Impacts from cascading multi-hazards using hypergraphs: a case study from the 2015 Gorkha earthquake in Nepal

Response to reviewers

Reviewers 1

Dear Authors,

I was invited to review the Manuscript Number: egusphere-2024-1374 “Impacts from cascading multi-hazards using hypergraphs: a case study from the 2015 Gorkha earthquake in Nepal”.

The use of graphs is certainly very interesting for exploring interactions between multi-hazards. The challenge of applying such a method on a large national scale is overcome by the proposed hypergraph approach. The main benefit derived is efficiency. The work is clearly and well-presented in its overall logic. The research question, case study, and methodology provide the necessary information to appreciate the approach in its generality. However, some passages are unclear and require minor additional information, as detailed below.

I would like to highlight a general aspect that I believe needs further clarification: are the limitations of this approach attributed to the use of hypergraphs or to the individual models used to model specific hazards (e.g., fragility functions, estimation of susceptibility maps, etc.)? In my understanding, the limitations are due to the choice of the latter. If so, I think it is important to clarify this in the discussion and propose alternatives for future implementations that could improve these limitations. Additionally, what are the advantages of using hypergraphs beyond the computational efficiency that makes them applicable on a large scale?

The graph methodologies in risk assessment allow, among other things, the analysis of graph topology to highlight potential systemic behavior and impact propagation mechanisms (see as example ref 1). Is this possible with hypergraphs? I invite the authors to consider to discuss these potential applications or limitations. My question upon reading the novelty of the manuscript is whether hypergraphs are an innovative algorithm extending traditional risk of multi-hazard methodologies (beyond the multi-layer single hazard) to larger scales (thanks to their efficiency) or if they introduce a conceptually different approach to impact estimation? Please clarify this aspect in the discussion section

[Authors] Thank you for your comments. The use of hypergraph has two main advantages, one was correctly identified as being computationally efficient. The other advantage is the capacity of this framework to overcome the problem of combining hazard models of different nature for cascading multi-hazard risk assessments by

simplifying and standardizing the structure of the initial model's datasets. The limitations mentioned in section 5.3 Limitations are wide ranging in their domains, from engineering to the resolution of landslide susceptibility models. Academics are trying to overcome those limitations in their own rights. The purpose of the paper herein is to provide an innovative framework which allows cascading effects to be modelled while allowing any progress across modelling domains to be captured.

In the paper herein, the hypergraph constitutes the backbone of the propagation algorithm (i.e. cascading scenarios) as it was initially realized in previous papers by the author using standard graphs (Dunant et al., 2021) and typological measures were not the target of this study. The typology of hypergraphs can indeed be studied with measures such as centrality (Hypergraphx and HyperG are examples of libraries). It might be interesting to dedicate a future paper to study various topological measures for longer cascading scenarios (e.g. added interactions landslide / river) and a deeper network of interactions.

Detailed aspects include:

- Lines 284-292 are unclear; please reformulate with more explanations for clarity.

  [Authors] The paragraph has been amended for clarity

- The susceptibility section was too hasty, particularly the process of identifying "slope units" and the relationship between "slope units" and the extension of the landslide. Additionally, it is unclear whether the buildings and roads affected by landslides are only those falling within the "slope units" or if there is some estimation of the landslide's influence area. In either case, further explanation is needed.

  [Authors] Additional information about the creation of the slope units has been added to the manuscript Lines 194-195 in addition to the Supplementary information material.

- A table summarizing the data used, specifying the main characteristics, including the different resolutions used could help the reading.

  [Authors] all the data sources, resolutions and use are describe as part of the flow of the paper and we believe that adding a table as supplementary material would therefore be redundant.

- Figures 5 and 7 use a continuous scale for discrete colors, which is not intuitive. I suggest to explore other legend options.

  [Authors] The figures will be updated for clarity as it was mentioned by the other reviewer as well.

- The quality of the figures is low, which may be a pre-print issue. I suggest to check before the final version.

  [Authors] All the figures have been saved with a DPI of 300 which should show a sharp image for the final version.

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ref 1: Arosio, M., Martina, M.L.V., Figueiredo, R., "*The whole is greater than the sum of its parts: A holistic graph-based assessment approach for natural hazard risk of complex systems.*", Natural Hazards and Earth System Sciences, 2020, 20(2), pp. 521–547