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Reply on RC2

Roberto Bentivoglio et al.

Author comment on "Deep learning methods for flood mapping: a review of existing applications and future research directions" by Roberto Bentivoglio et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-83-AC2, 2022

>> We thank the Reviewer for the comments. We address each of them in the following lines.

> This paper presents a review of the applications of deep learning models for flood inundation, susceptibility, and hazard mapping in a period between 2010 and 2021, leading to reviewing a total of 58 papers. The manuscript is well-rewritten and organized and provides information for international readers. However, two important weaknesses exist; these can both be strengthened relatively easily. (1) The objectives should be better presented. A numbered list of objectives would work better.

>> We thank the reviewer for this suggestion. We have organized the main contributions of our paper in a list, in lines 70-76:

"The main insights from this paper can be summarized as follows:

- We identify common patterns and deduce general considerations based on the presented results while highlighting individual innovative approaches;
- We compare against traditional methods to further validate the benefits of employing DL models;
- We identify a series of current knowledge gaps and propose possible solutions to them drawing from recent advancements in DL."

> (2) The conclusions section should be rewritten and further improved to address the objectives. This section should also include the limitations of the current work and suggestions for further research in the future. For example, the authors can suggest a more systematic Bibliometric/scientometric analysis and the use of several well-established metrics for future research. See https://www.mdpi.com/2071-1050/13/15/8261/htm are the references therein.

>> We thank the Reviewer for the suggestion. We have now modified the conclusions section to enforce a clearer connection between the research objectives and the conclusions we obtained, in lines 775-804:

"This paper presented a review of current applications of deep learning models for flood mapping. The chosen search criteria yielded a total of 58 papers published between 2010 and 2021. From our analysis we found common patterns that can be summarized as follows:

- Flood inundation, susceptibility, and hazard mapping were investigated using deep learning models. Flood inundation considers as the main data images of floods, mostly taken via satellite. The main and most accurate deep learning models were CNNs. In flood susceptibility, deep learning models consider several inputs, the most important being slope, land use, aspect, terrain curvature, and distance from the rivers. The main deep learning model used were MLPs, often in combination with other statistical techniques although CNNs provided more accurate results. Deep learning for flood hazard mapping generally involves developing surrogates of numerical models that estimate water depths in a study area. For this application, there are no deep learning model preferences. However, RNNs are preferable for spatio-temporal simulations.
- MLPs and CNNs were the most common type of deep learning model considered in flood mapping, while RNNs were less used. To overcome their lack of inductive biases and achieve good accuracy, MLPs are often coupled with other statistical techniques. On the other hand, thanks to their spatial and temporal inductive biases, CNNs and RNNs were found to regularly outperform other models.
- Most papers dealt with river and urban floods, while only a few works described applications for flash, coastal, and dam break floods. Case studies were mainly addressed at local or regional scales, arguably due to the availability of high-resolution data. Conversely, the community should further investigate the suitability of deep learning models for flood applications at larger scales.
- Concerning the development data, we found that models producing susceptibility and inundation maps rely on the availability of real flood observations. Instead, DL-based surrogate models for hazard mapping require target data from numerical simulations.

In terms of comparison with traditional and machine learning approaches we found that:

- Regardless of the application, results show that deep learning solutions outperform traditional approaches as well as other machine learning techniques.
- Deep learning models used for surrogate modeling provide significant speed-up (up to three orders of magnitude) while maintaining sufficient accuracy.

This review did not consider works featuring ML methods alone. Therefore, further research is needed to thoroughly compare ML against DL methods, especially with respect to explainability, generalization ability, and data requirements. This review also outlined several knowledge gaps, which can be addressed via deep learning to improve the state of the art of flood mapping. To solve these gaps we proposed possible solutions based on recent advances in fundamental machine learning research:"

>> Regarding the limitations of our work, we believe that our selection procedure has gathered enough relevant papers to carry out this critical review, as stated in lines 266-268. While the current literature in deep learning for flood mapping is probably not large enough for a bibliometric analysis (see Donthu et al., 2021), we thank the reviewer for recommending this approach. Indeed, we now report the suggested reference, mentioning the potential benefits of conducting a bibliometric analysis for a broader area of research, encompassing deep learning for water resources and natural hazards in lines 822-825:

"While our review draws insights for future research directions from the machine learning literature, further understanding may emerge from a broader review including deep learning applications across other water- and natural-hazard-related fields, and featuring a bibliometric analysis (Fazeli-Varzaneh et al., 2021). This approach may facilitate cross-

fertilization between sister disciplines, especially with respect to the successful implementation of advanced deep learning methods for spatial analysis."

References:

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N. and Lim, W.M., 2021. How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, 133, pp.285-296.

Fazeli-Varzaneh, M., Bettinger, P., Ghaderi-Azad, E., Kozak, M., Mafi-Gholami, D. and Jaafari, A., 2021. Forestry research in the Middle East: A bibliometric analysis. Sustainability, 13(15), p.8261.