

Dear Editor,

We sincerely thank the Editor and the two reviewers for taking the time to carefully review our manuscript and for providing thoughtful and constructive feedback. We have carefully considered all comments from all two reviewers and have responded to each point to the best of our abilities. We believe that the revisions have strengthened the manuscript and improved its clarity. A detailed point-by-point response to each comment is provided below.

Kind regards,

Poppy Webb on behalf of all co-authors

Reviewer #1

The paper investigates compound flooding associated with Tropical Cyclone Idai in Mozambique, combining qualitative research based on eight key informant interviews on which are constructed causal-loop diagrams. The quantitative scenarios compare observed land cover (in 2000 and 2020) and climate conditions (with and without anthropogenic climate change), while the qualitative component is used in parallel to identify socio-economic drivers such as charcoal-related deforestation, informal urban expansion, poverty, and limited government capacity, as drivers of the flood risk.

The paper currently conflates flood-hazard attribution with impact attribution. The quantitative model estimates changes in flood depth, extent, volume, and discharge under selected counterfactuals; it does not quantify changes in damages, displacement, affected population, livelihoods, or other societal impacts.

Separately, the qualitative analysis provides interesting (if unsurprising) interpretation, but it is not integrated at all into the quantitative estimates; the two parts are not integrated but are conducted in parallel, ostensibly to shed light on each other, but with little evidence of that.

Maybe most importantly, the paper compares the actual impact of the storm against three counterfactuals: (1) without climate change; (2) with 2000 LULC rather than 2020 LULC; (3) combining (1) and (2). Counterfactual (1) was already investigated in a previous paper by some of the same authors; (2) is possibly interesting but has nothing to do with attribution or climate change; and the relevance of this is not very clear, as we don't really know much about impacts (see comment below); and it is not entirely clear why (3) is an interesting question. Clearly, if the changes in LULC made the flooding more severe, they would have made the attributable flooding more severe as well. Why the question which one is more important is a worthwhile question to ask is not made clear at all. I think the reader deserves to know that. This is not, as far as I can tell, a policy-relevant question, so what is it useful for?

Response: We thank the reviewer for their thoughtful comments. We agree that our analysis attributes changes in flood hazard rather than flood impacts. While event attribution studies typically do not extend beyond meteorological drivers of extreme weather events, in our study we analyze how the compound flood, which was the primary driver of impacts, was affected by both climate change and land cover change. We agree that it is important to clearly distinguish between climate, hazard, and impact attribution, and we will therefore revise the title and rephrase sections of the introduction, discussion, and conclusion to make these distinctions more explicit:

- We have revised the title by removing the 'Impact' of the attribution. We acknowledge this paper is framed at making advances towards a broader concept of impact attribution but given that we do not actually quantify the impacts, the title simply refers to a 'Attribution', to avoid confusion.

- In the second paragraph of the Introduction, we define the differences between impact, climate and, hazard attribution- more appropriate to our study yet not formally defined. We have added: *“Impact attribution, an evolving concept within attribution science, aims to quantify the extent to which observed social or economic impacts from an extreme event are attributable to climate change (Hope et al., 2022)-This differs to climate attribution which quantifies the effect of climate change on the likelihood or intensity of the meteorological drivers of an extreme event (Hergel et al., 2010). Hazard attribution, although not yet formally defined, represents an intermediate step between climate and impact attribution by extending attribution to the resulting hazard, but not to exposure or vulnerability.” (L47-51).*
- In the discussion we have tightened the clarity of these terms. For example, in Section 4.2 ‘Implications towards mixed-method storyline attribution’ we clearly define the limits and scope of our analyses that we do not quantify the impacts from the compound flood hazard. In this paragraph it is now clearly stated for example that *“We demonstrate a proof of concept, that in data scarce regions, where it is difficult to fully quantify impacts, it is possible and highly feasible to integrate qualitative methods to gain a greater understanding of drivers of impacts and produce more policy-relevant insights (Jack., 2025; Grant et al., 2015). Within the rapidly evolving field of impact attribution (Perkins-Kirkpatrick et al., 2024), this research shows how integrating qualitative causal mapping with quantitative modelling provides a practical pathway for advancing impact attribution where observational data are limited.” (L420-422).*
- In the conclusion, we focus our narrative on the feasibility and benefits of a mixed method approach towards impact attribution, and the added value of integrating qualitative methods to contextualise quantitative modelled results. *“Our study exposed under-discussed but crucial drivers of the impacts of TC Idai such as that of charcoal driven deforestation and informal urban land conversions. Whilst the hydrodynamic modelling showed that land-use changes can amplify the flood hazard, the qualitative analysis contextualised the model results and revealed important socioeconomic drivers of this same hazard. By employing a mixed-method approach, our analysis highlights that TC Idai’s impacts were not only the result of the intense climatic hazards but also amplified by socio-economic drivers.” (L480-485).*

The reviewer is also correct that the quantitative and qualitative components of the study are not fully integrated. The main purpose of the qualitative analysis is to provide contextual information about tropical cyclone Idai and its drivers and consequences. This information informed the development of counterfactual scenarios and provides an important basis for interpreting the attribution results. In response to this comment, we have revised Figure 1 (see below) to more clearly illustrate the link between the quantitative and qualitative components of this study, specifically how the KIIs informed the construction of scenarios and modelling choices, and how the CLD helps placing the attribution statement in the appropriate context. We will clarify these links throughout the manuscript.

Finally, we would like to further elaborate on the relevance of attributing changes in LULC. Understanding the relative contributions of climatic and non-climatic drivers is essential for placing attribution results in a decision-making context. Climate change does not occur in isolation. While climate change may alter the probability or magnitude of hazards, land cover change and other societal factors can substantially influence the resulting hazard and associated impacts. To date, these dynamics are often much more important than the impact of climate change (Sauer et al., 2021; Rogers et al., 2025). Explicitly considering land cover change therefore helps identify opportunities for risk reduction that are within the control of local

and national decision-making. In the case of Idai, this broader perspective helps demonstrate that the impact of Idai, but also future risks, will depend not only on climate change, but also on societal and environmental changes that shape exposure and vulnerability.

Major Comments

1. Reframe or substantiate the claim of impact attribution

The title, abstract, and discussion frame the paper as an impact-attribution study. Yet the quantitative results are flood-hazard results: maximum flood depth, flood volume, flood extent, and discharge responses under climate and LULC counterfactuals. These are important hazard metrics, but they are not socio-economic, cultural, or environmental impact metrics. The qualitative interviews identify mechanisms of vulnerability and exposure, but the manuscript does not propagate the modelled hazard changes through exposed population, exposed assets, displacement caused, livelihoods lost, or damage experienced.

This matters because the strongest conclusion in the manuscript is that LULC changes amplified the impacts of TC Idai. The evidence supports the more cautious claim that LULC changes plausibly affected vulnerability/exposure (though this is not investigated) and that LULC changes modified flood hazard locally. We still don't know if impacts were amplified.

I would further recommend to use the terms hazard, exposure, vulnerability, risk, and impact consistently throughout the manuscript, following the IPCC or UNDRR definitions of these terms (both have glossaries where these are defined).

We agree with the reviewer for this comment and have revised our manuscript accordingly. Although we can extend the framework and compute exposed population or economic damages, for simplicity we decided to limit the analysis to flood hazard. However, as the reviewer points out, we could have made the implication of this choice clearer, and we could have been more cautious with our conclusions. In the revised manuscript, we now make a clear distinction between climate, hazard, and impact attribution, and we have used the risk terminology more consistently. For example:

- We now clearly defined the scope of our research that we limited our analysis to the flood hazard, and we do not make unjustified claims towards 'impact' attribution. In the Introduction, it now clearly defines the differences between climate, hazard and impact attribution and frame our analysis as hazard attribution:
- In the Introduction we explain that *"Impact attribution, an evolving concept within attribution science, aims to quantify the extent to which observed social or economic impacts from an extreme event are attributable to climate change (Hope et al., 2022). This differs to climate attribution which quantifies the effect of climate change on the likelihood or intensity of the meteorological drivers of an extreme event (Hergel et al., 2010). Hazard attribution, although not yet formally defined, represents an intermediate step between climate and impact attribution by extending attribution to the resulting hazard, but not to exposure or vulnerability"* (L46-51).
- In the methods we explain in greater detail storyline attribution and explain: *"Storyline attribution examines the causality chain through conditional explanations (Shepherd, 2016; Sillmann et al., 2021). This method uses KIs to examine the causality chain beyond LULC, where the quantitative conditional approach (conditioning on TC track) examines the causal chain from driver to hazard. Our objective is not to provide a statistically representative assessment, but rather to demonstrate, as a proof of concept, how key informant interviews (KIs) combined with causal*

loop diagrams (CLDs) can strengthen the development and interpretation of modelling results. (L117-123).

- In the discussion we have clearly stated the implications of limiting our analysis to the flood hazard. For example, *“We recognise that within the scope of this paper, we do not quantify the realized impacts from the compound flood hazard, which would require include exposure and vulnerability data. We demonstrate a proof of concept, that in data scarce regions, where it is difficult to fully quantify impacts, it is possible and highly feasible to integrate qualitative methods to gain a greater understanding of drivers of impacts and produce more policy-relevant insights (Jack., 2025; Grant et al., 2015). Within the rapidly evolving field of impact attribution (Perkins-Kirkpatrick et al., 2024), this research shows how integrating qualitative causal mapping with quantitative modelling provides a practical pathway for advancing impact attribution where observational data are limited.” (L420-427).*

2. The LULC counterfactual requires stronger justification and sensitivity testing

The study uses a 2020 LULC map to represent factual conditions during TC Idai, which occurred in March 2019, and a 2000 LULC map as the counterfactual. This choice is driven by data availability, but it is a potential weakness of the paper. The 2020 map may include post-Idai land-cover changes, storm damage, reconstruction, or recovery signals; it is difficult to believe that such a big event did not lead to significant LULC changes. The 2000 map represents a historical landscape in an arbitrary point in time rather than a clearly defined counterfactual based on policy changes, demographic shifts, or any other change related to this exact timing.

The manuscript also attributes observed LULC changes to socio-economic drivers identified in interviews. That is plausible, but the causal link between the mapped 2000-2020 land-cover changes and the interview-derived drivers is not established (other than by the claims from the 8 KIIs). The higher resolution is used to justify the 2000-2020 choice, but this decision involves a significant trade-off. Is it possible to use remote sensing products to construct LULC maps that would be better timed (and many higher frequency), even if they will be less spatially detailed.

We acknowledge the potential weakness of using the 2020 LULC map and possibility that this map may include post-Idai land-cover changes.

It is possible to construct LULC maps from 2019 Landsat imagery using remote sensing products, but this was beyond the scope and purpose of this study. For the highest resolution and accuracy maps available, we chose to use the existing maps created by Lisboa et al., (2024). It is possible that the 2020 LULC from Lisboa et al. (2024) dataset includes post-Idai LULC changes. Charrua et al. (2021) found a decrease in dense vegetation by 59% following the cyclone in the most damaged areas, and therefore it is likely that the 2020 dataset includes some of these changes.

All different LULC datasets classify satellite imagery using different methods and classify land cover into different classes, and therefore it is difficult to compare pre-existing LULC maps from 2019 and 2020 (both world cover LULC datasets and localized studies such as Charrua et al. (2021) and Lisboa et al. 2024). It was beyond the scope and purpose of the study to conduct our own LULC classification. In addition, Charrua et al. (2021) found that the intensity of damage to different vegetation classes is closely related to their physiognomy and distance to Idai's trajectory. An intense cyclone like Idai caused significant damage to dense vegetation, wetland vegetation due to great defoliation, branch stripping, affecting the condition of the vegetation (Charrua et al., 2021), but may have not changed the broad LULC classes used in the model. We therefore assume that the 2020 classification is unlikely to misrepresent the broader hydrological land-

cover distribution at the time of the event, and that the use of the 2020 dataset as our factual is valid for the main purpose of our study. These assumptions have now been made explicit in the Methods:

- *“We use the LULC map of 2020 to represent the factual conditions during TC Idai, which occurred in 2019. We recognize that using the 2020 LULC map may include post-Idai land cover changes. Whilst it is possible to construct LULC maps from 2019 Landsat imagery using remote sensing products, this was beyond the scope and purpose of this study. With a 30m resolution, we chose to use the existing maps created by Lisboa et al., (2024), that have a higher resolution and accuracy than global datasets. An intense cyclone like Idai caused significant damage to dense vegetation, wetland vegetation due to great defoliation, branch stripping, affecting the condition of the vegetation (Charrua et al., 2021), but may have not changed the broad LULC classes used in the model. We therefore assume that the 2020 classification is unlikely to misrepresent the broader hydrological land-cover distribution at the time of the event, and that the use of the 2020 dataset as our factual is valid for the main purpose of our study. The choice to use the Lisboa et al. (2024) dataset is intended to represent the broad scale, accumulated land-cover changes over the last two decades, not the one-year affect post TC Idai. We use the LULC map of 2000 as a counterfactual scenario and represents the situation before extensive socio-economic development of the region in the last two decades, as revealed through a literature review at the beginning of this research. We recognize the limitation of this assumption and highlight future research possibilities in the Section 4.3.” (L187-199).*

In addition, it is likely that both direct and indirect LULC changes from Idai (longer term vegetation decline or human activities like forest degradation from charcoal burning) may not be as prominent in the 2020 dataset but have continued to have implications on LULC change since 2020. Post-Idai land cover changes would be interesting to investigate, especially following the results from our qualitative analysis, but was not the purpose of this study. We have added this limitation explicitly and future research suggestion in the Discussion as follows:

Following the results from our qualitative analysis, it would be interesting to quantify post-Idai LULC changes, both direct and indirect (such as longer-term vegetation decline or human activities like forest degradation from charcoal burning) and their implications on LULC change since 2020.

- *“A major limitation is using the Lisboa et al. (2024) 2020 landcover dataset, as the ‘factual’ dataset for 2019. This landcover map therefore is likely to include LULC changes from TC Idai itself or in the recovery period after (Charrua et al., 2021)”.* (L437-439)
- *“Following the results from our qualitative analysis, it would be interesting to quantify post-Idai LULC changes, both direct and indirect (such as longer-term vegetation decline or human activities like forest degradation from charcoal burning) and their implications on LULC change since 2020.”* (L466-468)

The choice to use the Lisboa et al. (2024) dataset is intended to represent accumulated land-cover changes over the last two decades, not the one-year affect post TC Idai. The year 2000 may to some degree represent an arbitrary point in time, but we used this Lisboa et al. (2024) dataset as the best available dataset to represent broad scale changes. A thorough literature review at the beginning of this research revealed extensive demographic shifts in this region since 2000, and therefore this dataset captures this wider pattern.

The major LULC transitions identified between 2000 and 2020 represent longer-term changes, particularly the conversion from forest to cropland. We interpret the 2020 LULC map as an approximation to the pre-Idai LULC state and acknowledge this temporal mismatch as a source of uncertainty. We have highlighted this limitation within our study in both the methods and discussion.

- For example, in the discussion it now states: “*We interpret the 2020 LULC map as an approximation to the pre-Idai LULC state and acknowledge this temporal mismatch as a source of uncertainty*” (L439-441-).

Reference:

Charrua, A. B., Padmanaban, R., Cabral, P., Bandeira, S., & Romeiras, M. M. (2021). Impacts of the Tropical Cyclone Idai in Mozambique: A Multi-Temporal Landsat Satellite Imagery Analysis. *Remote Sensing*, 13(2), 201. <https://doi.org/10.3390/rs13020201>

3. The hydrological interpretation of LULC effects needs more explanation

I wasn't able to follow the hydrological modelling (I am not a hydrologist), but since this is based on a previous paper, and there is nothing new here, maybe this is not an issue.

We indeed use the same modelling framework as in related work (Vertegaal et al., 2026). As such, we focus on the parts of the hydrological modelling that are not covered by other studies.

References:

Vertegaal, D. M., van den Hurk, B. J. J. M., Couasnon, A., Aleksandrova, N., Bovenschen, T., Gradiyanto, F., Leijnse, T. W. B., Goulart, H. M. D., and Muis, S.: Climate and impact attribution of compound flooding induced by tropical cyclone Idai in Mozambique, *Nat. Hazards Earth Syst. Sci.*, 26, 1417–1433, <https://doi.org/10.5194/nhess-26-1417-2026>, 2026.

4. The qualitative component needs more methodological transparency

The qualitative strand is central to the claimed contribution of the paper (since the quantitative part is very similar to the previous paper published in the same journal). The authors acknowledge the limited number of key informants and the lack of local community and government perspectives. That limitation is important because the paper makes claims about poverty, charcoal livelihoods, informal settlement dynamics, urban planning, and humanitarian access. The paper should make clearer which claims are based on direct interview evidence, which are supported by the literature, and which are interpretive syntheses by the authors.

I would probably also argue that using only 8 KII, neither of them, as far as I can tell, a resident of the affected area, and all of them with limited experience there (and possibly even limited experience in Mozambique) is a significant weakness, even if it is acknowledged. Why not increase the number and variety of KIIs?

The text of the paper should also mention whether the research received ethics approval (or did the authors decide one is not required for the KIIs interviews).

In response to this comment, we more carefully phrased our results, clarifying how certain claims are derived. Specifically, we rephrased in Section 3.2 to ensure that all claims and sentences made are referenced by either the KII or literature sources. In Section 3.2, literature references and corresponding interview references have been added to ensure clarity on how all claims are derived. Changes such as the following were made throughout this section (modified text is underscored):

- Sect. 3.2: *“Figure 3 shows the CLD that synthesizes the dominant causal mechanisms and feedback loops, interpreted by the author from direct KI evidence and supported by available literature.” (L242-245)*
- *“This rural feedback is further intensified by urban demand (see the blue lines in Fig. 3). As found by Sedano et al. (2016), and explained by KI8, growing urban populations, such as cities such as Beira, sustains the demand for charcoal that drives continued deforestation upstream.” (L326-328)*
- *“The displacement of urban agricultural practices also reduces food security, and livelihood diversification (Shannon et al., 2021), thereby as KI1 made the link increasing socio-economic vulnerabilities, and heighten future flooding impacts”. (L335-337)*

While the inclusion of eight key informants (KIs) may appear limited, we consider this number sufficient for the purpose of this study. The KIs were carefully selected based on their expertise and knowledge of the region. Our objective is not to provide a statistically representative assessment, but rather to demonstrate, as a proof of concept, how key informant interviews (KIIs) combined with causal loop diagrams (CLDs) can strengthen the development and interpretation of modelling results. We acknowledge that none of the KIs were residents in the area affected. This was a limitation of conducting this analysis remotely without field research. The 8 KIs selected all had considerable experience and insights for the context of this analysis. The aim is to develop and showcase a proof of concept and the value of integrating qualitative information in storyline attribution analysis, which has been made explicit as follows:

- Introduction: *“We use eight KIs, as a proof of concept, ranging from disaster risk reduction practitioners, researchers to humanitarian aid workers, all with experience in Beira, pre- and/or post-TC Idai.” (L104-106)*
- Abstract: *“By combining the attribution of hazard drivers with qualitative localized contextual information of impact drivers, this paper demonstrates a proof of concept to mixed-method attribution in data-scarce settings.” (L24-26)*
- Discussion: *‘In our study, we use a storyline attribution approach to generate climate change and LULC counterfactuals, that are supported through a qualitative analysis.’ (L375-277).*
- Discussion: *“We demonstrate a proof of concept, that in data scarce regions, where it is difficult to fully quantify impacts, it is possible and highly feasible to integrate qualitative methods to gain a greater understanding of drivers of impacts and produce more policy-relevant insights (Jack., 2025; Grant et al., 2015).” (L420-424)*
- Discussion: *‘The integration of local contextual insights with quantitative modelling, enabled us to interpret the quantitative results and identify socio-economic drivers and their interactions that likely contributed to the experienced cascade of impacts associated with TC Idai. (L386-388).*
- Conclusion: *“By combining quantitative hydrodynamic modelling with qualitative methods, we demonstrate a proof of concept for how storyline attribution analyses can use a mixed-methods approach.” (L474--477)*

The impacts of disasters are strongly shaped by their social context, including pre-existing vulnerabilities, governance structures, and risk management practices. These factors and their dynamic interactions are difficult to capture using quantitative methods alone. Despite the clear potential of mixed-method approaches to address these complexities, such approaches remain uncommon in peer-reviewed attribution studies. This study provides an example of how quantitative modelling can be complemented with qualitative insights in a data-poor context. We do not expect that including additional KIs would substantially change the main conclusions of the study.

In response to the comment regarding an ethics approval, the research was undertaken within the VU Amsterdam research ethical guidelines.