Reply to Reviewer 3 comments:

We would like to mention that the line numbers now mentioned in the comments are the new line numbers after revising the text.

Title: Increasing flood risk in the Indian Ganga Basin: A perspective from the night-time lights

This study assessed the flood hazard, exposure, vulnerability and risk level of the Indian Ganga Basin based on a multi-criteria risk assessment methodology (hierarchical analysis) using selected hazard, exposure and vulnerability assessment indicators. The novelty of the study lies in using night-time lights as a proxy for exposure within the basin, unlike the conventional population data.

I have a few comments/questions:

- The abstract section of the manuscript is illogical and lengthy. For example, the innovation of the paper is highlighted twice in the beginning and the end of the abstract. It is recommended that the authors rewrite the abstract section according to research background, methods and content, results, validation, innovativeness and application value.

  Thank you for the feedback. We have rewritten the abstract as suggested. The new abstract is –

  "Floods in the Ganga Basin, one of India's most densely populated and geomorphologically dynamic regions, have intensified in frequency and severity due to changing climatic regimes, extreme rainfall events, and rapid land-use transformations. Understanding the spatial and temporal evolution of flood risk—arising from the interaction between hazard, exposure, and vulnerability—is critical for evidence-based risk management.

  Here, we present a spatially explicit flood risk assessment using the Analytical Hierarchy Process (AHP), which is a Multi-Criteria Decision Making (MCDM) model. The methodology integrates remote sensing and geospatial datasets to map flood risk using flood hazard and vulnerability, while introducing a novel exposure metric based on NASA's Black Marble Nighttime Lights (NTL) data. Unlike traditional demographic proxies, the NTL dataset captures temporally resolved patterns of human presence and economic activity, enabling dynamic representation of exposure at large spatial scales.

  Our results indicate a marked escalation in flood risk across the eastern Ganga Basin, with high-risk zones concentrated in Bihar, eastern Uttar Pradesh, eastern Madhya Pradesh, and northern West Bengal. Validation against historical flood impact data from the EM-DAT and GDIS databases yields an accuracy of ~70%, underscoring the model's robustness. The analysis reveals increasing human exposure and shifts in rainfall intensity as dominant drivers of emerging flood risk hotspots. This study leverages the temporal availability of the data, enabling a real-time distribution of human activities at a large scale and with greater temporal resolution.

  This study demonstrates the applicability of dynamic, satellite-derived exposure indicators within an established flood risk assessment framework. The approach facilitates scalable, data-driven risk mapping with relevance for anticipatory planning and regional-scale disaster risk reduction across transboundary flood-prone landscapes".

- The confusing use of professional terms such as "flood risk" and "flood susceptibility" means that the professional level of research manuscripts needs to be improved.

  We have carefully clarified the use of the terms flood risk and flood susceptibility, as we have explained above in response to Reviewer 2

- I disagree with the discussion of the superiority of the methodology of this study in lines 652-655 of the manuscript. Accurate flood risk assessment results are obtained by driving a hydrological-hydraulic model to capture flood hazard, and then combining exposure, vulnerability, and the level of prevention and mitigation. The use of multi-criteria methods to assess flood risk levels in this study may be limited by data and technical expertise. Hydrological and hydrodynamic models can simulate the depth and range of flooding and obtain more accurate risk assessment results.

  Lines 652-655: "Our flood risk map of the Ganges basin was developed using an integrated hydrogeological approach and AHP methodology, which is superior to traditional hydrological and hydraulic modelling as it combines physical (geomorphological) criteria with hydrometeorological data. This emphasises a process-based understanding that overcomes the need for intensive hydrological data required for flood hydraulic models (Mishra and Sinha, 2020)".

  We thank the reviewer for this important observation and fully acknowledge the strengths of hydrological and hydrodynamic models in simulating flood depth, extent, and hazard with high precision. We agree that such models are essential tools in flood risk assessment, particularly when high-resolution, long-term hydrological data are available.

  However, as noted in the revised manuscript from lines 107-11*3, "Hydrodynamic Models are a subset of numerical models that simulate the temporal and spatial variation of water flow and are widely used for flood forecasting and inundation mapping (Horritt & Bates, 2002). It requires a variety of input data, including precipitation records, discharge data, and flow depth measurements, which are typically collected via rain gauges, river gauge stations, and hydrological datasets. Many regions lack publicly accessible, consistent, or high-quality rainfall and discharge data. In addition, hydrological station coverage may be sparse. The data gathering can be time-consuming, particularly for large geographic regions, making it impractical within the scope and time constraints of this study."*

  Line 118-126: "Given the above limitations, we adopted a multi-criteria decision-making (MCDM) approach using the Analytic Hierarchy Process (AHP), which allows for the integration of geomorphological, hydrometeorological, and socio-environmental factors. AHP was developed by Saaty (1980) and is one of the widely known approaches for flood risk mapping (Sinha et al, 2008; Chakraborty and Mukhopadhyay, 2019; Ghosh and Kar, 2018; Grozavu, 2017; Huang et al., 2011; Mishra and Sinha, 2020). This approach uses pairwise comparisons to assess the extent to which one factor within the model is more important than the other, thereby producing a weighting for each factor. While we do not claim that this method is universally superior to hydrodynamic modelling, it offers a practical and intuitive framework for flood risk assessment in data-limited contexts. Empirical approaches such as MCDM have been widely used in flood studies and are considered effective when supported by robust spatial datasets and expert judgment (Teng et al., 2017).

  Accordingly, we have revised the original statement in lines 652–655 (original manuscript) to reflect a more balanced and accurate comparison in line 700-703 - *"Our flood risk map of the Ganges basin was developed using an integrated hydrogeological approach and AHP methodology, which offers a practical alternative to traditional hydrological and hydraulic modelling in data-scarce regions. By* *combining physical (geomorphological) criteria with hydrometeorological data, this approach supports a process-based understanding of flood risk where intensive hydrological datasets are unavailable (Mishra and Sinha, 2020).*

We hope this clarification addresses the reviewer's concern and improves the scientific accuracy and objectivity of the manuscript.

- The vulnerability assessment in the study used existing vulnerability products, the reliability of which was not verified. In addition, which indicators considered in the vulnerability assessment were not clearly given.

We thank the reviewer for raising this important point regarding the vulnerability assessment. In our study, the vulnerability component of flood risk was derived from the **Climate Vulnerability Assessment Report- DST 2020**, developed by the **Department of Science and Technology (DST), Government of India**. We have now clarified in the manuscript the indicators used for developing the vulnerability index from lines 240-246. However, the methodological details to evaluate whether the Indian government's vulnerability assessment is or is not fully reliable are beyond the scope of this paper.

- The novelty of the work lies in using night-time lights as a proxy for exposure within the basin, unlike the conventional population data. However, in the flood risk assessment framework based on multi-criteria methods, using night light data instead of population and economic data as an innovation in flood risk assessment seems to be somewhat insufficient for the entire study, but it is acceptable.

In flood risk assessment, research innovation would be more prominent if hazard assessment used flood inundation information obtained based on remote sensing data, while taking into account changes in flood vulnerability.

We thank the reviewer for this constructive feedback and for acknowledging the novelty of using night-time lights (NTL) data as a proxy for exposure in flood risk assessment. We agree that integrating flood inundation data derived from remote sensing or hydrodynamic models could further enhance the robustness of hazard assessment. This is indeed a valuable direction for future research, which was also suggested by Reviewer 1.

However, Sentinel-1 SAR data, while effective for flood detection due to its cloud-penetrating capabilities, has limited temporal resolution (typically 12-day revisit period over non-European countries). This makes it challenging to capture short-duration flash flood events unless they coincide with the satellite overpass. Optical datasets (e.g., MODIS, Landsat) provide higher temporal coverage but suffer significantly from cloud cover, especially during monsoon events when flood mapping is most needed. Moreover, mapping potential (rather than past or observed) flood hazard using satellite data would require long-term archival image analysis, which becomes methodologically and computationally intensive, particularly for a large study area (approximately 860,000 km^2). Integrating multiple satellite sources to address temporal and spatial gaps would further increase the complexity and resource demands of the study, which was not feasible within the scope of this research.

Regarding the dynamic nature of vulnerability, we fully agree that incorporating temporal changes in vulnerability would significantly enrich flood risk assessments. However, such an approach would require high-resolution, time-series socio-economic and infrastructural data, which are currently limited in availability and consistency across the study region. We acknowledge this as a promising area for future research and have added a note to this effect in the revised manuscript.

The dynamic trends of flood risk levels should be placed in the results section of the study rather than the discussion section, which should focus on the superiority of using nighttime light data for flood exposure and risk assessment.

We sincerely thank the reviewer for this thoughtful suggestion. We carefully considered the placement of the dynamic trends of flood risk levels during the manuscript development process, including extensive discussions among co-authors. Our rationale for presenting these trends in the Discussion section is that they are not standalone empirical results derived directly from the modelling outputs, but rather an interpretive synthesis of observed spatial and temporal patterns about socio-environmental dynamics. We intended this section to serve as a bridge between the quantitative results and their broader implications for flood risk management, policy, and exposure assessment.

We explored putting this in the results, but on balance, given this interpretive nature, we believe the **Discussion** section is the most appropriate place for this content. However, we appreciate the reviewer's perspective.