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Editorial

Special Issue on *Disaster Risk Reduction in Mountain Areas*

Disaster risk reduction in mountain areas: a research overview

ALCÁNTARA-AYALA Irasema[1*] https://orcid.org/0000-0003-0794-1201; e-mail: ialcantara@geografia.unam.mx

CUI Peng[2] https://orcid.org/0000-0002-3973-5966; e-mail: pengcui@imde.ac.cn

PASUTO Alessandro[3] https://orcid.org/0000-0002-9926-9581; e-mail: alessandro.pasuto@irpi.cnr.it

* *Corresponding author*

1 Institute of Geography, National Autonomous University of Mexico (UNAM), Mexico City 04510, Mexico

2 Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu 610041, China

3 CNR-IRPI, Research Institute for Geo-Hydrological Protection, C.so Stati Uniti, Padova 4 35127, Italy.

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Abstract: This paper gives an account of the diverse dimensions of research on disaster risk reduction in mountain regions derived from an open call of the *Journal of Mountain Science* that brought 21 contributions. This special issue includes topics as diverse as landslide dynamics and mechanisms, landslide inventories and landslide susceptibility models, insights to landslide hazards and disasters and mitigation measures, disaster response and disaster risk reduction. The overall structure of the paper takes the form of three sections. The first part begins by laying out the significance of disaster risk reduction in mountain areas, whereas the second one looks at the research insights on disaster risk reduction in mountains provided by the contributions comprised in the special volume. The final section identifies areas for further research.

Keywords: disaster risk reduction, hazards, integrated disaster risk management, mitigation measures, response, mountains

In view of the global disaster caused by the COVID-19 pandemics, society realized the level of uncertainty in which we live as a result of the degradation of the planet and existing inequalities. Greater attention has been paid to the importance of the systemic nature of risk in everyday life, but also to the global ripple effects that diverse types of hazards can produce (UNDRR 2019; Maskrey et al. 2021; Sillmann et al. 2022). Considering that policy choices can accelerate risk reduction (UNDRR 2022), this crisis also raised concerns about the way disaster risk is managed and the dilemma faced by disaster risk governance in moving towards fairer and more equitable conditions from the local to the global scale (Alcántara-Ayala et al. 2021).

Parallel to the pandemic, the occurrence of disasters associated with natural hazards in mountain areas was also of great significance. Such was the case of the Glacial Lake Outburst in the state of Uttarakhand in India on February 7, 2021, in which 234 people died (EM-DAT n.d.). Likewise, in Turkey, the Sivrice-Elazığ earthquake of January 24, 2020 (Mw = 6.8) involved 41 fatalities; 1,540 buildings were moderately damaged, and 8,519 buildings were severely damaged or collapsed (Sayın et al. 2021).

As mountains have experienced above-average warming and increasing precipitation and this trend is expected to continue, climate change also adds another dimension of concern for mountain systems in relation to increasing disaster risk (Fig. 1).

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Fig. 1 On August 12 - 14, 2010, a series of rainfall-induced debris flows occurred in 21 ravines around the towns of Qingping, Mianzhu City, Southwest China's Sichuan province, in areas previously affected by the 2008 Wenchuan earthquake. Consequences were devastating particularly in the housing and infrastructure sector (top right photo by courtesy of Hong Xie, other photos by courtesy of Yong You).

Furthermore, there is a high degree of confidence that the character of natural hazards in mountain areas, such as droughts, floods, landslides, GLOFs, flash-floods, and others will favour cascading impacts (Adler et al. 2022).

There is a general consensus on the relevance of systemic risk in mountain systems. Along this vein, the IPCC WGII Sixth Assessment Report Cross-Chapter Paper on Mountains (Adler et al. 2022) calls for promoting cooperation in disaster risk management that considers downstream nations, since mountains are mostly transboundary and, in fact, not limited to political borders.

In seeking holistic perspectives, it is equally important to foster integrated disaster risk research and develop transdisciplinary strategies. However, this is still a very difficult endeavour to achieve. Understanding disaster risk beyond disciplinary visions implies uniting natural and social sciences and building a spatial perspective in which the territory is a key element (UNDRR 2021). In the same way, managing disaster risk presupposes moving towards a collaborative research field upon which co-design and co-management can be built through sustained collaboration with all disaster risk relevant stakeholders and, in particular with authorities of different administrative levels (Pasuto and Schenato 2021). Such an effort will help to strengthen integrated disaster management and governance (Cui et al. 2021).

The purpose of this special issue was to explore the experiences on the diverse dimensions of disaster risk reduction research in mountain regions and help advance the implementation of the Sendai Framework for Disaster Risk Reduction (UNISDR 2015). Relevant themes included in the call for papers comprised the understanding of physical processes of mountain hazards, vulnerability, exposure, integrated research on disaster risk, disaster risk mitigation and management, disaster risk governance, policy making and best practices across different time scales and mountain regions of the world, instructive practices or obstacles for implementation, and coherence among post-2015 international frameworks. However, submissions were largely focused on landslides.

For the benefit of thematic perspectives, the 21 accepted contributions were grouped into four categories: landslide dynamics and mechanisms (7 papers); landslide inventories and landslide susceptibility models (6 papers); landslide hazards and disasters (4 papers); and mitigation measures, disaster response and disaster risk reduction (4 papers).

1 Landslide Dynamics and Mechanisms

The study of debris flow movement process is of great significance for disaster prevention. Li et al. (2022a) presented a case study of a debris flow in Ganluo County, Sichuan Province, China. The geological conditions, causes and main characteristics of the landslide-generated debris flow that occurred at Heixiluo gully on August 30, 2020, in Ganluo County, Sichuan, China, were examined based on a comprehensive investigation including field surveys, remote sensing data, unmanned aerial vehicle (UAV) image data and numerical simulation. The results of this study provided both a deeper understanding of this type of debris flow and further geological hazard alleviation measures.

The Chinese Loess Plateau is characterised by extremely fragile geological and ecological environments, prominent hydraulic and gravity erosion. The failure processes of check dams are highly relevant to the sensitivity of loess to water. Jiang et al. (2022) focused on the failure mechanisms of check dams, and techniques for risk mitigation to improve their actual applications. First, hydraulic characteristic curves and strength properties of naturally intact and mechanically compacted loess were determined. Subsequently, the water-sensitive deformation potentials of the two types of loess were identified by defining the water sensitivity coefficient. Second, considering the slope stability analysis method based on the local factor of safety, a two-dimensional finite element numerical model was constructed to reveal the two general modes and failure processes for a certain check dam under different infiltration conditions. Finally, two key technologies for effectively mitigating the risk of check dam failure were discussed. These results contribute to the in-depth understanding of the surface-subsurface hydrological processes affecting check dams.

The Xinmo rockslide is regarded as the most catastrophic rockslide in recent years in China and has attracted much attention from researchers from around the world. Zhou et al. (2022) used detailed information, including the physical parameters, chemical elements and microstructure of the rock masses, together with regional climate, historical seismic records and numerical simulations, to offer a comprehensive picture of the failure mechanism of the Xinmo rockslide. Outcomes of this research are directed to improve and deepen the understanding of the occurrence and mechanisms of large-scale rockslides.

To determine the whole-process, characteristics and failure mechanisms of flow-slide failure of granite residual soil slopes, Bai et al. (2022) conducted a detailed hazard investigation in Minqing County, Fujian Province, which was impacted by Typhoon Lupit-induced heavy rainfall in August 2021. The research group designed an indoor model test to capture the whole process of flow-slide failure of granite residual soil slopes under heavy rainfall. The results fully captured the flow-slide failure process of granite residual soil slopes under the action of heavy rainfall. The test phenomena are highly consistent with the characteristics of the landslide cases examined in the field investigation.

Tian et al. (2022) explored the instability process for the ancient landslides along the Longwu Riverbanks. Of significant relevance was the analysis performed to understand the influence of Neo-tectonic movement on the formation of landslides, which involved a detailed field investigation, regional geological background data, drilling data, remote sensing images, and tests of rock and soil Mechanics. According to the investigation the formation of these ancient landslides was closely associated with the uplift of the Tibetan Plateau and the erosion of the Longwu River. The reactivation mechanism of ancient landslides was further studied, and derived insights showed significant relevance to understand disasters risk in Tongren Basin of Longwu River Basin.

Slope instability is a progressive failure process subjected to natural or engineering disturbance. Zhang et al. (2022) dissected the progressive deformation process of an excavated slope in detail based on comprehensive monitoring of both surface and underground deformation for over 5 years. They conducted in-depth analysis for such a long-term deformation process based on ground and subsurface monitoring data, collected successive data with a series of monitoring equipment such as automated total station, borehole inclinometers and other auxiliary apparatus, and identified the deformation process based on the comprehensive analysis of monitoring data as well as field investigation. This research introduced a typical slope deformation model influenced by both natural and engineering aspects, which can provide experiences for comparable projects.

To investigate the fracturing mechanism of the Dulong slope in the Three Gorges Reservoir area, Xie et al. (2022) used a 3C geophone network deployed at the borehole and out of the sliding mass to build a rupture model. Source parameters were obtained after the process of noise suppression, picking up of the first break time, and full waveforms inversion. The results showed that the Dulong slope is a shallow rockslide in the state of creep deformation, and the rupture mechanism of the rock mass is left-lateral normal fault with shear failure, and continuous rainfall is more likely to cause the increase of microseismic events. Insights derived from this research are needed to the development of early warning and prevention of rockslides.

2 Landslide Inventories and Landslide Susceptibility Models

Yang et al. (2022) presented a case study from Yunnan Province, China, showing field observation of debris-flow activities in the Jiangjia Gully initiation area, where landslides constitute an important source for sediment supply. The research evaluated that the occurrence of debris-flow in this area is influenced by both infiltration and runoff-dominated processes. In practical terms, the observations also suggested that using precipitation thresholds described by a power-law relationship between mean intensity and duration and by a linear relationship between 10-minute rainfall peak and antecedent rainfall, false alarms in early warning systems can be reduced.

As technology evolves, new methodologies for landslide recognition have been developed, including optical remote sensing imaging, InSAR technology, and airborne LiDAR. The paper by Gao et al. (2022) provides new insights concerning an object-oriented image analysis method based on slope unit division and multi-scale segmentation to obtain accurate location and boundary extraction of early landslides. The results of applying this classification method in the Xianshui River Basin of Sichuan, China, indicated that landslide-susceptible areas can be defined through the rapid extraction of slope units. It also proved to be useful in improving the accuracy of boundary extraction and matching the demands of early detection of different types of landslides.

Owing to their socio-economic impact, earthquake-induced landslides are of great relevance in different parts of the world, particularly in China. Cui et al. (2022) built a coseismic landslide inventory for the areas of high coseismic intensity (VIII–X) of the Ms 7.7 Tonghai earthquake, which occurred on January 5, 1970, in Tonghai county, Yunnan Province, China. Visual interpretation of the landslides was performed using Keyhole satellite imagery on a GIS platform. According to the analysis carried out, this type of images can provide basic data for studies of seismic landslides and the evolution of the landscape in the short term.

Several countries, among them Mexico, lack national and subnational scale landslide inventories. These are of major relevance as inputs for hazard and disaster risk assessments. The paper by Valdés Carrera et al. (2022) presents a multitemporal landslide inventory and analyses instability conditioning factors in the Pico de Tancítaro stratovolcano, in the state of Michoacán, Mexico. The inventory comprised 505 landslides, triggered by intense precipitation caused by hurricanes and tropical storms that were classified in slides and flows, and occurred in 1995, 2004, 2010, and 2015. Areas susceptible to landslides were characterised by the presence of volcanic cones, slopes and mountain river valleys, covered by Andosols and Leptosols with oyamel fir and mixed forests.

Landslide susceptibility maps are useful tools to recognise areas prone to landslides. Although they differ from landslide hazard maps, they provide the spatial extent on which critical areas can be further identified and analysed. There are various types of landslide maps, and diverse approaches have been developed in recent years to improve accuracy of results. Lima et al. (2022) conducted a bibliometric analysis using Web of Science, Clarivate Analytics database on data-driven landslide susceptibility models, which are based on statistical or machine learning approaches. The results suggested that the topic is undergoing rapid development and thus, there are numerous challenges and limitations that these models must overcome. These were categorised into five main themes, which were discussed in detail by the authors: study site extent and landslide inventory; modelling unit and spatial resolution; landslide predictors; classification techniques; and model quality, sampling partitioning strategies and performance evaluation.

Changes in land cover are significant factors influencing hillslope instability and water balance changes. This is the case of the eastern Hindu Kush region, a semi-arid mountain region characterized by complex terrain, vegetation variation, and precipitation seasonality, which was analysed by Khan et al. (2022). Using Landsat time series from 1988 to 2020, they recognise the significant change in land cover and floods and the consequent occurrence of debris flows and river erosion. Loss of agricultural land, housing, and other community infrastructure were among the most important impacts derived from the 2013 and 2015 floods in Kalash, Rumbur, and Ayun valleys of Chitral.

3 Landslide Hazards and Disasters

As for landslide, one of the worse disasters ever occurred is those related to Vaiont landslide, occurred in Italy in 1963. This is certainly among the most investigated landslide in the world with a broad published literature. New interpretation about such phenomenon is presented by Dykes and Bromhead (2022). They identify and examine all of the issues surrounding the Vaiont dam and landslide in order to define causal factors, contributory factors (including aggravating factors) and underlying factors, concluding that in any case the Vaiont landslide would probably have occurred at some time after 1963 because the northern slope of Mt Toc comprised a significantly adverse combination of geological characteristics, including thin, weak clay beds that dipped significantly towards the Vaiont gorge throughout the slope. However, since the disaster was caused by a huge volume of water in an almost-full reservoir being displaced by the rapidly moving landslide the circumstances that gave rise to the existence of the reservoir and its high-water level, mean that the disaster must ultimately be attributed to the Vaiont dam project and not simply the landslide.

Apparently, Vaiont slide was not conditioned by climate changes; no clear evidence had yet been attributed to these processes in the 1960s. The interesting case study presented by Sun et al. (2022) is instead strictly related to the recent climatic trend. Indeed, the disaster occurred in Izu Mountain area, Shizuoka Prefecture, (Japan) is an example of the effects of extreme meteorological events in a highly urbanized area. In this case, a debris flow, most probably triggered by landslides caused the destruction of more than 130 buildings and 26 casualties. Coupling numerical modelling and remote sensing image processing important achievements have been reached such as (i) the pore pressure ratio is an important factor affecting the damage range of this debris flow; (ii) the increase of the pore pressure ratio in the landslide makes the runout distance of debris flow significantly high. Therefore, it is of great significance to consider the meteorological conditions in the early stage of debris flow warnings, especially the effect of antecedent rainfall events. The changes in pore water pressure caused by such rainfall input may be one of the main factors worsening the debris flow effects.

The landslide hazard analysis applied to a case of landslide in the red bed area of Western Yunnan is presented by Zhao et al. (2022). The geological formations outcropping in such area strictly condition the landslide behaviour which poses significant challenges to the prevention and control of landslide disasters, especially for slope and tunnel engineering projects. In order to face with the peculiar features of the gravity-induced mass movements affecting this area, the Authors developed an interdisciplinary approach combining surface and deep deformations and key influencing factors (formation lithology, rainfall and groundwater level variations) for the identification of deformation mechanisms and fine spatiotemporal characteristics. The research activities conducted on the Abi landslide reveals the characteristics of the surficial movements and their spatial and temporal evolution, the zoning effect of groundwater fluctuations on deformations and the role of rainfall input on dynamic characteristics of the landslide activities, thus providing useful data for hazard assessment.

The understanding of impact of freeze and thaw cycles on vulnerable elements such as buildings and infrastructure is certainly a major issue in high mountain area and cold regions since their related instability processes can lead to great disasters. Wu et al. (2022) present a study on highway Qinghai-Tibet affected by this type of problem; in particular laboratory experiments were conducted in order to analyse the effects of fine particle content, initial water content, and number of freeze-thaw cycles compared with frost depth, temperature gradient, total water intake, and water intake flux. This activity led to a definition of a modified model of migration potential related to fine particle content, freeze-thaw history, and freezing time.

4 Mitigation Measures, Disaster Response and Disaster Risk Reduction

Salgado et al. (2022) provided a comprehensive study of evacuations by water in the remote region of Northern Patagonia. The interruption of land-transport networks due to the fall of ash from the Chaitén, Cordón Caulle and Calbuco volcanoes in Chile, between 2008 and 2015, the isolation of a city due to the blocking of roads associated with a massive rock topple event and a severe snowstorm were considered in the analysis. Evacuations involved the displacement of urban residents, tourists, rural families, and livestock. The research revealed a number of problems with these types of procedures, including poor hazard-related knowledge; limited ground-based accessibilities; inter- and intra-organizational issues; and absence of knowledge regarding the vulnerability characteristics of water transport networks, in the face of different natural hazards.

The landslide hazard and risk mitigation represent the last phase of an emergency management plan and a reliable prevention and preparedness activity to be promoted at all levels. In such perspective Genevois et al. (2022) after a comprehensive literature review, illustrate two case studies occurred in the Italian Dolomites that is a renowned touristic site and, above all, a UNESCO World Heritage Site. The Authors pointed out that the mitigation procedures consist of five basic steps: (a) acquisition of the knowledge of the hazard process; (b) risk assessment with identification of possible disaster scenarios; (c) planning and designing of specific remedial measures to reduce and/or eliminate the potential risk; (d) slope monitoring after application of remedial measures, (e) transfer of knowledge to the stakeholders. In this framework they described the practice for the design of the mitigation measures adopted for debris flow and active landslide sites.

A completely different approach and application are presented by Li et al. (2022b) that illustrate a deep understanding of freezing-thawing (FT) mechanisms in the soils of alpine mine restoration areas and the influencing factors of these mechanisms on soil erosion, thereby supporting the development of erosion prevention and control measures. The investigated area is represented by an iron mine in Xinjiang Uygur Autonomous Region. Summarizing the study tested two key hypotheses namely: i) the FT cycles accelerate the irreversible loss of water, sediment, and nutrients; and ii) the runoff, sediment, and nutrient losses in the mine restoration area follow certain laws and are affected by FT cycles and soil moisture content (SMC). To this end, FT cyclic and rainfall simulation experiments were systematically carried out to evaluate the effects of FT cycles, soil SMC, and their interactions on the runoff, sediment, and nutrient loss characteristics in the study area. The complex analysis conducted led to establish that the altering of physico-chemical composition of soil in a way that improves its resistance to low temperatures is the key to reducing soil erosion and restoring mining areas affected by glacial snowmelt.

To close the special issue, the article by Alcántara-Ayala et al. (2022) discusses the role of healthy and productive mountain households and livelihoods in achieving global sustainability. Building on the perspective of the social construction of systemic risk and the consequent complexity of prevailing socio-environmental changes, they argued that the successful functioning of mountain livelihoods is strongly intertwined with integrated disaster risk reduction and management. They also pointed out that the establishment of multiple Post-2015 international frameworks does not benefit the articulation of commitments, responsibilities, and accountability of actions. In the tangible world this also can be seen as a conceptual and practical segmentation in the attempt to co-produce knowledge based on transdisciplinary and the mainstreaming of comprehensive policies and practices.

5 Disaster Risk Reduction in Mountain Areas: A Societal Endeavour

While it was not the intent of this special issue to provide an exhaustive review of the dimensions of disaster risk reduction research in mountain regions, the studies presented here thus far provide evidence that research to date has tended to focus on understanding of mountain hazards rather than mountain disaster risk. As several studies have documented, most work done in disaster risk reduction lacks integrated perspectives (Gall et al. 2015).

Nonetheless, the complex systemic nature of disaster risk also calls for a better understanding of hazards, as human influence on hazard occurrence is greater every day and emergent hazards involve impacts in more complex, compound, multiple, concatenated or cascading and sequential ways (Maskrey et al. 2021).

Yet, undoubtedly, influencing the formulation and practice of policies based on integrated science is and will continue to be our main task.

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