



Editorial

# Editorial to the Special Issue: Impacts of Compound Hydrological Hazards or Extremes

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Hydrological hazards, or ‘hydro-hazards’, are defined as “extreme events associated with the occurrence, movement and distribution of water, such as floods and droughts” (Visser-Quinn et al., 2019 [1]). Singular or interacting physical process which drive hydro-hazards can combine to produce a range of compounding and cascading impacts, which may interact across multiple spatial and temporal scales. For example, urban flooding may result from excess runoff from one or multiple sources (e.g., extreme rainfall, groundwater), causing disruption to the built environment.

Hydro-hazards have devastating social, environmental, and economic impacts, with vulnerable members of society often disproportionately affected (Visser-Quinn et al., 2019 [1]; Hao et al., 2018 [2]). The impacts cross many different sectors and communities, including infrastructure, natural environment, economic activity, cultural heritage, and human health. The impact intensity can be assessed via risk assessment methods, considering the system exposure, susceptibility, and lack of resilience. Globally, rapid urban expansion is taking place against a background of climate change; increased losses due these hydro-hazard impacts are expected; however, the extent of this increase is uncertain (Collet et al., 2018 [3]).

At present, existing methodologies which assess hydro-hazard interconnections are limited in their scope and practice, in particular with respect to changing exposure and cascading impacts, as well as inadequate representation of uncertainty (Visser-Quinn et al., 2019 [1]).

This Special Issue aimed to collect the most recent efforts to face this challenge and invited studies looking at the impacts of hydro-hazards, especially compound hydro-hazards (e.g., extreme precipitation, river discharge or storm surge interactions leading to floods; multi-hazard assessment, response, recovery, and planning tools for decision support; resilience assessment and modelling for hydro-hazard resilient environments).

There are seven papers in this Special Issue, addressing a range of compound hydro-hazards, and introducing novel ways of addressing the issues arising with multiple hazards and processes. The compound hazards range from precipitation events coinciding with extreme sea level rise, or coastal surge events, the impacts of urban growth and extreme events, to the combined effects of fluvial and sediment events.

Saber et al. (2019) [4] investigates the relative impact of urban growth and rainfall intensification on flood vulnerable areas in several cities in Egypt. The research suggests that the dominant control on flood vulnerability is urban growth and that better planning, taking into account flood hazard zoning, would have a positive impact on flood exposure. Jonoski et al. (2019) [5] use optimisation techniques to explore the minimisation of risk and damages simultaneously in two locations. The case study explores the trade-off between dual use flood storage areas flooding and downstream urban flood risk.

It is clear that, in such cases, compound hazards are complex to manage. The paper explores different techniques to explore the problem and concludes that more detail in model structure is advantageous in order to map the pareto front as efficiently as possible.

Pizarro et al. (2019) [6] explores the compound hazard of multiple flood events resulting in scouring at bridge piers. Uncertainty quantification techniques are used to explore the relevant controls on the system, with hydrograph timing and shape being investigated. Similarly, Oubennaceur et al. (2019) [7] investigated the relative importance of bed topography, mannings  $n$  and flow rate inputs in a 2D model on simulated water depths in a river reach. Bed topography was found to have the greatest influence on water depths in this study; suggesting that sediment movement in rivers is an important consideration when investigating the impacts of compound events.

Coastal flood hazard is the topic of the paper by Antunes et al. (2019) [8], where sea level rise and extreme coastal events are modelled together, and the influence of climate change is analysed. Coastal hazard is the topic of the paper by Paul et al. (2020) [9] and Ullman et al. (2019) [10]; both of whom explore extreme hurricanes, which often have compounding effects.

From these papers, a number of challenges are identified. Firstly, when considering more than one hazard occurring at a time, the system modelled becomes more complex. The consideration of timing of events, across multiple spatial and temporal scales, introduces a further dimension. It is clear that most studies limit the complexity by investigating two different factors at once, perhaps also factoring in the influence of time (e.g., Pizarro et al., 2019 [6]); however, studies that explore cascading or triggering hazards are less common, and methods are needed that support such complex understanding.

These papers—and the challenges they identify—contribute to wider efforts across the scientific community to improve our understanding of compound hazards, including hydro-hazards, and to quantify the interaction of the processes that drive them. Recent collaborative efforts, such as Zscheischler et al. (2018; 2020) [11,12], and the DAMOCLES European Cost Action ‘Understanding and Modeling Compound Climate and Weather Events’, are helping co-produce and share new research findings and build capacity to help address some of these challenges. However, these efforts are ongoing and many challenges remain, which are summarized by the following recommendations for future work:

- A programme that refocuses some the activities of the climate science community towards compound events;
- An impact-oriented compound events modelling community that focuses on impacts of compound events rather than on drivers and processes;
- A broadening of compound events modelling to include cascading and triggering hazards;
- Increased cross-sectoral collaboration leading to compound events methodologies that are stakeholder/end-user driven;
- Improvements to global climate model to better model the complex interactions between hazards and processes and reduces uncertainties;
- A framework that supports the integration of compound events in natural hazard risk assessment.

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