address this need, ICL has developed a set of teaching materials that can benefit university students, government officials, non-governmental organizations (NGOs), and the general public. These resources offer practical guidance for teaching the skills and knowledge necessary for landslide risk reduction (He et al. 2014).

Along those lines, Matsuoka and Gonzales Rocha (2020) emphasized the importance of collaboration in building resilient communities and nations for sustainable development. Therefore, disaster risk reduction is essential, and the Sendai Framework Voluntary Commitments online platform monitors progress and showcases the work of all stakeholders. This platform provides an opportunity to identify oversights and opportunities for improvement. Recent data from the platform revealed that landslides are the third most covered hazard, focusing on capacity development, risk management, and community-based DRR. Increased partnerships and innovative technology solutions are needed to address these challenges effectively. Joint action from all stakeholders is necessary to implement the Sendai Framework successfully. Nonetheless, progress in the implementation relies on the commitment of national governments.

Bhuiyan and colleagues (2023) analyzed landslide databases in relation to the SFDRR indicators. They also evaluated the availability of damage data and assessed the compatibility of current data collection practices with SFDRR guidelines. Furthermore, the feasibility of using existing data to estimate landslide costs was examined. Their study unveiled insufficient damage data in existing national databases and identified gaps in current landslide data management practices in Malaysia.

The International Consortium on Landslides drives global research and disaster risk reduction (Fig. 2). Through the implementation of the Sendai Landslide Partnerships 2015–2025 and the Kyoto Landslide Commitment 2020, ICL has brought together various scientific communities to participate in global agendas and promote knowledge sharing. ICL's commitment to building capacity, particularly in developing countries, is a testament to its dedication to making a positive impact. By bridging the gap between science and policy-making, the ICL equips its members to interact with policymakers and build trust with other major stakeholders in landslide DRR (Alcántara-Ayala and Sassa 2021).

To effectively manage the risk of landslide disasters, ICL develops three key cornerstones. These include the Tokyo Action Plan, the ISDR-ICL Sendai Partnerships, and the Kyoto Landslide Commitment 2020.

In 2006, the Tokyo Action Plan, "Strengthening research and learning on landslide and related earth system disasters for global risk preparedness," was adopted at the United Nations University in Tokyo, Japan. The actions proposed in the Plan include organizing the World Landslide Forum, identifying World Centres of Excellence on Landslide Risk Reduction, and establishing the IPL Global Promotion Committee to manage the International Programme on Landslides. The IPL supports disaster risk reduction efforts made by the International Strategy for Disaster Reduction (ISDR), which is currently known as the United Nations Office for Disaster Risk Reduction (UNDRR) (Sassa 2006).

The ISDR-ICL Sendai Partnerships were established during the Third World Conference on Disaster Risk Reduction in Sendai, Japan, in 2015. These partnerships aim to reduce landslide disasters and align with the SFDRR. The partnerships support all four priorities of the SFDRR, including understanding disaster risks, strengthening disaster risk governance, investing in disaster risk reduction, and enhancing disaster preparedness. The ICL, a core activity of the Sendai Partnerships, produces Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools (Sassa 2015).

On November 5, 2020, the Kyoto Landslide Commitment 2020 (KLC2020) was adopted. This commitment aligns with the ISDR-ICL Sendai Partnerships 2015–2025, the SFDRR, the 2030 Agenda Sustainable Development Goals, the New Urban Agenda, and the Paris Climate Agreement. The 2020 Kyoto Declaration was launched on the same day. Additional signatories were later approved by the General Conference at the Fifth World Landslide Forum in Kyoto, Japan, on November 2–6, 2021. The KLC2020 comprises 10 priority actions aimed at research and capacity-building activities, and it is expected to continue until 2030, as stated by Sassa (2021) and Sassa et al. (2021) (Table 1).

In an effort to provide scientific evidence for landslide disaster risk management, the ICL is publishing the "Progress in landslide research and technology" Open Access book series (Sassa et al. 2023; Alcántara-Ayala et al. 2023a, b). This series is a valuable platform for the latest advancements in landslide research and technology, which can be applied in practical settings to benefit society. Additionally, it contributes to the KLC 2020 and promotes global understanding and the reduction of landslide disaster risk in line with the Sustainable Development Goals of the 2030 Agenda.

Thanks to ongoing collaboration with its members and partners, the ICL has successfully bolstered landslide disaster risk management capabilities at the international, regional, national, and local levels. The strides in landslide research and practice have been fruitful, fostering a greater understanding of landslide disaster risk by bringing together diverse disciplines and stakeholders.

Concluding remarks

The *Landslides Journal* contains numerous papers on landslide hazard dynamics and topics related to risk management. This virtual issue has been carefully curated to showcase articles that provide valuable insights into the relationship between landslide research and practices required for disaster risk management. These thought-provoking pieces delve into various related topics, offering a comprehensive and informative look at the challenges facing those tasked with reducing landslide disaster risks.

Besides hazard dynamics, landslide disaster risk drivers can be attributed to population growth, poverty, inequality, urbanization, environmental degradation, climate change, and the increased use of land and resources for profitable activities. The risk of landslides

Fig. 2 Timeline of the UN international strategies concerning DRR and the initiatives promoted by the ICL (source: modified from Alcántara-Ayala and Sassa 2021)

Table 1 Priorities of Action of the Kyoto Landslide Commitment 2020 (Sassa et al. 2021)

Priorities of Action of the Kyoto Landslide Commitment 2020
Action 1 Promote the development of people-centered early warning technology for landslides with increased precision and reliable prediction both in time and location, especially in a changing climate context.
Action 2 Advance hazard and vulnerability mapping, including vulnerability and risk assessment with increased precision, as well as reliability as part of multi-hazard risk identification and management.
Action 3 Improve the technologies for monitoring, testing, analyzing, simulating, and effective early warning for landslides suitable for specific regions considering natural, cultural and financial aspects.
Action 4 Apply the ISDR-ICL Landslide Interactive Teaching Tools for landslide risk reduction in landslide prone areas and improve them with feedbacks from users in developed and less developed countries.
Action 5 Promote open communication with local governments and society through integrated research, capacity building, knowledge transfer, awareness-raising, training, and educational activities, to enable societies and local communities to develop effective policies and strategies for reducing landslide disaster risk, to strengthen their capacities for preventing hazards from developing into major disasters, and to enhance the effectiveness and efficiency of relief programs.
Action 6 Investigate the effect of climate change on rainfall-induced landslides and promote the development of effective rainfall forecasting models to provide earlier warning and evacuation especially in developing countries.
Action 7 Investigate the mechanism and dynamics of submarine landslides during earthquakes that may cause or enhance tsunamis, as well as develop and upgrade its hazard assessment and mitigation measures.
Action 8 Promote geotechnical studies of catastrophic megaslides and develop their prediction and hazard assessment.
Action 9 Foster new initiatives to study research frontiers in understanding and reducing landslide disaster risk by promoting joint efforts by researchers, policy makers and funding agencies.
Action 10 Facilitate and encourage monitoring, reporting on, and assessing progress made, through the organization of progress report meetings at the regional and national level, to take place in respective countries, in order to show delivery and performance on progress made towards achieving the Kyoto Landslide Commitment priority actions No.1–9. Participating parties and relevant stakeholders reporting on deliveries and achievements at these meetings are invited to report on this progress in the monthly full color journal "Landslides" so as to allow viewing progress in addressing landslide risk reduction. They are also encouraged to cooperate, as feasible and appropriate, with countries, the United Nations family, regional organizations, and all other partners and stakeholders concerned with landslide risk in their contribution to the Sendai Monitor System and the Voluntary National Reviews, and in their reporting on relevant key SDGs, notably on resilient and sustainable cities and climate action and on the Paris Agreement follow-up.

is also increased by urban sprawl and expensive housing or tourist spots on unstable slopes.

Climate change is expected to exacerbate the intensity and frequency of precipitation and temperature extremes, thereby intensifying the vulnerability and exposure of people in areas susceptible to landslides. This, in turn, will significantly impact diverse regions and may influence and trigger landslides. Extreme drought, wildfires, and snow melting will contribute to slope instability by inducing increased runoff due to changes in hydrological processes, vegetation, and ground cover removal, which reduces soil infiltration capacity and increases soil erosion. Likewise, floods will favor slope undercutting and landslide occurrence.

Disasters triggered by landslides can have serious consequences, including loss of life, property damage, environmental destruction, and harm to livelihoods. To manage landslide disaster risk, the participation of a range of stakeholders and taking an integrated disaster risk approach is necessary. This involves a complex process aiming at predicting, reducing, and permanently controlling landslide disaster risk drivers while aiming for sustainable human, economic, and environmental development.

Dynamic landslide inventories are fundamental for mapping landslide susceptibility, hazard, and risk. By leveraging this information, stakeholders can better assess and manage the potential impact of landslides on public safety and infrastructure. Understanding the geological, geomorphological, environmental, and social factors contributing to landslides is essential for developing effective mitigation strategies. Therefore, sustained collaboration between science and policy-making is critical to managing landslide disaster risks.

The promptness and implementation of such endeavors will strengthen disaster risk governance and ensure better preparation and prevention measures. The ICL is committed to this cause, and together all its members and partners can make a difference in understanding, mitigating, and reducing landslide disaster risk around the world.

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