

Reviewer #2

This manuscript investigates how climate change, land-use/land-cover change, and underlying socio-economic processes influenced compound flooding during TC Idai in Mozambique using a mixed-method approach. The manuscript would benefit from a clearer distinction between flood-hazard attribution and impact attribution, as the quantitative analysis estimates changes in flood depth, and extent. However, it does not quantify impacts through exposure and vulnerability analysis. The integration between the qualitative and quantitative components should also be explained more explicitly. These revisions would strengthen the methodological part and interpretation of the results. I therefore recommend major revisions before the paper can be considered for publication.

We thank the reviewer for their useful and thoughtful comments. We have made changes throughout the manuscript to distinguish with greater clarity the difference between flood-hazard attribution and impact attribution, particularly in Introduction and the Discussion. For example, in the Introduction we have now clearly made the distinction between impact attribution and flood-hazard attribution: *‘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 (Hegerl 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)

We chose in our analysis to attribute changes in flood hazard, rather than changes in flood impacts, and therefore we have explained this with greater clarity for example in the Discussion section:

- *“We recognize that within the scope of this paper, we do not quantify the realized impacts from the compound flood hazard, which would require 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).”*(L419-422)

We have updated Figure 1 (Page 5) and have explained more explicitly the link between the qualitative and quantitative components. Specifically, we explain how the KIs informed the construction of scenarios and modelling choices, and how the CLD helps place the attribution statement in the appropriate context. We have clarified these links throughout the manuscript.

- *“This methodology illustrates how the qualitative approach using KIs and causal mapping (Section 2.1) informed the construction of the scenarios used in the compound flood modelling chain (Section 2.2). The causal loop diagram also helped place the attribution analysis in context, contributing to the overall storyline attribution analysis.”* (L114-116)

We hope that these revisions will provide greater clarity to the interpretation of the results.

Introduction

1. The definition of compound flooding in terms of fluvial, pluvial and coastal flooding is appropriate for the focus of this study. However, I wonder whether it would be useful to briefly clarify at this point that these represent the flooding-related drivers considered in the study, rather than the complete set of physical hazards associated with a tropical cyclone. TC Idai also involved strong winds, as the authors themselves acknowledge later in the Introduction (lines 74-76). Previous studies on tropical cyclones in Mozambique, including TC Idai, have shown that wind and flooding may contribute differently to direct and indirect impacts (e.g. Mühlhofer et al., 2023; Espejo et al., 2025). A short clarification here would help distinguish the broader physical drivers of TC impacts from the specific compound-flooding processes investigated in this study, without changing the scope of the analysis.

References

Espejo GG, Stalhandske Z, Mühlhofer E, Rösli T, Brönnimann S, Bresch DN and Zischg AP (2025) From hazard to disruption: forecasting direct and indirect tropical cyclone impacts on infrastructure in Mozambique. *Front. Clim.* 7:1666586. doi: 10.3389/fclim.2025.1666586

Link: <https://www.frontiersin.org/journals/climate/articles/10.3389/fclim.2025.1666586/full>

Link:

https://scholar.google.com/citations?view_op=view_citation&hl=en&user=2TrzxOQAAAAJ&citation_for_view=2TrzxOQAAAAJ:eQOLeE2rZwMC

We agree with this comment and made revisions accordingly. Specifically, we have adjusted the introduction (lines 102) and have added these suggested references:

“Whilst TC Idai also involved very strong winds (Espejo et al., 2025; Mühlhofer et al., 2023), we focus specifically the compound flooding processes.” (L96-97)

2. In line 69 in the introduction. There is a typo error probably. “This can be achieved by using a mixed-method approach that combines qualitative and qualitative methods”. Is it maybe quantitative?

Indeed, yes, this is amended.

Methods

The quantitative framework itself is clear: The combination of KIs/causal mapping with a SFINCS- workflow compound-flood chain and four factual/counterfactual scenarios. But I see the following points worth checking.

3. In Section 2.2.2, the authors describe the use of the 30 m Lisboa et al. (2024) LULC dataset and use the 2020 map to represent factual land-cover conditions for TC Idai, which occurred in 2019. I assume this choice is related to the lack of a comparable regional dataset at that resolution for 2019. However, the current description raises some questions, since the objective is to represent land-cover conditions before the TC Idai 2019. Could the authors clarify why the 2020 dataset is considered representative of conditions

during TC Idai, and whether land-cover changes between March 2019 and 2020, including changes caused by Idai itself or post-event recovery/reconstruction, could affect the factual scenario?

The manuscript also states that the Lisboa et al. dataset was “minorly” merged with the 2019 Buchhorn et al. global LULC product to cover the full model domain. Could the authors clarify which parts of the domain required for this additional dataset and approximately what proportion of the model area it represents? If feasible, a brief sensitivity check comparing the results with and without this merged area would help demonstrate whether the merging has a significant influence on the results and would support the statement that the merge is minor.

The 2020 dataset was considered the closest available representation of 2019 conditions. We acknowledge there is a mismatch and the possibility the 2020 dataset may include changes by Idai itself or post-event activities. The purpose of using the Lisboa et al. (2024) dataset was to highlight the broad-scale LULC changes over the 20 years 2000 to 2020, for example the conversion of forest land to cropland. It was beyond the scope of this analysis to conduct our own LULC classification of satellite imagery, and therefore we chose the dataset to represent with greatest accuracy broad-scale LULC changes.

Land-changes occurring post-Idai were identified by Charrua et al. (2021) and therefore are likely to affect the factual scenario. We do not dismiss this claim and have highlighted these limitations with greater clarity in Discussion. However, due to differences in classification methods of different datasets, it is difficult to quantify and truly identify the extent to which the 2020 dataset we used may include post-Idai LULC changes. It is highly probable that damage to vegetation from TC Idai will have damaged the vegetation condition but not necessarily changed the classification of the LULC class used in the maps. We acknowledge these limitations in the data resolution and highlight the purpose of this analysis is to use the 2020 dataset as an approximation of the 2019 conditions.

- In the methods we now explicitly state *“We use the LULC map of 2020 to represent the factual conditions during TC Idai, which occurred in 2019. We recognize the limitation 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.” (L184-196).*

In response to the comment regarding the merging of the Lisboa et al. land use land cover (LULC) dataset with the 2019 global LULC product (here referred to as Vito), we have performed an additional sensitivity analysis using the European Space Agency (ESA) Worldcover global land cover dataset (Zanaga et al., 2021) instead (Figures R1-4 below). Merging with an additional LULC product is necessary to ensure complete coverage of the hydrological model domain and to correctly represent the catchment boundaries (Figure R1a). The area covered by the supplementary dataset represents 24.8% of the model domain and is indicated by the hatched region in Figure 2 of the submitted manuscript. Figures R1b-c show the land use maps resulting from merging the Lisboa dataset with the Vito and ESA products, respectively.

The sensitivity analysis indicates that the choice of supplementary LULC dataset has only a minor influence on the simulated discharge (Gauge 1 and 3, most affected by the merged area, and flood depths (Figures R2-R3), with the largest differences observed at gauges 1 and 3. These differences are substantially smaller than those associated with the LULC change between 2000 and 2020. We therefore conclude that the model results are largely insensitive to the choice of supplementary dataset and that the merging procedure is justified. Moreover, any residual differences are effectively cancelled when comparing the factual and counterfactual scenarios, as both use the same supplementary LULC dataset. Using the Vito dataset, which is adopted in the manuscript, produces slightly lower flood depths than the ESA-based merge (Figure R3c), making our results marginally more conservative. The locations of the wflow gauges used to force the flood model are shown in Figure R4.

Reference:

- Zanaga, D., Van De Kerchove, R., De Keersmaecker, W., Souverijns, N., Brockmann, C., Quast, R., Wevers, J., Grosu, A., Paccini, A., Vergnaud, S., Cartus, O., Santoro, M., Fritz, S., Georgieva, I., Lesiv, M., Carter, S., Herold, M., Li, L., Tsendbazar, N.-E., ... Arino, O. (2021). *ESA WorldCover 10 m 2020 v100 (Version v100) [Dataset]*. Zenodo. <https://doi.org/10.5281/zenodo.5571936>

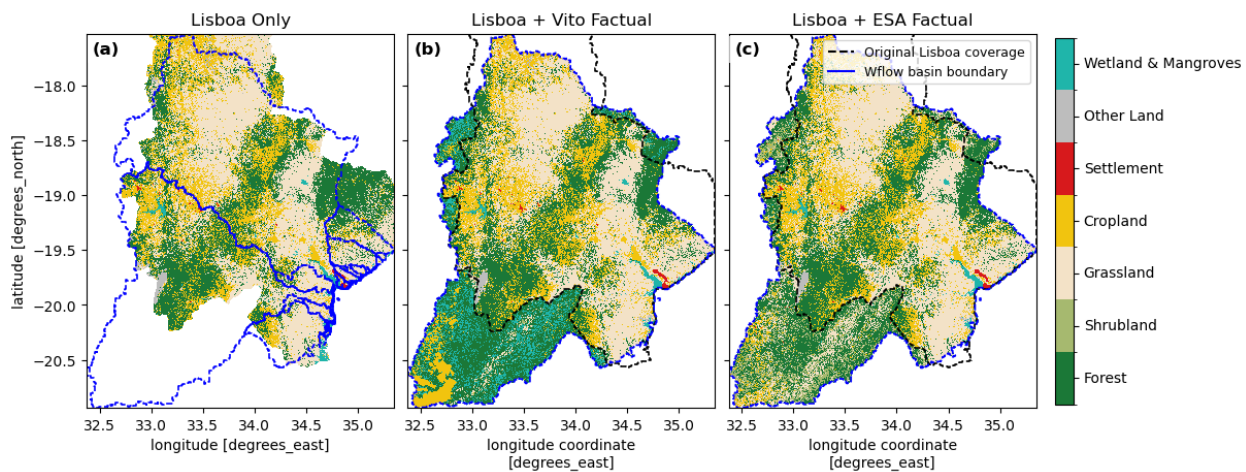


Figure R1: Maps of the Factual Lisboa land use map for 2020 (a) merged with Vito (b) and Esa Worldcover (c) for the missing land use data in the wflow domain that aligns with the upstream catchment of our flood model area. The Lisboa dataset coverage is outlined in a black dashed line and the wflow basin boundary in a blue dashed line (showing all basins in panel a).

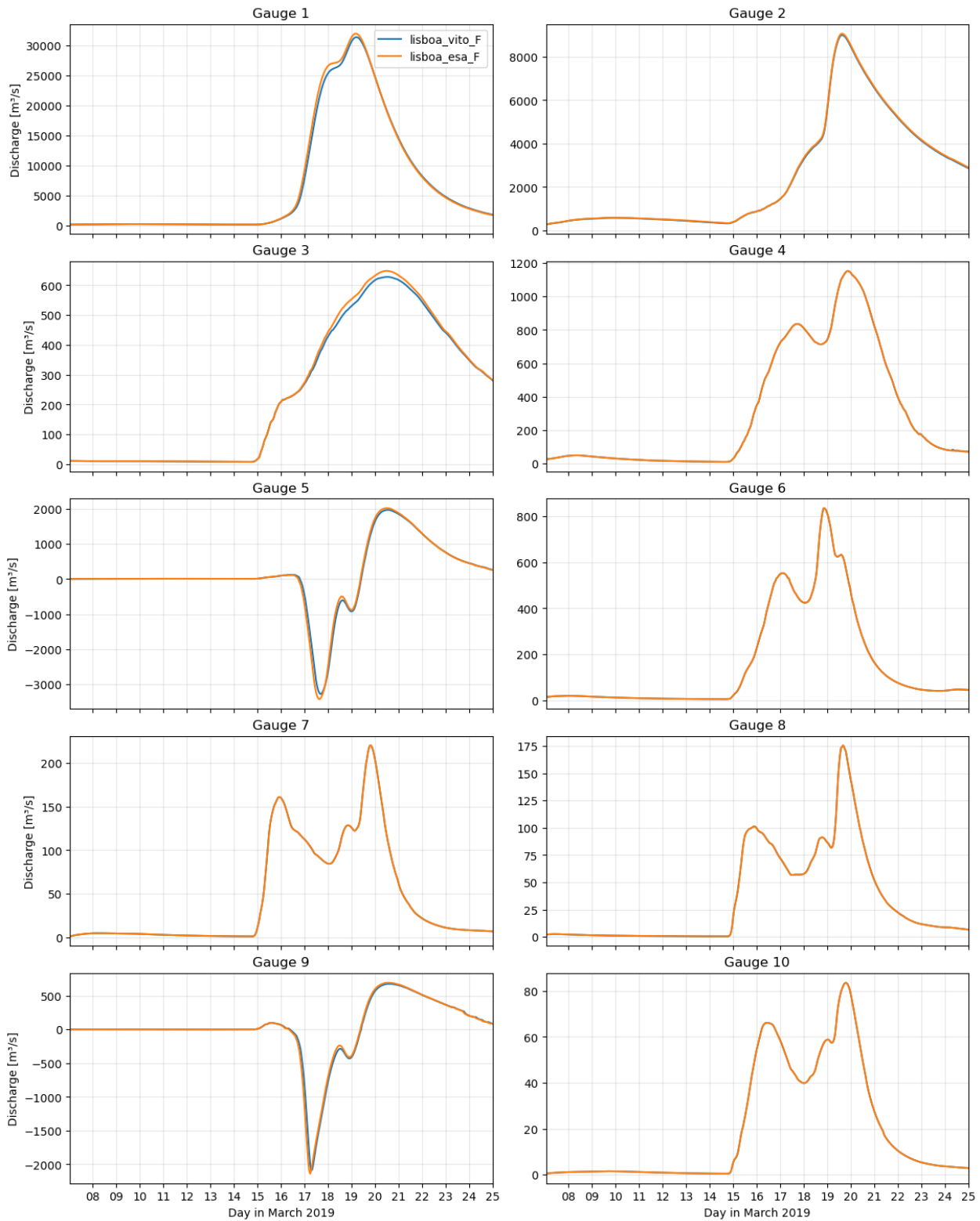


Figure R2: Modelled discharge during TC Idai for different wflow gauges, which flow into the flood model. The modelled discharge uses Lisboa 2020 merged with Vito (blue) or Lisboa 2020 merged with ESA Woldcover as land use dataset (orange). Location of the different gauges can be found in Figure R4.

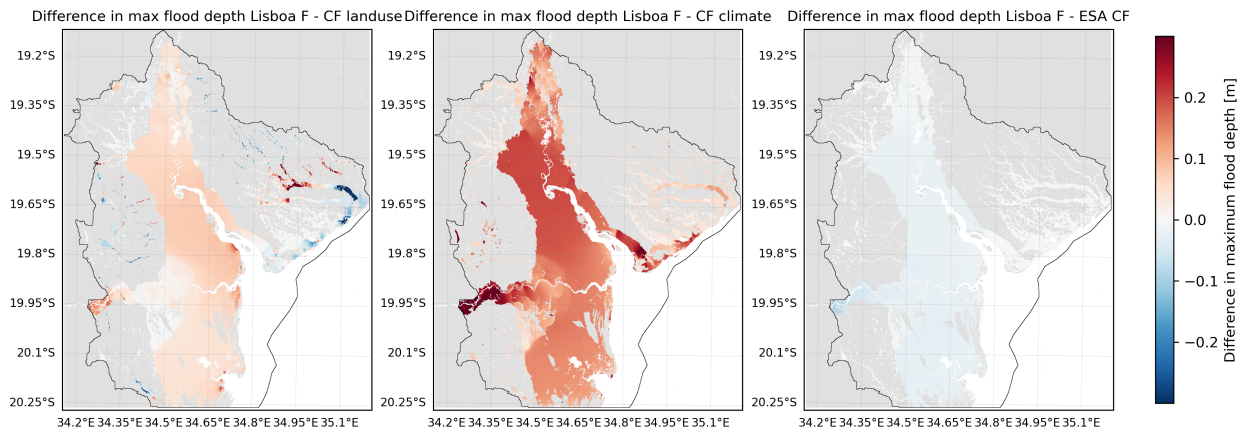


Figure R3: Maps showing the difference in maximum flood depth between the factual and counterfactual land use and climate change scenarios, between the factual (Lisboa merged with vito) and factual merged with esa worldcover land use dataset.

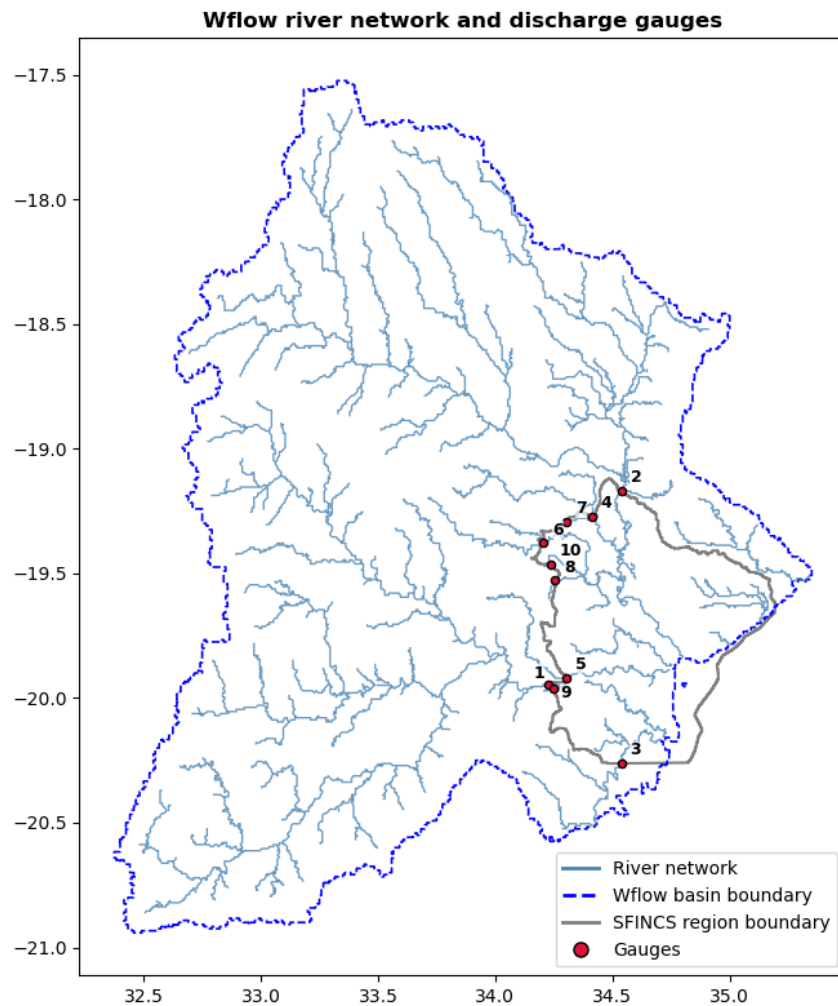


Figure R4: Overview of the wflow and flood (SFINCS) model boundaries in dashed blue and grey, respectively, including the river network and gauge locations.

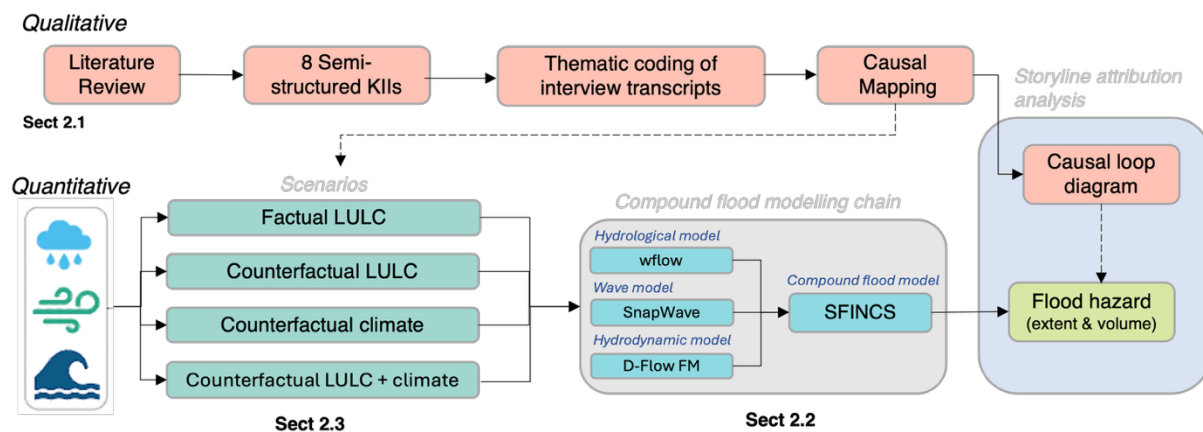
4. After line 105 the Figure1; I suggest reviewing it and modified

Figure 1 may be slightly misleading in the way the qualitative and quantitative components are linked. The arrow from the causal loop diagram directly to “Flood hazard (extent & volume)” suggests that the qualitative analysis is used as an input to the flood-hazard calculation. However, as I understand the methodology, the quantitative modelling chain assesses how the LULC and climate scenarios influence flood hazard, while the KIIs and CLD are used to identify and interpret the socio-economic drivers underlying the observed LULC changes.

I therefore suggest revising Figure 1 or adding a complementary schematic to make the sequence of the mixed-method approach clearer. For example, were the KIIs conducted and analyzed first to develop the CLD, and was the CLD then used to interpret the observed differences between the 2000 and 2020 LULC maps? Or were the LULC changes identified first and then used to guide the qualitative analysis? Clarifying this sequence would help the reader understand how the two components are integrated and avoid the impression that the CLD directly feeds into the quantitative flood model.

Explain it for steps maybe to understand the sequence.

Thank you for these constructive comments. We have revised Figure 1 by removing the inaccurate line that went directly from the ‘Causal loop diagram’ to the ‘Flood hazard’ box. We have added two dashed lines to represent the integration of the qualitative information both in the construction of the scenarios, and in complimenting the analysis of the storyline attribution of the flood hazard. The dashed lines are used to represent the more interpreted links between the qualitative and quantitative methods. The box ‘Storyline attribution analysis’ was added to around the ‘flood hazard’ to represent the integration of the qualitative insights from the causal loop diagram with the attributed flood hazard information.



5. Figure 4 effectively shows the spatial differences in maximum flood depth between the factual and counterfactual scenarios. However, the interpretation of the positive and negative differences, particularly in the LULC-change panel, could be explained more explicitly in the text. For example, it would be useful to clarify why some areas experience increased flood depth while others show decreases under the factual LULC scenario, and to relate these spatial patterns to the main LULC transitions identified earlier (e.g.

deforestation, cropland expansion, urbanization or reforestation). This would help connect the mapped differences more directly to the physical mechanisms discussed in the study.

For example:

Please clarify the physical mechanism proposed for the local decrease in flood depth northwest of Beira. The statement that reforestation reduces land-cover roughness and therefore decreases water velocity appears counterintuitive. Could you please review it. Is right the description?

We thank the reviewer for pointing out this counterintuitive statement and agree this was an error. We have reviewed the text associated with Figure 4, and made the following revision:

- *“In the area Northeast of Beira, Figure 4 (panels a and b) shows a local decrease in flood depth (shown in blue). This can be linked to local reforestation (Figure 2), resulting in increased surface roughness, and therefore decreased water velocity that potentially corresponds to the localised reduction in flood depth.” (L360-365)*

6. In line 260 there is a part to edit maybe: of “socioeconomic deprivation ... was. Those points

Amended.

7. Section: Impacts of changes in climate and LULC on flood hazard.

The combined climate + LULC scenario results in a 12% increase in flood volume, compared with 9% and 2% for the individual effects. Could the authors clarify whether this difference is due to rounding?

The effect is not due to rounding but due to non-linear effects.

8. In lines 377–382, the manuscript refers to assessing impacts and integrating exposure and vulnerability. However, these components are identified qualitatively rather than quantitatively assessed. I suggest using more cautious wording and clearly distinguishing flood-hazard attribution from qualitative interpretation of exposure, vulnerability, and socio-economic drivers. If the authors wish to claim impact assessment more explicitly, this could be strengthened in future work by combining the hazard results with exposure data such as buildings, population, or crops.

I am referring to this part: “We combine a quantitative attribution framework with KIIIs visualised in a CLD to assess cascading drivers, impacts, their interactions and consequently reinforcing socio-economic feedback cycles in rural and urban areas. We propose a mixed-methods approach to truly understand real-world impacts and identify drivers of vulnerability and exposure for compound flooding after TC Idai. By doing so, we consider all risk components (Simpson et al., 2021), particularly integrating exposure and vulnerability as they drive the experienced impacts”

We agree with the reviewer that our attribution analysis does not fully include exposure and vulnerability. Therefore, we have made the following revisions:

10. The dataset referenced at <https://doi.org/10.5281/zenodo.19328562> could not be accessed. Please check that all the data is available and code. You could add also add the repository in GitHub for the modelling chain, as it is open source so far I understand.

We find it important that our work is reproducible and have checked the link and ensures all data and code is openly available. The zenodo link actually links to a specific release on GitHub of our modelling chain. The correct Zenodo link has now been added: <https://doi.org/10.5281/zenodo.20505361>.