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Title: Are heavy rainfall events a major trigger of associated natural hazards along the German rail network?

Reviewer: Ugur Ozturk

Overview and general comments:

The manuscript demonstrates the integration of damage data from infrastructure operators with climate data from weather services, aiming to discern potential relationships that could enhance proactive management of natural hazards. The authors' perspective, primarily through the lens of a railroad operator, brings a focused approach to understanding and mitigating disruptions to railroad operations caused by climate extremes. This perspective is particularly timely, given the anticipated increase in such disruptions under the impact of climate change, highlighting the urgent need for targeted countermeasures.

As I read the manuscript, I found the unique approach to examining rainfall, associated hazards, and their impact on the rail network from a rail network operator's standpoint to be both enlightening and compelling. The entire analysis bears the imprint of this distinctive viewpoint, offering insights that are both practical and relevant to the field. However, I feel that certain aspects of the study and the choices made therein would benefit from additional elucidation, and there may be room to broaden some analyses to further strengthen the findings and their implications.

My **major concerns** concentrate around the method choices forming the foundation of the current study. I highlight the line number of a piece from the manuscript in quotation marks which is followed by my comments after the sign of -->.

Line 79: "spatially intersected with the German rail network" --> Is this intersection achieved considering purely spatial overlap, or are rainfall runoff conditions taken into account as well? For instance, rainfall upstream could potentially impact tracks downstream, even in the absence of local precipitation.

Line 97: "one heavy rainfall event" --> Could the authors clarify if they are referring to hydrogeomorphological events, including mass-wasting process? I suspect that the tree falls might relate more to wind than rainfall. If the tree fall process is indeed related to wind, it might be beneficial to consider a term that encompasses all three phenomena. Perhaps including wind events as a factor, or alternatively, reconsidering the inclusion of tree fall cases, might provide a more concise, easy-to-explain analysis.

Line 158: "e.g. shown for shallow landslides" --> While the observation may hold true for shallow landslides, it's important to note that gravitational mass movements also encompass deep-seated landslides, where the lag time could extend significantly, potentially reaching years. Even excluding these exceptional cases, a lag time of 10-15 days appears realistic, as evidenced by Dille et al. (2022; https://doi.org/10.1038/s41561-022-01073-3). Should the focus be on shallow landslides, it would be helpful if this distinction is made clear. The choice of a 2-day lag for considering landslides raises some concerns for me, and I kindly suggest revisiting this aspect for a more nuanced discussion. The term "gravitational mass movements" might cover more processes than the authors intended.

Lines 200–202: "The segment is considered to have been affected by a heavy rainfall event on a given day if a heavy rainfall event from the CatRaRE database has occurred on that day up to a maximum of two days previously." --> As I mentioned in my previous comment, I'm

concerned that the proposed time-lag window might not adequately capture the lag time associated with landslides. Later on, in the results (below comment) authors highlight that only a small fraction of mass wasting events were linked to certain rain events. Hence, as previously mentioned, extending this window could offer a more accurate representation of the impact of heavy rainfall on landslide occurrences.

Line 275: "a total of 59 events (14 %)" --> I wonder if the correlation might become more pronounced if the lag time were extended to 15 days or more. This adjustment could potentially offer a more comprehensive analysis of the impact of heavy rainfall on these events.

Lines 278-279: "Of the 14461 tree fall events, a total of 312 (2 %) events can be spatially and temporally linked to a heavy rainfall event." --> This observation might suggest a less direct connection between rainfall and tree falls, potentially implicating other factors such as wind (as discussed by Gardiner et al.; http://dx.doi.org/10.2139/ssrn.4576016) or flooding (Lucia et al., 2018; https://doi.org/10.1016/j.scitotenv.2018.05.186). Further exploration of these factors could enrich the study.

My **minor concerns** primarily revolve around the use of terminology and the occasional absence of detailed explanatory statements that could further enhance the manuscript's readability and comprehension. Clarifying these aspects could improve the overall understandability for the readers. I list the minor comments in the attached file to keep my online comments concise.

Line 6: "associated natural hazards" --> Could you please specify which natural hazards are being referred to here?

Line 8: "random-effects logistic models" --> At this juncture, I'm finding it challenging to grasp the specifics of this model. Could you possibly elaborate further for clarity?

Line 8: "DB Netz AG" --> I'm concerned that this acronym might not be readily understood by a significant portion of the NHESS readership outside of Germany. Could a brief explanation be provided for broader accessibility?

Line 8: "CatRaRe" --> Similarly, this acronym might not resonate with the wider NHESS audience. A definition could greatly aid in understanding.

Lines 10-11: "Twenty-three percent of the flood events, 14% of the gravitational mass movements and 2% of the tree fall events" --> I'm having a bit of difficulty following these percentages. To clarify, does this imply that 77% of the flood events are not attributed to heavy rainfall?

Lines 12-13: "a heavy rainfall event significantly increases the probability of occurrence of a flood by a factor of 34.29." --> Am I correct in understanding that, according to the authors, there are floods that occur independently of heavy rainfall events?

Line 12: "Tree fall" --> I'm struggling to conceptualize how heavy rainfall directly leads to tree fall. Could you provide further insight into this connection?

Lines 13-14: "the 21-days antecedent precipitation index" --> I'm not entirely versed in the conventional determination of the 21-day threshold. If it's based on specific constraints, might I suggest clarifying or possibly reevaluating its presentation in the text?

Line 15: "with no significant increase for gravitational mass movements" --> This finding seems to be at odds with existing literature. Could the authors confidently assert the robustness of their data in this regard? Further emphasis on this point might be warranted,

especially given the indicated positive correlation between increasing rainfall and landslide occurrences in Figure 4.

Line 15: "21 day threshold" --> Once again, the 21-day threshold's basis is not clear to me. If it's a discretionary choice, clarifying its rationale or considering its removal for a more straightforward explanation might be beneficial.

Lines 15-16: "The results underline the importance of gaining more precise knowledge about the impact of climate triggers on natural hazard-related disturbances" --> The connection to this conclusion in the abstract seems somewhat tenuous. A more detailed exposition in the text might help in directly leading the reader to this message. Alternatively, authors could consider revising the final message that summarizes their results.

Lines 19-26: "" --> This is a really nice start to the manuscript. It really caught my attention.

Line 28: "significant" --> I would advise against using 'significant' unless it is in a statistical context. Perhaps 'considerably' could serve as a suitable alternative.

Line 39: "Within the framework of proactive natural hazard management" --> Is this framework well-documented in the literature, or is it an innovative concept proposed by the authors? A reference or a detailed explanation would be valuable for readers.

Line 98: "Starkregenindex SRI" --> Could the authors kindly provide a citation for this index? If it is a novel introduction, a detailed explanation within the manuscript would enhance understanding.

Line 100: "Lower Saxony" --> Given the frequent references to federal states, it may be helpful to include a reference map for those less familiar with Germany's geographical and political landscape.

Line 111: "with event-specific search terms" --> Could you specify which search terms were used?

Line 128: "the period 1 January 2017-16 December 2020" --> I'm curious as to why data from earlier years and for 2021 were not included. This query also pertains to mass-wasting events. If they were absent in the data, do the authors know the reason behind.

Line 132: "Explanatory control variables" --> It would be immensely helpful to visualize these data. Is it possible to include them in one or more figures within the manuscript?

Lines 153-154: "Thus, there are event locations where more than 50 heavy rainfall events from 2011 to 2021 can be found." --> Could this indicate that a single event, such as gravitational mass movements, might be attributed to multiple heavy rain events? This clarification would greatly aid in understanding the methodology applied.

Line 161: "for deep landslides" --> It may be more accurate to refer to these as "deep-seated landslides" to ensure clarity and precision in terminology.

Line 166: "the data set" --> It appears the term "dataset" is used inconsistently. Adopting a uniform usage could enhance the manuscript's readability.

Line 270: "events" --> Could you specify which events are being referred to here? Are these meant to be natural hazards?

Lines 322-323: "After two days, the probability of a gravitational mass movement is no longer different from a situation with no heavy rainfall." -->

Lines 325-326: "In contrast, one day after a heavy rainfall event, a tree fall event is 2.4 times more likely to occur than in days with no heavy rainfall." --> The linkage of tree falls to heavy rainfall events, as highlighted here, is quite intriguing, especially considering that 98% of tree

fall events were not directly linked to rainfall in the previous sections. Further clarification on this discrepancy would be beneficial.

Lines 352–353: "In the case of b) and e), the distance becomes greater at higher values, i.e., the higher the amount of accumulated precipitation, the more a heavy rainfall event increases the probability of occurrence of a flood or gravitational mass movement." --> It might be worthwhile for the authors to explore the findings of Saito et al. (2014; https://doi.org/10.1130/G35680.1), which suggest that increasing rainfall totals enhance landslide activity up to a certain threshold beyond which the effect does not apply. This could provide valuable insights into the study's analysis.

Line 398: "susceptible" --> The use of "susceptible" might be slightly misleading, potentially being confused with the term 'landslide susceptibility.' Perhaps "prone" could be a more precise alternative, avoiding any ambiguity.

Lines 414-415: "for gravitational mass movements it was as much as 17 % (Figure 1)" --> The low percentage of gravitational mass movements attributed to heavy rainfall seems somewhat unexpected, given that rainfall or related floods are the main triggers for landslides in Germany. This observation suggests the 2-day threshold might be too restrictive. Extending this threshold could potentially reveal a more nuanced impact of rainfall on landslide occurrence. It's commonly suggested that lag times of 10 to 15 days are realistic, with some extreme cases even longer, which could be an important consideration for the study.

Figures:

Figure 1 --> The resemblance between subplot d and f is quite notable. This observation raises an interesting question: might the authors consider the possibility that landslides along tracks are more influenced by flood processes than by rainfall alone? This could potentially be attributed to processes such as slope undercutting or toe removal by floodwaters. In times these floods might be caused by a rain event upstream that is spatially not overlapping with the landslide location. Further exploration of this hypothesis could provide valuable insights.

Figure 2 --> It would be beneficial if the authors could provide a more detailed explanation of how the intersection depicted in this figure was calculated. This aspect seems crucial and might be more appropriately discussed in the results section to enhance the reader's understanding of the methodology. If it is discussed later than the figure’s location, it might be an option to add a sentence summary in the caption.

Figure 3 --> Currently, I find this figure somewhat challenging to interpret. Might the authors consider revising it to enhance its clarity and accessibility? Providing additional context or simplifying the presentation could improve its comprehensibility and overall impact on the reader's understanding.