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EDITORIAL

Editorial: novel tools for multi-risk assessment

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Natural hazards are a recurring threat to mankind. In parallel, global urbanization processes and population growth reshape the surface of our planet. Natural hazards that had little impact in the past, when they hit sparsely populated settlement areas, can nowadays eventually affect agglomerations with millions of inhabitants. At the same time, numerous hazards do not occur in an isolated manner but form complex chains of events with disastrous cascading effects.

In order to mitigate affiliated perils, detailed information about multi-risk situations is required. However, the quantification of such risks poses major challenges regarding the conceptual embedding, comprehensiveness of data, tailored analysis methods, and valid modelling techniques, respectively. Remarkably, a vast body of technologies emerged over the last decade comprising novel data collections mechanisms and interpretation techniques. Today, sensor data from multiple sources, i.e., modalities, capturing built and natural environments, are almost ubiquitously available. This includes ground-based imagery, geo-located social media data, various sources of Volunteered Geographic Information (VGI), as well as earth observation data, among others. To extract relevant thematic information from the data, novel methods related to the field of machine learning and Artificial Intelligence (AI) are increasingly deployed.

Consequently, the overall aim of this Special Issue is to inform the multi-disciplinary disaster risk community on the latest developments, capabilities, and limitations regarding the multimodal characterization of built and natural environments regarding risk-related properties (with particular focus on exposure and vulnerability) for usage in multi-risk assessment approaches.

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1 We present a set of twelve full papers and nine short communications

The governing idea behind this combination of scientific papers and short communications is to document the scientific status quo which is simultaneously mirrored by contributions from business, policy, and additional relevant stakeholders. The special issue documents scientific progress regarding the spatial refinement of existing natural hazard-related exposure information based on earth observation data (Geiß et al. 2022.), bottom-up modeling of an elements-at-risk database (Bhuyan et al. 2022), and mapping of exposure including static and functional components in a multi-hazard context (Pittore et al. 2023). Moreover, novel epistemological insights regarding the timely evolution of exposure patterns are provided for the cities of Nairobi and Nyeri in Kenya (Fekete 2022) and Medellín in Colombia (Kühnl et al. 2022) concerning floods and landslides, respectively. Moreover, an innovative multi-hazard susceptibility index and a transferrable disaster risk approach are presented (Kabiru et al. 2023). New analytical tools are provided in the context of potential disruptions of the road infrastructure (Solheim et al. 2023), assessment of the vulnerability of atmospheric storage tanks (Wang and Weng 2021), and impact of high-velocity and debris-laden floods in steep terrains on riparian buildings (Gautam et al. 2022). To establish a holistic risk perspective, a Baseline Resilience Indicators for Communities framework is introduced (Buck et al. 2022). Also, a multi-risk assessment workflow is proposed in the context of seismic and flood hazards (Arrighi et al. 2022). Finally, a novel software tool for multi-risk assessment is introduced (Paulik et al. 2022).

In greater detail, Geiß et al. (2022) exploit measurements from the earth observation missions TanDEM-X and Sentinel-2, which collect data on a global scale, to characterize the built environment in terms of constituting morphologic properties, namely built-up density and height. Subsequently, they deploy this information to constrain existing exposure data based on a spatial disaggregation approach. Finally, the authors present loss estimations due to seismic ground shaking using the generated exposure data with enhanced spatial resolution properties. This top-down exposure disaggregation approach is complemented by Bhuyan et al. (2022) who model exposure from a bottom-up perspective. In detail, the authors present a semi-automated workflow for the development of an elements-at-risk database of buildings by detecting building footprints with deep learning techniques and characterizing the footprints with building occupancy information using both building morphological metrics and open-source auxiliary data for flood exposure analysis. Pittore et al. (2023) establish an integrated approach for multi-hazard exposure modeling including both static and functional components. The model is based on a homogeneous planar tessellation composed of hexagonal cells and a graph-like structure which describes the functional connections among the cells. To exemplify the methodology, a combination of static (buildings, protective forests), dynamic (population), and functional (road-based transport system) components were jointly considered, respectively. From an application-oriented point of view, they show the relevance of the model in the context of border-independent multi-functional, multi-hazard exposure modeling for Alpine regions.

The subsequent two studies provide insights into the evolution of exposure patterns over time: Fekete (2022) quantifies urban growth into hazardous areas in urban rims of Nairobi and Nyeri in Kenya. A change assessment from 1948 to 2020 is conducted by aerial imagery, declassified satellite images, and recent data. The change assessment reveals that urban growth rates are 10- to 26-fold, while growth into flood exposed areas ranges from 2- to 100-fold. Thus, the study demonstrates unused opportunities for expanding existing land-use change analysis back to the 1940s in data-scarce environments. Kühnl et al. (2022) focus on economically deprived population groups, which often have no other option than to build informally in high-risk areas. Against this background, the authors examine how risks related to landslide hazards emerge over 24 years, i.e., from 1994 to 2018, for the city of Medellín in Colombia. They take into account three time steps regarding the citywide exposure. Empirical results uncover the highly dynamic growth in total population and urban areas. Thereby, the city's expansion is socially unevenly distributed. People of higher vulnerability who reside in informal settlements are found to settle in areas exposed to landslides much more frequently compared to the average population. Kabiru et al. (2023) also take a closer look on deprived populations. The authors create a multi-hazard susceptibility index and a transferrable disaster risk approach to be adapted to cities located in low- and middle-income countries using low cost methods. In detail, they identify multiple hazards in Nairobi's selected case study areas and construct a susceptibility index. Then, they test the predictability of deprived settlements using the multi-hazard susceptibility index in comparison with earth observation texture-based methods. Lastly, they survey 100 households in two deprived settlements, i.e., typical and atypical slums, in Nairobi and use the survey outcomes to validate the multi-hazard susceptibility index.

With a specific look at certain exposed elements, Solheim et al. (2023) focus on the assessment of natural hazards along 720 km of planned roads in Norway. To this purpose, a GIS-based tool was developed to utilize publicly available data and dynamic runout models. The output is an outline of the most critical locations which subsequently serves to limit the extent of necessary in situ field work for assessing risks related to the disruption of the road infrastructure. Wang and Weng (2021) introduce a sound, yet simplified methodology to quickly and flexibly assess the vulnerability of atmospheric storage tanks regarding multiple natural disasters in Natech events. The method internalizes eight steps, relying on a simplified physical model of tank damage caused by natural disasters. Thereby models of wind overturning tank and tank buckling caused by hail are proposed. In addition, the assessment process of tank vulnerability is demonstrated from two aspects: deterministic analysis and probabilistic analysis. The uncertain parameter set proposed in the method and the Monte Carlo simulation method can help to analyze the effects of model parameterization in a targeted manner. Gautam et al. (2022) study the impact of high-velocity and debris-laden floods in steep terrains on riparian buildings. To this purpose, they compile vulnerability information of riparian-reinforced concrete buildings using forensic damage interpretation methods and empirical/analytical vulnerability analyses. Beyond, they propose the concept of functionality loss due to flooding in residential reinforced concrete (RC) buildings using empirical data. Fragility functions using inundation depth and momentum flux are presented for RC buildings considering a recent flooding event in Nepal. The results show that flow velocity and sediment load, rather than hydrostatic load, govern the damages in riparian RC buildings. However, at larger inundation depth, hydrostatic force alone may collapse some of the RC buildings.

From a more holistic perspective, Buck et al. (2022) focus on the shortcomings of current resilience measures in capturing neighborhood disparities. They reason that much like vulnerability and sustainability, local disparities will have a deleterious impact on the community as a whole. They implement the Baseline Resilience Indicators for Communities framework and downscale the index using neighborhood-level Census data (tracts) and variations in household access to community resources. These added variables represent the variation of resilience indicators across a community and capture cross-scale relationships that exist between county and Census tract characteristics. Finally, they apply scaled variables in the Pensacola Bay Watershed to demonstrate cross-scaled interactions in the

Florida panhandle. Potential modifications and applications of the concepts are also discussed. From a stringent multi-risk perspective, Arrighi et al. (2022) codify a multi-risk workflow for seismic and flood hazards. In detail, they focus on site-scale applications in historical cities, which provide the Average Annual Loss for buildings within a coherent multi-exposure and multi-vulnerability framework. The proposed methodology includes a multi-risk correlation and joint probability analysis to identify the role of urban development in re-shaping risk components in historical contexts. Empirical results are presented for the city center of Florence (Italy), which is listed as UNESCO World Heritage site since 1982. Finally, Paulik et al. (2022) present a novel tool for multi-risk assessment: RiskScape is an open-source software with a flexible modeling engine for multi-hazard risk analysis. The RiskScape engine implements modeller-defined risk quantification workflows as 'model pipelines'. Model pipeline steps and functions analyze hazard, exposure, and vulnerability data across different spatio-temporal domains using geoprocessing and spatial sampling operations. The RiskScape engine supports deterministic and probabilistic risk quantification. RiskScape advances modeling software for multi-hazard risk analysis through several implementation features.

The Special Issue is completed by a short communications section. There, authors from science, intergovernmental organizations, and the commercial sector give lively examples of past experiences, current best practices, and exigent future challenges and needs, respectively.

The short communications section starts with Wyss et al. (2022), who compiled a catalog of earthquake fatalities for the world, covering the period 856 BC to March 2022. Overall more than 8.33 million fatalities are counted for that period. They further introduce the earthquake potency measure for a country, defined as the sum of recorded fatalities divided by the number of earthquakes that it took to accumulate them. Silva (2022) draws a unique picture of the evolution from seismic hazard assessments to actual seismic risk studies. For the future, the latter need to comprise a more holistic perspective to meet societal needs: it is no longer sufficient to simply calculate economic losses and fatalities due to damage in the residential building stock, but to account for the impact on the commercial and industrial building stock, to assess whether education and healthcare facilities will be functional, and to evaluate the performance of the transportation, water supply, and electrical infrastructure, respectively. Subsequently, new technologies including a plethora of sensor data and numerical modeling and machine learning techniques are identified which have the potential to generate risk assessment strategies that match the aforementioned requirements. Cienfuegos (2022) outlines the increasing risk of flooding to coastal areas as exposed regions and emphasizes controlling the exposure dimension. Urban and infrastructure engineering design and planning processes should work hand in hand, therefore. Sharma et al. (2022) characterize diverse natural hazards in the central Himalayas, including their cascading mechanisms and potential impacts. A scientifically sound understanding of the cascading hazards, underlying mechanisms, and appropriate tools to account for the compounding risks are crucial for informing the design of risk management strategies. Werthmann (2023) reasons from the perspective of academia and discusses the challenges of bringing development from projects into practice. He reflects on attempts to develop an integrated early warning system regarding landslides in an informal neighborhood with its social dynamics, political uncertainty, and unforeseen challenges. So (2022) identifies a set of measures to realize a comprehensive understanding of global disaster risk: compilation of a standardized set of vulnerability-relevant exposure data for different natural perils, development of innovative approaches to collect asset data at a local and global scale, and agreement on vulnerability function development methodologies and global data-sharing.

Beyond this, it is crucial to establish global risk auditing protocols, which measure disaster risk profiles and changes over time to assess whether countries are making progress in disaster risk reduction. Villagran (2022) calls on science to transform achieved results into usable products. He also outlines the central role of trained technical staff in government agencies who take scientific results and products to generate relevant policies, norms, and regulations that should be used by those at risk to minimize the potential impact of natural or technological hazards based on the notions of risks. Thiebes and Winkhardt-Enz (2022) highlight the fact that the management of multi-risks remains a challenge for risk managers and decision-makers even in highly developed countries as exemplified by the 2021 flood events in Germany. Yet, innovative technologies incorporating earth observation, AI, and social media are being utilized in all phases of disaster risk management nowadays. However, solely closer collaboration between scientific research, operative civil protection, and political decision-making will allow for further reduction of natural hazard multi-risk situations. Finally, Klotz et al. (2023) state that remote sensing technologies have still some way ahead to become a better ally in building sustainable risk intelligence solutions and data for insurance applications. The demand for such information by the industry exists without a question, but in reality, the interfaces have not yet been fully exploited.

The Special Issue shows that scientific, technical, and social advancements in risk assessment and reduction have been made in a variety of ways. In doing so, it seamlessly follows two Special Issues (Taubenböck and Strunz 2013; Taubenböck and Geiß 2017) in the Natural Hazards Journal that document these developments over time. In the synopsis with these contributions, a wide field of data, methods, and thematic approaches emerges, which allow to determine the risks more precisely. However, the compendium of works also shows that there is still a gap between science and practice that needs to be bridged in order to reduce the risk for people and societies. The Special Issue here at hand, "*Multi-modal Characterization of Built and Natural Environments for Multi-Risk Assessment*", is an attempt to make these challenges visible through a burning glass and to show engaging ways to move forward.

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