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Preface: Hydro-meteorological extremes and hazards: vulnerability, risk, impacts, and mitigation

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1 Introduction

This preface summarizes the contents of the special issue "Hydro-meteorological extremes and hazards: vulnerability, risk, impacts, and mitigation", which is an outcome of the European Geosciences Union (EGU) session that has run since 2019 under the HS7 subdivision Hydrological Sciences, Precipitation and Climate[1].

Extreme hydro-meteorological events drive hazardous hydrological and geomorphic responses, which pose significant challenges to communities, economies, and ecosystems around the world (Borga et al., 2014; Paprotny et al., 2018; Markonis et al., 2021). The continuous increase in population and urban settlements in areas prone to hazards (Ceola et al., 2014; Andreadis et al., 2022), combined with the increasing evidence of variations in extreme-weather events due to ongoing climate change (Fisher and Knutti, 2016; Winsemius et al., 2016; Fowler et al., 2021), leads to a worrying increase in risks associated with hydro-meteorological hazards (Kron et al., 2019). To improve societal resilience, we need to better understand these hazards, quantify our vulnerability to their impacts, and improve risk mitigation and adaptation strategies.

The special issue collects the contributions of the most recent research advances in hydro-meteorological extremes related to both water excess (precipitation, floods, landslides, and storm surges) and water deficit (droughts and fire weather). It covers extreme-event studies from hazard assessment to vulnerability analysis, impact prediction, and mitigation strategies. This preface aims to direct the reader to the articles that are most relevant to their interests and to identify key topics that deserve further attention. It is hoped that the articles presented here will stimulate further research, lay the ground for interdisciplinary collaboration, and inform evidence-based policies aimed at mitigating the risk of hydro-meteorological extreme events.

Articles addressing hazards related to excess water are presented in sections dealing with extreme precipitation (Sect. 2), floods (Sect. 3), landslides (Sect. 4), and coastal hazards (Sect. 5), while articles dealing with hazards related to water deficit (droughts and fire weather) are presented in Sect. 6.

2 Precipitation hazard

Heavy precipitation is one of the key hydro-meteorological hazards addressed in this special issue. It constitutes a major trigger of several of the hazards described in the following, but three articles included in this collection directly in-

[1]Before 2021, the title of the session was "Precipitation-induced hazards: vulnerability, risk, impacts, and mitigation".

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vestigate different aspects of extreme precipitation. In particular, they provide an overview of rainfall measurements, future rainfall estimation, and potential impacts of rainfall extremes, with a focus on the urban environment. Since pluvial flood generation in urban areas is usually very fast (e.g., Cristiano et al., 2017), high-resolution measurements are required to detect rainfall events in a timely manner. A brief communication by Peleg et al. (2023) discusses the potential for installing low-cost acoustic sensors in urban areas, comparing them with other common rainfall monitoring systems. Although such sensors do not provide accurate quantitative information, they could be useful in detecting incoming heavy rainfall, thus improving the real-time flood warning in vulnerable urbanized areas.

With the aim of ensuring high temporal resolution in the estimation of future rainfall extremes in Germany, Ebers et al. (2024) modified a micro-canonical cascade model, adding temperature dependence and evaluating the possibility of a parameter reduction. The temperature-dependent disaggregation model improved the rainfall extreme estimation and showed how sub-daily extreme rainfall events mostly occur at higher temperatures. Future research should be directed towards a better understanding of such issues.

In populated and heavily urbanized areas, precipitation hazard is strongly associated with the potential failure of critical services and infrastructure (e.g., transportation or power utilities). Zhang et al. (2024) investigated how extreme rain and snow events could affect emergency medical services, focusing on the relevant study case of Beijing. Based on traffic data for 2019, the analysis showed that, in presence of intense events, the area that can be reached by medical services within 15 min strongly decreases, especially in peri-urban areas and during snow events.

3 Flood hazard

Altogether, 10 of the articles published in this special issue provide a comprehensive overview of flood risk research. They address various aspects of flood hazards, from physically-based models and machine learning techniques to nature-based solutions and compound risk analysis. By examining different geographical regions and flood types, the articles offer valuable insights into the evolving challenges posed by flood risks, particularly in the context of climate change and socioeconomic vulnerability.

Several articles highlight significant advances in flood modeling, particularly the integration of hydrological processes with advanced techniques. Viviroli et al. (2022) contribute to this by demonstrating the potential of comprehensive space–time hydro-meteorological simulations for the estimation of extremely rare floods in large river basins. Their work focuses on Switzerland's Aare River basin, using exceedingly long-term simulations to estimate floods with return periods well beyond 100 years. Pakdehi et al. (2024) explore the transferability of machine-learning-based models to predict maximum flood depths in coastal watersheds, presenting a novel approach that performs effectively in regions with limited local data. Khanam et al. (2023) employ a geomorphologically guided machine learning framework to predict flood impacts in High-Mountain Asia, addressing the challenges of modeling flood susceptibility in data-scarce high-altitude regions.

Nature-based solutions for mitigating hydro-meteorological risks are another key theme of this issue. Enu et al. (2023) present a comprehensive review of the potential of nature-based solutions to reduce flood risks in sub-Saharan Africa, a region highly vulnerable to climate change and rapid urbanization. Their work identifies common practices, such as mangrove and wetland restoration, and emphasizes the need for improved implementation of these strategies in areas facing severe flood risks. This theme is echoed by Wang et al. (2023), who assess the effectiveness of geotechnical and ecological interventions in reducing sediment transport and mitigating post-earthquake flood risks in China. In particular, they highlight the importance of combining engineering and nature-based solutions in flood-prone areas.

Several distinct but complementary aspects of flood risk management are addressed in two papers. Charpentier-Noyer et al. (2023) focus on short-range hydro-meteorological forecasts, offering a framework for improving the quantitative accuracy and the spatial localization of flash flood predictions, crucial for effective real-time management and emergency responses in rapidly evolving flood scenarios. In contrast, Eilander et al. (2023) address the complexities of compound flood risks, emphasizing the need for integrated models that account for the interaction between multiple flood drivers, such as coastal surges, river discharge, and heavy rainfall. Their study in Mozambique highlights how understanding the co-dependence of these drivers is key to assessing and mitigating large-scale flood risks. Together, these studies enhance the spectrum of flood risk understanding, from the precision of localized flash flood forecasting to the broader challenges of multi-hazard flood events.

Improving the resilience of flood defenses and early-warning systems is another critical focus. Houdard et al. (2023) conduct a sensitivity analysis of erosion of an earthen flood defense in southern France, exploring how erosion patterns influence the return periods of damage events. Their findings emphasize the importance of reliable dike characterization to improve flood defense resilience. Silva and Eleutério (2023) examine flood warning and evacuation systems in the context of a tailings dam failure in Brazil. Their study underscores the need for robust early-warning systems to minimize the loss of life in such events. Last, Abbate et al. (2024) introduce the CRHyME model, an innovative tool for geo-hydrological hazard assessment that integrates hydrological and geomorphological processes. Their study demonstrates the effectiveness of the model in simulating rainfall-induced hazards, such as landslides and sediment transport, across northern Italy, offering a valuable tool for civil protection and multi-hazard risk assessment.

Overall, the flood-related articles in this special issue illustrate significant progress in flood risk research, particularly in integrating advanced modeling techniques, nature-based solutions, and multi-hazard approaches. However, looking ahead, several key challenges need to be addressed to further improve flood risk assessment and mitigation. First, improving the availability and quality of data in underrepresented regions remains a critical issue (Enu et al., 2023; Khanam et al., 2023). Developing more adaptable models that can perform well even with limited data is crucial. Second, the complexity of compound flood risks requires further refinement of integrated models that account for the interactions between various flood drivers (such as coastal, fluvial, and pluvial flooding but also in combination with other perils like severe convective storms) or processes (for example, flood and sediment transport) (Abbate et al., 2024; Eilander et al., 2023). Third, while advances in early-warning systems and evacuation planning have been made, there is a need for more robust and globally scalable solutions that can be tailored to local conditions (Silva and Eleutério, 2023) and be effective also for flash floods. Finally, promoting the implementation of nature-based solutions and combining them with traditional engineering approaches and their overall maintenance will be essential to create more sustainable and resilient flood defenses, particularly in the face of climate change and increasing urbanization (Enu et al., 2023; Wang et al., 2023). Interdisciplinary collaboration and continued innovation in modeling techniques, data integration, and policy frameworks will be essential to meet these challenges in the coming years.

4 Landslide hazard

Five articles from this special issue focus on rockfall and landslide hazards. Birien and Gauthier (2023) use high-resolution laser scans to identify over 1000 rockfalls in three work walls in Quebec (Canada). They use this dataset to investigate the climatic conditions leading to rockfalls, with the objective of improving knowledge and implementing more efficient risk management strategies. Their findings underline the importance of weather conditions in determining the frequency and magnitude of rockfalls, with winter freeze–thaw cycles and moderate rainfall driving the frequency of low-magnitude rock instabilities and with high-intensity rainfall and spring thaw driving the frequency of large-dimension rockfalls.

The other studies focus on landslide initiation thresholds. These consist of precipitation (and other variable) thresholds that, when exceeded, are likely to initiate landslides in the region of interest. They are used to provide early warnings at the regional scale and are therefore among the most widely adopted approaches in civil protection (Piciullo et al., 2018). Despite this, landslide initiation thresholds can have important limitations related to (1) the abundance and quality of the available landslide data and precipitation estimates and (2) the rather simplistic representation of landslide processes that we need to use to build such thresholds on a regional level (e.g., Bogaard and Greco, 2018).

Palazzolo et al. (2023) address the issue of having a more realistic representation of landslide initiation by adopting hydro-meteorological thresholds, that is, using information on both precipitation and soil moisture conditions to derive landslide initiation thresholds for Sicily. They use principal component analysis to combine information on soil moisture at different depth layers. The performance of the thresholds obtained with multi-layer soil moisture information is similar to the one of thresholds obtained from a single layer, suggesting that landslides in Sicily could be mainly influenced by soil moisture in the most shallow soil layers.

Some studies also address the issue of data limitations. Millán-Arancibia and Lavado-Casimiro (2023) derive and test rainfall thresholds from daily meteorological information from a novel gridded dataset developed for Peru, finding that traditional thresholds based on average precipitation intensity and duration of precipitation are the most efficient at supporting disaster risk management in the region. Uwihirwe et al. (2022) evaluate the potential for using satellite information to derive landslide initiation thresholds in Rwanda, where only poor in situ information is available. They use both precipitation and soil moisture estimates from satellites to build hydro-meteorological thresholds. They find that 3 d cumulative precipitation is the best predictor of landslide initiation in Rwanda. Including root zone soil moisture information on similar temporal scales in a hydro-meteorological threshold model could improve the warning capabilities by reducing false alarms, although at the price of more missed events. Patton et al. (2023) overcame the challenge of a sparse landslide inventory in Alaska by developing a specifically tailored probabilistic model. Using maximum 3 h precipitation as a predictor, they were able to effectively distinguish days with landslides from days without slide activity. Interestingly, including information on precipitation in the previous days/weeks did not lead to an improvement in the performance of their model. This suggests that either soil moisture conditions are less important in Alaska with respect to Rwanda (Uwihirwe et al., 2022) or Sicily (Palazzolo et al., 2023) or that antecedent precipitation indices are not adequate proxies of soil moisture conditions.

These articles show that landslide initiation thresholds are still the subject of extensive research efforts, probably because of their wide diffusion as regional early-warning tools. The inclusion of antecedent soil moisture conditions, in addition to precipitation, in the hydro-meteorological thresholds advocated for by Bogaard and Greco (2018) is gaining momentum. We hope that future research will further define these approaches, which are still in an early stage, thus leading to more efficient regional early-warning systems. To this end, the role of moisture in different soil layers and in different areas probably requires a large-scale investigation.

5 Coastal hazards

Three studies in this special issue deal with coastal hazards related to atmospherically generated waves and storm surges. Meyer and Gaslikova (2024) combine hydrodynamic models with century-long reanalysis simulations to investigate the climatology of severe surge induced by storms in the German Bight. They found that winds observed in storms with northerly tracks can be better associated with extreme water levels due to lower variability in wind speed. They further investigate the co-occurrence of severe storms with high tides instead of the low tides actually observed during these storms, showing that such conditions would have led to record-breaking water levels. Hsu et al. (2023) investigate the relative contributions of storm surge and wave runup for three tropical cyclones that propagated along the shelf in the South Atlantic Bight. They show that the maximum storm surge and peak wave runup are mainly explained by the intensity of the cyclones, by the distance from the eye, and by the cyclone direction. Notably, slow-propagating cyclones lead to longer flooding, resulting in more severe losses.

The last type of coastal hazard investigated in this special issue is the meteotsunami. Meteostunamis are fast-developing coastal waves generated by atmospheric phenomena, which can pose a significant hazard to life and infrastructures. Lewis et al. (2024) present a new meteotsunami intensity index (no such index was previously available) to quantify the severity of such events in a standardized way. The new Lewis meteotsunami intensity index was tested over the United Kingdom and will provide a shared language and framework for meteotsunami analysis and comparison across the globe.

6 Hazards related to water deficit

With the aim of developing an early-warning system to mitigate drought impacts (e.g., livestock deaths, crop losses, and malnutrition) in Kenya, Lam et al. (2023) linked these impacts to common drought indices, water scarcity, and aridity, with the support of a random-forest model. The analyses underlined a relationship between the frequency of drought impacts and the severity of the drought. Results also highlighted the importance of evaluating the spatial variability of water scarcity, aridity, and socioeconomic conditions when investigating the links between the impacts of drought and the indices. In addition to the impacts on food security, droughts could have strong effects on environmental flow, making it difficult to guarantee minimum flow requirements to ensure ecosystem services. Using a threshold regression, Rahman et al. (2024) analyzed how drought impacts affect environmental flow in the Indus River basin (Pakistan), highlighting the finding that the frequency and magnitude of extremely low-flow and low-flow events increase with the severity of drought.

Another relevant risk that could arise from a water deficit is wildfire, an issue that is becoming more and more frequent globally (Jones et al., 2022). Using a regional single-model initial-condition large ensemble, Miller et al. (2024) investigate the changes in fire hazards under future climate scenarios. They examined areas that are currently not prone to wildfires, showing a potential increase in severe fire events even in these regions. This analysis suggests the importance of creating fire management policies not only in arid and semi-arid areas.

In general, a precipitation deficit can drive hazards with impacts at least as severe as excess precipitation. These hazards traditionally pertain to semi-arid and arid regions, and most research is conducted in these areas (Lam et al., 2023; Rahman et al., 2024). However, climate change challenges us with a potential dramatic increase in the extent and frequency of such events in other areas and climates, as clearly exemplified by the European drought of 2022. The importance of the spatial variability in water scarcity and of the socioeconomic conditions highlighted by Rahman et al. (2024) calls for global action at all levels, from hazard research to risk management and impact mitigation.

7 Conclusions

The articles within this special issue underscore the importance of interdisciplinary collaboration to address the multifaceted challenges posed by hydro-meteorological hazards. The studies highlight the need for enhanced connections between researchers and practitioners, ensuring that models and findings are not only scientifically robust but also aligned with the needs of local stakeholders, such as emergency responders and policymakers. By fostering closer integration between different disciplines, we can better understand the dynamics of hazards and develop actionable, regionally relevant solutions.

This special issue also emphasizes the potential of nature-based solutions and innovative technologies, such as low-cost sensors and machine learning, especially in data-scarce and vulnerable areas. Expanding these approaches, along with improved early-warning systems and rapid response frameworks, will be critical to building resilient communities. Moving forward, a holistic and practical approach that combines advanced modeling with field-ready applications will be essential for effective hazard mitigation and adaptation strategies.

Hydro-meteorological hazard research continues to face several challenges, including improving data accessibility, especially in underrepresented or remote regions, where machine learning tools may have a transformative impact. In addition, addressing the complexity of compound hazards, such as simultaneous flooding and landslides, demands integrated models that account for interacting risks, particularly under changing climate conditions. To make meaningful progress, future work must combine advanced multidisciplinary modeling with field-ready applications and collaborations that translate scientific insights into effective resilience strategies for vulnerable communities.

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References

Abbate, A., Mancusi, L., Apadula, F., Frigerio, A., Papini, M., and Longoni, L.: CRHyME (Climatic Rainfall Hydrogeological Modelling Experiment): a new model for geo-hydrological hazard assessment at the basin scale, Nat. Hazards Earth Syst. Sci., 24, 501–537, https://doi.org/10.5194/nhess-24-501-2024, 2024.

Andreadis, K. M., Wing, O. E., Colven, E., Gleason, C. J., Bates, P. D., and Brown, C. M.: Urbanizing the floodplain: global changes of imperviousness in flood-prone areas, Environ. Res. Lett., 17, 104024, https://doi.org/10.1088/1748-9326/ac9197, 2022.

Birien, T. and Gauthier, F.: Assessing the relationship between weather conditions and rockfall using terrestrial laser scanning to improve risk management, Nat. Hazards Earth Syst. Sci., 23, 343–360, https://doi.org/10.5194/nhess-23-343-2023, 2023.

Bogaard, T. and Greco, R.: Invited perspectives: Hydrological perspectives on precipitation intensity-duration thresholds for landslide initiation: proposing hydro-meteorological thresholds, Nat. Hazards Earth Syst. Sci., 18, 31–39, https://doi.org/10.5194/nhess-18-31-2018, 2018.

Borga, M., Stoffel, M., Marchi, L., Marra, F., and Jacob, M.: Hydrogeomorphic response to extreme rainfall in headwater systems: flash floods and debris flows, J. Hydrol., 518, 194–205, https://doi.org/10.1016/j.jhydrol.2014.05.022, 2014.

Ceola, S., Laio, F., and Montanari, A.: Satellite nighttime lights reveal increasing human exposure to floods worldwide, Geophys. Res. Lett., 41, 7184–7190, https://doi.org/10.1002/2014GL061859, 2014.

Charpentier-Noyer, M., Peredo, D., Fleury, A., Marchal, H., Bouttier, F., Gaume, E., Nicolle, P., Payrastre, O., and Ramos, M.-H.: A methodological framework for the evaluation of short-range flash-flood hydrometeorological forecasts at the event scale, Nat. Hazards Earth Syst. Sci., 23, 2001–2029, https://doi.org/10.5194/nhess-23-2001-2023, 2023.

Cristiano, E., ten Veldhuis, M.-C., and van de Giesen, N.: Spatial and temporal variability of rainfall and their effects on hydrological response in urban areas – a review, Hydrol. Earth Syst. Sci., 21, 3859–3878, https://doi.org/10.5194/hess-21-3859-2017, 2017.

Ebers, N., Schröter, K., and Müller-Thomy, H.: Estimation of future rainfall extreme values by temperature-dependent disaggregation of climate model data, Nat. Hazards Earth Syst. Sci., 24, 2025–2043, https://doi.org/10.5194/nhess-24-2025-2024, 2024.

Eilander, D., Couasnon, A., Sperna Weiland, F. C., Ligtvoet, W., Bouwman, A., Winsemius, H. C., and Ward, P. J.: Modeling compound flood risk and risk reduction using a globally applicable framework: a pilot in the Sofala province of Mozambique, Nat. Hazards Earth Syst. Sci., 23, 2251–2272, https://doi.org/10.5194/nhess-23-2251-2023, 2023.

Enu, K. B., Zingraff-Hamed, A., Rahman, M. A., Stringer, L. C., and Pauleit, S.: Review article: Potential of nature-based solutions to mitigate hydro-meteorological risks in sub-Saharan Africa, Nat. Hazards Earth Syst. Sci., 23, 481–505, https://doi.org/10.5194/nhess-23-481-2023, 2023.

Fisher, E. M. and Knutti, R.: Observed heavy precipitation increase confirms theory and early models, Nat. Clim. Change, 6, 986–991, https://doi.org/10.1038/nclimate3110, 2016.

Fowler, H. J., Lenderink, G., Prein, A. F., Westra, S., Allan, R. P., Ban, N., Barbero, R., Berg, P., Blenkinsop, S., Do, H. X., Guerreiro, S., Haerter, J. O., Kendon, E. J., Lewis, E., Schaer, C., Sharma, A., Villarini, G., Wasko, C., and Zhang, X.: Anthropogenic intensification of short-duration rainfall extremes, Nat. Reviews Earth and Environment, 2, 107–122, https://doi.org/10.1038/s43017-020-00128-6, 2021.

Houdard, C., Poupardin, A., Sergent, P., Bennabi, A., and Jeong, J.: Sensitivity analysis of erosion on the landward slope of an earthen flood defense located in southern France submitted to wave overtopping, Nat. Hazards Earth Syst. Sci., 23, 3111–3124, https://doi.org/10.5194/nhess-23-3111-2023, 2023.

Hsu, C.-E., Serafin, K. A., Yu, X., Hegermiller, C. A., Warner, J. C., and Olabarrieta, M.: Total water levels along the South Atlantic Bight during three along-shelf propagating tropical cyclones: relative contributions of storm surge and wave runup, Nat. Hazards Earth Syst. Sci., 23, 3895–3912, https://doi.org/10.5194/nhess-23-3895-2023, 2023.

Jones, M. W., Abatzoglou, J. T., Veraverbeke, S., Andela, N., Lasslop, G., Forkel, M., Smith, A. J., Burton, C., and Betts, R. A.: Global and regional trends and drivers of fire under climate change, Rev. Geophys., 60, e2020RG000726, https://doi.org/10.1029/2020RG000726, 2022.

Khanam, M., Sofia, G., Rodriguez, W., Nikolopoulos, E. I., Lu, B., Song, D., and Anagnostou, E. N.: Predictive Understanding of Socioeconomic Flood Impact in Data-Scarce Regions Based on Channel Properties and Storm Characteristics: Application in High Mountain Asia (HMA), Nat. Hazards Earth Syst. Sci. Discuss. [preprint], https://doi.org/10.5194/nhess-2023-120, in review, 2023.

Kron, W., Löw, P., and Kundzewicz, Z. W.: Changes in risk of extreme weather events in Europe, Environ. Sci. Policy, 100, 74–83, https://doi.org/10.1016/j.envsci.2019.06.007, 2019.

Lam, M. R., Matanó, A., Van Loon, A. F., Odongo, R. A., Teklesadik, A. D., Wamucii, C. N., van den Homberg, M. J. C., Waruru, S., and Teuling, A. J.: Linking reported drought impacts with drought indices, water scarcity and aridity: the case of Kenya, Nat. Hazards Earth Syst. Sci., 23, 2915–2936, https://doi.org/10.5194/nhess-23-2915-2023, 2023.

Lewis, C., Smyth, T., Neumann, J., and Cloke, H.: Proposal for a new meteotsunami intensity index, Nat. Hazards Earth Syst. Sci., 24, 121–131, https://doi.org/10.5194/nhess-24-121-2024, 2024.

Markonis, Y., Kumar, R., Hanel, M., Rakovec, O., Màca, P., and AghaKouchak, A.: The rise of compound warm-season droughts in Europe, Sci. Adv., 7, eabb9668, https://doi.org/10.1126/sciadv.abb9668, 2021.

Meyer, E. M. I. and Gaslikova, L.: Investigation of historical severe storms and storm tides in the German Bight with century reanalysis data, Nat. Hazards Earth Syst. Sci., 24, 481–499, https://doi.org/10.5194/nhess-24-481-2024, 2024.

Millán-Arancibia, C. and Lavado-Casimiro, W.: Rainfall thresholds estimation for shallow landslides in Peru from gridded daily data, Nat. Hazards Earth Syst. Sci., 23, 1191–1206, https://doi.org/10.5194/nhess-23-1191-2023, 2023.

Miller, J., Böhnisch, A., Ludwig, R., and Brunner, M. I.: Climate change impacts on regional fire weather in heterogeneous landscapes of central Europe, Nat. Hazards Earth Syst. Sci., 24, 411–428, https://doi.org/10.5194/nhess-24-411-2024, 2024.

Pakdehi, M., Ahmadisharaf, E., Nazari, B., and Cho, E.: Transferability of machine-learning-based modeling frameworks across flood events for hindcasting maximum river water depths in coastal watersheds, Nat. Hazards Earth Syst. Sci., 24, 3537–3559, https://doi.org/10.5194/nhess-24-3537-2024, 2024.

Palazzolo, N., Peres, D. J., Creaco, E., and Cancelliere, A.: Using principal component analysis to incorporate multi-layer soil moisture information in hydrometeorological thresholds for landslide prediction: an investigation based on ERA5-Land reanalysis data, Nat. Hazards Earth Syst. Sci., 23, 279–291, https://doi.org/10.5194/nhess-23-279-2023, 2023.

Paprotny, D., Sebastian, A., Morales-Nápoles, O., and Jonkman, S. N.: Trends in flood losses in Europe over the past 150 years, Nat. Commun., 9, 1985, https://doi.org/10.1038/s41467-018-04253-1, 2018.

Patton, A. I., Luna, L. V., Roering, J. J., Jacobs, A., Korup, O., and Mirus, B. B.: Landslide initiation thresholds in data-sparse regions: application to landslide early warning criteria in Sitka, Alaska, USA, Nat. Hazards Earth Syst. Sci., 23, 3261–3284, https://doi.org/10.5194/nhess-23-3261-2023, 2023.

Peleg, N., Torelló-Sentelles, H., Mariéthoz, G., Benoit, L., Leitão, J. P., and Marra, F.: Brief communication: The potential use of low-cost acoustic sensors to detect rainfall for short-term urban flood warnings, Nat. Hazards Earth Syst. Sci., 23, 1233–1240, https://doi.org/10.5194/nhess-23-1233-2023, 2023.

Piciullo, L., Calvello, M., and Cepeda, J.: Territorial early warning systems for rainfall-induced landslides, Earth-Sci. Rev., 179, 228–247, https://doi.org/10.1016/j.earscirev.2018.02.013, 2018.

Rahman, K. U., Shang, S., Balkhair, K. S., Gabriel, H. F., Jadoon, K. Z., and Zaman, K.: Catchment-scale assessment of drought impact on environmental flow in the Indus Basin, Pakistan, Nat. Hazards Earth Syst. Sci., 24, 2191–2214, https://doi.org/10.5194/nhess-24-2191-2024, 2024.

Silva, A. F. R. and Eleutério, J. C.: Analysis of flood warning and evacuation efficiency by comparing damage and life-loss estimates with real consequences related to the São Francisco tailings dam failure in Brazil, Nat. Hazards Earth Syst. Sci., 23, 3095–3110, https://doi.org/10.5194/nhess-23-3095-2023, 2023.

Uwihirwe, J., Riveros, A., Wanjala, H., Schellekens, J., Sperna Weiland, F., Hrachowitz, M., and Bogaard, T. A.: Potential of satellite-derived hydro-meteorological information for landslide initiation thresholds in Rwanda, Nat. Hazards Earth Syst. Sci., 22, 3641–3661, https://doi.org/10.5194/nhess-22-3641-2022, 2022.

Viviroli, D., Sikorska-Senoner, A. E., Evin, G., Staudinger, M., Kauzlaric, M., Chardon, J., Favre, A.-C., Hingray, B., Nicolet, G., Raynaud, D., Seibert, J., Weingartner, R., and Whealton, C.: Comprehensive space–time hydrometeorological simulations for estimating very rare floods at multiple sites in a large river basin, Nat. Hazards Earth Syst. Sci., 22, 2891–2920, https://doi.org/10.5194/nhess-22-2891-2022, 2022.

Wang, D., Wang, M., Liu, K., and Xie, J.: An assessment of short–medium-term interventions using CAESAR-Lisflood in a post-earthquake mountainous area, Nat. Hazards Earth Syst. Sci., 23, 1409–1423, https://doi.org/10.5194/nhess-23-1409-2023, 2023.

Winsemius, H. C., Aerts, J. C. J. H., van Beek, L. P. H., Bierkens, M. F. P., Bouwman, A., Jongman, B., Kwadijk, J. C. J., Ligtvoet, W., Lucas, P. L., van Vuuren, D. P., and Ward, P. J.: Global drivers of future river flood risk, Nat. Clim. Change, 6, 381–385, https://doi.org/10.1038/nclimate2893, 2016.

Zhang, Y., Liu, K., Ni, X., Wang, M., Zheng, J., Liu, M., and Yu, D.: Spatial accessibility of emergency medical services under inclement weather: a case study in Beijing, China, Nat. Hazards Earth Syst. Sci., 24, 63–77, https://doi.org/10.5194/nhess-24-63-2024, 2024.