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Editorial

Geological Hazards and Risk Management

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1. Introduction

The occurrence of geological hazards is widespread, particularly in mountainous regions. Globally, the escalation of geological hazards can be attributed to factors such as climate variations, river dynamics, seismic activities, and human interventions. The increase in the human and economic consequences of geological hazards comes as a result of population expansion and infrastructural developments encroaching upon high-risk zones, thereby amplifying vulnerability to potential catastrophic geological phenomena. Recent years have seen notable development in various technologies, including artificial intelligence, remote sensing, geophysical surveys, and big data analytics, contributing significantly to the detection, monitoring, and warning of geological hazards (alongside evaluations of the risks they pose). These advancements offer invaluable insights into decision-making processes for the purpose of preventing and mitigating geological hazards in vulnerable regions.

To showcase the latest progress in this domain, a Special Issue titled "Geological Hazards and Risk Management" has been compiled. This issue contains 13 papers covering various topics such as predicting susceptibility to landslides, risk assessment, inventory and distribution of rainfall-induced landslides, slope stability analyses, the mechanisms of oil and gas pipeline disasters, the spatial distribution of urban flooding, and volcanic eruption preparedness.

2. Predicting Susceptibility to and Assessing the Risk of Regional Landslides

Landslide susceptibility prediction (LSP) serves as a fundamental pillar of risk management and plays a pivotal role in ensuring social resilience. However, the modeling of LSP is hindered by various factors. Ma et al. delved into LSP, focusing on landslides within the Yinghu Lake basin in Shaanxi (Contribution 1). They compiled an initial inventory of landslides (totaling 46 incidents) and updated it (totaling 46 + 176 incidents) through data compilation, remote sensing interpretation, and field surveys. Employing slope units as mapping units, they selected twelve conditioning factors, including elevation, slope gradient, aspect, topographic relief, elevation fluctuation coefficient, slope structure, lithology, normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), proximity to roads, proximity to rivers, and rainfall. The modeling utilized random forest (RF) and artificial neural network (ANN) machine learning techniques. The findings revealed RF's superior predictive performance, offering a foundational reference for uncertain LSP analysis and managing the risk of regional landslides.

Numerous machine learning techniques have been employed in landslide susceptibility mapping (LSM). However, utilizing models for susceptibility prediction that lack interpretability could bring significant challenges in practical scenarios. Fang et al. conducted a thorough assessment of LSM in Nayong, Guizhou, China, employing explainable artificial intelligence techniques (Contribution 7). This study integrated remote sensing data, field surveys, geographic information system methodologies, and interpretable machine learning approaches to analyze landslide sensitivity and compare it with conventional

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models. The study highlighted the effectiveness of the GAMI-net-based model, demonstrating strong predictive capability and enhanced interpretability, both of which are pivotal in facilitating landslide management strategies and decision-making processes.

The conventional infinite slope model, pioneered by Newmark, remains a prevalent tool for evaluating coseismic landslide hazards. However, it is limited in that it overlooks the impact of rock mass structure on slope stability. Introducing a novel approach, Li et al. considered the roughness of potential slide surfaces within the slope, offering a fresh perspective on coseismic landslide hazard mapping. The authors refined their methodology using datasets from the 2013 Lushan earthquake (Contribution 3), incorporating geological data, peak ground acceleration (PGA) measurements, and high-resolution digital elevation models (DEMs). These components were integrated into the infinite slope model, incorporating Newmark's permanent deformation analysis. The outcome is a hazard map delineating zones prone to coseismic landslides, thereby offering valuable insights for both infrastructure development and post-earthquake reconstruction efforts.

The accurate evaluation of landslide hazards, vulnerabilities, and risks is of huge importance when devising effective mitigation strategies, planning changes in land use, and executing developmental projects. However, such evaluations are often challenging in complex and data-scarce regions. Shah et al. present an integrated approach to assessing the risk of landslides by leveraging freely available geospatial data and semi-quantitative techniques in landslide-prone regions within the Hindukush mountain ranges of northern Pakistan (Contribution 8). The resulting landslide risk index map aids in identifying areas prone to landslide risks, thereby facilitating subsequent efforts to mitigate and reduce risk.

3. Rainfall-Induced Landslide Inventory and Distribution

As climate change continues to escalate, heavy rainfall events have become increasingly frequent, leading to a surge in rainfall-triggered landslides, which rank among the most prevalent geological disasters globally. Employing high-resolution remote sensing imagery both before and after these events, Xie et al. conducted visual interpretations, mapping in detail the distribution of rainfall-induced landslides in Jiexi County, Guangdong Province, China (Contribution 2). Their findings revealed 1844 instances of rainfall-induced landslides within Jiexi County during one specific rainfall event; they were primarily concentrated in the northeastern, central, and southwestern regions, thereby aligning with the distribution pattern of rainfall intensity. To delve deeper into the impact of the regional environment on the occurrence of landslides, the study assessed eight influencing factors, including elevation, slope aspect, slope angle, topographic wetness index (TWI), topographic relief, lithology, distance to the river, and accumulated rainfall. Through statistical analysis conducted on a data analysis platform, the study unveiled the relationship between landslide distribution and the triggering factors associated with this event. These findings enhance our collective understanding of trends in the regional growth in rainfall-induced landslides and contribute to disaster prevention and mitigation efforts.

NASA's Global Landslide Catalog (GLC) provides a comprehensive compilation of rainfall-triggered landslide events sourced from media reports, academic publications, and existing databases worldwide. Dandridge et al. conducted an assessment of global landslide reporting patterns using data from the GLC (Contribution 6). This assessment comprises an examination of the spatial and temporal distribution of landslide events globally, including associated casualties, and comparisons with other landslide inventories. The GLC serves as a valuable tool for identifying landslide hotspots, analyzing geographical patterns in landslides, and training and validating landslide models on both a local and global scale.

4. Characteristics and Formation Mechanisms of Geological Hazards

In periods of drought, the occurrence of cracks in loess due to shrinkage is common, resulting in the precipitation and accumulation of salt on the surface. Understanding the influence of soluble salt content on the cracking characteristics and mechanisms of loess is of great importance in engineering projects and for preventing geological issues and disasters in salinized loess regions. Wei et al. conducted a study involving the desiccation of loess samples with varying NaCl concentrations (Contribution 5). Utilizing scanning electron microscopy (SEM) and energy-dispersive spectrum (EDS) methods, they analyzed the microstructure and elemental distribution of their samples. Their findings revealed the impact of NaCl concentrations on the cracking characteristics and mechanisms of loess, indicating that higher NaCl concentrations led to reduced evaporation rates and increased residual water contents, thereby restraining crack expansion.

Massif rupture does not always occur under saturated conditions, meaning analyses of unsaturated phenomena in specific scenarios are required. Costa et al. employed a probabilistic approach to exploring unsaturated and transient conditions, aiming to elucidate the roles of physical and hydraulic parameters within slope stability (Contribution 4). Their model, founded on the infinite slope method and a novel unsaturated constitutive shear strength model introduced by Cavalcante and Mascarenhas in 2021, demonstrated promising outcomes. It emphasized a shift from deterministic to probabilistic analyses, accounting for numerous stochastic variables. This model aids in comprehending the impact of the moisture content on slope stability, offering potential utility in managing the risk of natural disasters.

Landslides may be particularly damaging to oil and gas pipelines, with varying cross-cutting relationships playing a pivotal role in the occurrence of pipeline landslides. Thus, it is crucial that we study the stress and deformation characteristics of pipelines with various cross-cutting relationships. A et al. developed an optimal pipe–soil interaction model for oblique crossing landslides near oil and gas pipelines; they did so using FLAC3D (Contribution 9). Through analyzing a typical pipeline obliquely crossing landslide, they investigated how pipeline burial depth, sliding body displacement, and different intersection angles between the landslide and pipeline influence deformation and stress patterns. Their findings highlighted the intricate stress distribution in pipeline oblique crossing landslides, with notable concentrations of stress at the shear outlets and trailing edges of landslides. Additionally, they found that pipeline burial depth significantly affects displacement and stress, emphasizing depths of 3–3.5 m as particularly risky. Moreover, they found that the intersection angle between the pipeline and landslide notably impacts pipeline stress, offering crucial insights into how we might improve oil and gas pipeline landslide prevention and control measures.

Lemenkova and Debeir examined 2000 earthquake events from the IRIS seismic database over a 25-year period (1997–2021) in order to map seismic activity (Contribution 10). Their approach, combining GMT scripts with advanced GIS techniques, proved effective in spatial dataset mapping and swift data processing through iterative methods. This study lays the groundwork for predictive seismic analysis in geologically vulnerable regions of Venezuela.

5. Spatial Distribution, Influencing Factors, and the Evaluation of Geological Hazards

Rapid urbanization has led to a multitude of environmental challenges, with urban water security emerging as a prominent concern. Liu et al. conducted simulations of urban flooding in various land use and drainage system scenarios, focusing on Handan City (Contribution 11). Their study elucidated the impact of historical ground and underground constructions on waterlogging patterns. They found that changes in land use, particularly the expansion of sealed surfaces, amplified flood distribution and volume in Handan City; the drainage system, on the other hand, acted to alleviate flooding. Over time, shifts in flooding patterns indicated reduced risk in many areas due to enhanced drainage infrastructure. However, certain regions experienced exacerbations due to an increase in the number of impermeable surfaces, rapid pipe drainage, and inadequate outlets. This study highlights how alterations in both land use and drainage networks can shape the distribution of urban flooding, offering crucial guidance for bolstering urban water security and the sustainable management of water resources.

As volcanic eruption activity escalates worldwide, its disruptive impact on communities is becoming increasingly pronounced. In spite of this, there remains a gap in the literature concerning preparedness for volcanic eruptions. German et al. employed a machine learning ensemble to evaluate communities' preparedness for volcanic eruptions (Contribution 12). Their ensemble, comprising random forest classifiers and artificial neural networks, demonstrated high prediction accuracy (93% and 98.86%, respectively). Notably, they identified the media as the most significant factor influencing preparedness; its role in disseminating information significantly shapes the readiness of communities. Understanding the paramount influence of the media alongside other contributing factors such as personal experiences, social networks, and preparation through infrastructure reinforces the importance of the media in fostering communities that are well prepared for volcanic eruptions. This methodology is advantageous in assessing human behavior and predicting the factors that affect peoples' preparedness in the face of various natural disasters, offering valuable insights that are globally applicable.

Equations for predicting ground motion are pivotal in the assessment of seismic hazards, yet Pakistan lacks a dedicated equation derived from local seismic data. To address this research gap, Waseem et al. conducted an evaluation of equations for predicting global ground motion in shallow active regions using a Pakistani seismic ground motion database (Contribution 13). Their study assessed the applicability of thirteen equations using a dataset comprising peak ground accelerations from 27 shallow earthquakes in Pakistan. Through residual analysis and goodness-of-fit procedures, the study concluded that global ground motion prediction equations can be utilized to great effect in Pakistan's shallow active regions for studies of seismic hazards. These findings provide a foundation for implementing measures to mitigate the risk of disasters in Pakistan.

6. Conclusions and Future Perspectives

The articles featured in this Special Issue have made substantial contributions to advancing our understanding of geological hazards, offering innovative insights and paving the way for future developments and collaborations. We extend our appreciation to the *Sustainability* team for their invaluable support in organizing this Special Issue and overseeing the review process. Additionally, we express gratitude to all authors for their insightful contributions and to reviewers for their constructive feedback, which has enhanced the quality of the manuscripts. We look forward to continued progress and collaboration in addressing geological hazards for a sustainable future.

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