RESPONSE TO COMMENTS (Referee #1)

Integrating SMART principles in Flood Early Warning System Design in the Himalayas (NHESS-2025-2081)

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Dear Editor and Reviewers,

The authors would like to thank the reviewer for their careful review of our manuscript and for providing valuable comments and suggestions, which we found very helpful in improving the manuscript's quality. We have carefully addressed all your comments and integrated your insightful suggestions into the revised manuscript. In the subsequent detailed response, we have addressed each comment individually. Comments are written in red, and our responses follow each comment in black. All the new details added in the manuscript are highlighted as text in italics. We look forward to your positive feedback and hope you will find the revised manuscript satisfactory.

Response to Reviewer 1

1. The paper applies the main concepts of the SMART approach to catchment in the Himalayas, highlighting the relevant role of community participation in addressing the limitations of data-scarce regions and observation-based warning thresholds. To underline the importance of increasing population preparedness in catchments presenting short response times and urban settlements along rivers, the variability of recent hydrological events is investigated. The paper is generally well-organised, and the issue of improving the resilience against floods in catchments characterized by flash floods is worth investigation.

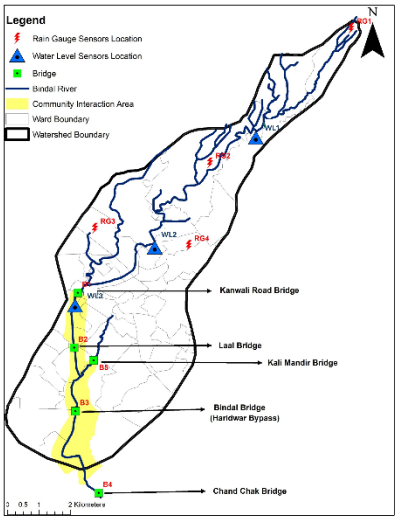
We sincerely thank the reviewer for encouraging comments regarding our application of the SMART approach to flood risk management in the Himalayan catchment. Your affirming remarks motivate us to continue refining and advancing our research in this important area.

2. Figure 1: The shape of the watershed does not correspond with the purple one in the inset. Please check;

Thank you for pointing out this potential source of confusion. The purple shape shown in the inset of Figure 1 represents the Dehradun district boundary, within which the smaller Bindal watershed is located. The main figure displays the detailed boundary of the Bindal watershed, which is a sub-catchment within the district. We have clarified this notation in the figure caption in the manuscript to avoid further confusion

3. Lines 140-144: The authors should include an image to help the reader understand the location of the mentioned stretches

Thank you for your valuable suggestion. The locations of these stretches are shown in Figure 3 of the manuscript, which we are further enhancing by adding additional map features based on suggestions from other reviewers.



We have added Figure 3 and a reference to Figure 3 in lines 140-144 to guide the reader directly to this visual for better understanding.

4. As community engagement is an essential part of the work, I encourage the authors to expand the description of the PRA exercises, further clarifying how their results could be applied within a real-time early warning 4 system. Since EWS typically rely on thresholds based on observed hydrological variables (e.g. water levels), how can community information be incorporated into such chains for prediction purposes? Moreover, it would be interesting to compare the information provided by the participants with that derived from recorded hydrological observations for some events, e.g. by representing on the same map the locations where the most critical flood issues were recorded and remembered. This will further clarify the role of community memories. Finally, since flood perception is often influenced by past flood experiences, it would be interesting to understand if the authors noticed differences in the information provided by the participants according to their age;

Thank you for your observation. We have revised lines 147-159, as follows.

Participatory Rural Appraisal (PRA) exercises (Reddy et al., 2016), along with Focus Group Discussions (FGDs) with concerned community and ward members from the concerned flood-affected colonies, including slums along the four mentioned stretches, were conducted to gather crucial information required to develop early warning systems for the Bindal watershed. The PRA exercises included temporal analysis (such as historical transects, trend diagramming, and seasonal diagramming), spatial analysis (including socio-resource mapping), and relationship analysis (Venn diagrams and Scoring and Ranking). About 20-30 households participated in each of these exercises.

Historical transects documented events related to development (such as the establishment of colonies, roads, public buildings, protection walls, bridges, and sewer lines) along the selected river stretches, tracing back to the last 60 years. Past floods, along with their severity, were also noted. 2006, 2013, and 2018 were recently reported flood years resulting in significant damage. FGDs around the historical transect further helped in understanding the impacts of the above developmental activities on the nature of floods and related losses (riverbank erosion, public and private property loss, and livelihood loss). Trend analysis recorded decadal changes over a 40-year period, which helped examine changes in encroachment, settlement density, rainfall behavior, river base flows, flood frequency, and flood severity, as well as their correlations. For seasonal diagramming, a month-wise matrix was developed with the help of residents to understand seasonal changes with respect to river flow and record peak flows. The peak flows were reported for the period July to September, depending upon rainfall in the upper reaches of the Bindal watershed. The base flow of the river was reported to have decreased in all the stretches over the last four decades. However, the frequency and intensity of floods were reported to have increased during the last two decades.

During FGDs, residents identified the more vulnerable sites within concerned colonies and most affected households and structures based on experiences of previous floods. Bank erosion during floods resulted in damage to public and private property. Lohiya Nagar and Mehboob Colony (located on the right bank) and Dehra Khas (located on the right bank), in the second stretch were identified as the worst affected colonies during floods. These colonies are situated just after the confluence of the tributary (passing through Patel Nagar) with the main Bindal river. The other flood prone localities identified were Sanjay Colony (on the left bank) in the first stretch and Chota Bharuwala (on the right bank) in the third stretch, both subjected to bank erosion.

FGDs were held to understand the role of different institutions and effectiveness of rendered services. Scoring and Ranking exercise was undertaken with the participants to understand the extent of flood damages (loss of home, livestock, other assets, and livelihoods) across different occupational categories, namely services, business, labour, and unemployed. The daily wage labour class living in slums and having mud houses closer to the riverbanks, was most severely affected along the different stretches. At the household level, the losses reported were in terms of damage to the houses, loss of livestock and even family members, and assets like utensils, bicycles, television, etc.

The elderly people, those above 50 years, were more informative about the earlier status of the river, changes in rainfall behavior, encroachment along the river stretches, drainage and sewer systems, and occurrence of floods and related damages. The younger generation and middle-aged persons (20 –40 years old) provided information related to the role of different departments in river and flood management and were more interested in the flood EWS.

Water inundation levels for past flood events were marked on the social-resource maps, which later helped in validating and determining the different levels of thresholds, warning, and actions required. The participants were also encouraged to identify sites where water level sensors and rain gauges need to be installed.

5. Line 234: In addition to what was mentioned at the previous point, please clarify the criterion adopted to join the "community engagement" with the flood alert thresholds reported in Table 2

Thank you for this important question regarding the integration of community engagement into the determination of flood alert thresholds. As described in lines 231-236 of the manuscript, water level thresholds were initially determined through a combination of rigorous statistical analysis and participatory validation.

The primary criterion for setting alert thresholds was statistical, using percentile-based methods to identify extreme flood events specifically; water levels exceeding the 99.9th percentile was flagged as significant. Flood events during the study period and corresponding water inundation levels in the selected stretches of rivers helped in deciding upon the threshold values. However, to ensure these threshold values were both meaningful and actionable at the local level, community engagement through referring to the water inundation levels of past floods identified during social-resource mapping exercises, was employed to adjust and confirm these figures. Interactions with elderly residents during field visits and concerned Municipal Councilors during stakeholders' workshop where the research findings were shared, contributed their experiential knowledge of past flood events, helping to validate and refine the thresholds so that they corresponded with observed flood impacts and perceptions.

6. Page 1, line 35: In addition to the acronym, please define SMART;

Thank you for your careful examination. *SMART refers to Shared understanding of risks, Monitoring of risks, building Awareness, Response action on Time.* For brevity, we have used the acronym in the abstract, as it should be limited to 200 words. However, in the main manuscript (Introduction Line 88-91: Therefore, the present work emphasizes adopting SMART approach (Shared understanding of risks, Monitoring of risks, building Awareness, Response action on Time) proposed by Yasmin et al. (2023), which promotes inclusiveness and a bottom-up strategy to maximize local relevance and effectiveness.) the acronym has been explained thoroughly before being used in the subsequent sections.

7. Please, make sure that the reference section actually includes all the cited papers: several works mentioned in the paper are actually missing, such as Papalexioux & Montanari, 2019 (line 42), Rentschler et al., 2022 (line 46), Gu et al., 2019 (line 60), and many others;

Thank you for bringing this to our attention. We have carefully reviewed the reference list and ensured that all papers cited in the manuscript, including Papalexioux & Montanari (2019), Rentschler et al. (2022), Gu et al. (2019), and others, are now correctly included and formatted in the reference section. We appreciate your diligence in helping us improve the completeness and accuracy of our citations.

8. Line 49, a point is missing before "The";

Thank you for pointing out this typographical error. We have corrected the sentence by adding the missing full stop before "The" at line 49 in the revised manuscript.

9. Line 57, a point is missing before "Rapid";

Thank you for pointing out the missing punctuation. We have corrected this typographical error by adding the missing period before "Rapid" at line 57 in the revised manuscript to improve clarity and readability.

10. Line 62: Please check the consistency of "reach become";

Thank you for pointing out this inconsistency. We agree that "reach" alone correctly conveys the intended meaning, and the phrase has been revised accordingly. The sentence now reads:

"*Furthermore, the global urban population growing from 13% in 1900 to 49% in 2005 is estimated to reach 60% by 2030*." This change can be found in the revised manuscript.

11. Lines 180-181: R1, R2, R3, and R4 are actually RG1, RG2, RG3, and RG4. Please correct;

Thank you for pointing out this inconsistency. We have carefully reviewed the manuscript and corrected the abbreviations in lines 180-181 from R1, R2, R3, and R4 to the correct RG1, RG2, RG3, and RG4 throughout the text.

12 Line 383: Please check the sentence;

Thank you for your valuable comment regarding the clarity of the statements in lines 383 to 387. We agree that the original text could be more clearer. Accordingly, we have rewritten this section to improve readability and provide a more precise explanation of the analysis and figure presentation. The revised text now reads as follows:

"Rainfall and water level data were analyzed to understand watershed dynamics and their relationship with flood warnings. The peak rainfall intensity at 15-minute intervals was calculated for each rain gauge during three distinct periods: (a) Monsoon 2022, (b) Non-monsoon 2023, and (c) Monsoon 2023. Figure 7 presents the probability density functions (PDFs) of the 15-minute maximum rainfall intensities recorded at each rain gauge for these

different seasons. The Y-axis represents density, a smoothened estimate of the probability distribution of the data.

13. Reference section: Some references are listed twice. Please check.

Thank you for noticing this issue. We have carefully reviewed and cleaned the reference section to remove any duplicate entries, ensuring that each reference appears only once. The reference list in the revised manuscript is now updated.