Community Comments:

The manuscript "Dynamics and Impacts of Monsoon-Induced Geological Hazards: A 2022 Flood Study along the Swat River in Pakistan" offers an insightful analysis of geological hazards and flooding in northern Pakistan. It effectively explores the spatial distribution of these events, their hydro-meteorological triggers, and their impact on mountainous landscapes. While the study fits well within the scope of NHESS and is well-written, with strong results and discussions supporting the conclusions, minor revisions are needed to enhance clarity and robustness. This work is significant because it detailed examines monsoon-induced hazards and their implications for disaster management and risk mitigation. Publishing this study in NHESS will provide valuable insights for the scientific community and policymakers, particularly regarding climate change, deforestation, and the interaction of extreme weather events. The following detailed concerns should be addressed point by point:

We thank the comments for their positive feedback and valuable comments. We are glad the study's focus and significance were well-received. All concerns have been addressed point by point, and revisions have been made to enhance clarity and robustness.

Abstract: It would be better to reduce the abstract to focus on the main points and avoid repetition.

Reply: Thank you for your suggestion. The authors revised the abstract to eliminate repetition and focus solely on the main points for greater clarity and conciseness. Please see the revised manuscript's abstract.

Introduction: The authors effectively convey the study's significance in the introduction. However, they should cite more relevant studies to highlight the study's significance and worth further. Some minor concerns are highlighted below:

Reply: thank you for your comments; the references have been updated to both the introduction and discussion sections in the main draft.

The introduction states, "The registration of economic losses and human casualties due to extreme phenomena is higher in developed countries than in developing countries (Atta-Ur-Rahman, 2010)." This contradicts the subsequent statement, "Developing countries are hot spots for catastrophe events."

Reply: Thank you for your suggestion. The authors have added additional relevant citations in the introduction to emphasize the study's significance and value further.

Could you clarify whether the registration of losses refers to absolute numbers or the proportion relative to population and GDP?

Reply: The registered losses refer to absolute values.

The introduction mentions various statistics and data points from different sources and years (e.g., CRED, German Watched, NDMA). Could you specify the sources more clearly and consistently? Ensure the data is recent and relevant to support the discussion of trends.

Reply: Thank you for your valuable suggestion. We have revised the introduction to ensure clearer and more consistent citation of sources. Specifically, we have updated the data and statistics mentioned, using the most recent and relevant sources to strengthen the discussion of trends. For example, we have cited the most recent report from CRED (Centre for Research on the Epidemiology of Disasters) and the NDMA (National Disaster Management Authority) to reflect up-to-date information on disaster frequency and impacts. We have also ensured that the data from Germanwatch's Global Climate Risk Index (2023) is more directly linked to the trends observed in recent climate-related disasters.

Line 47: Please check whether the reference conveys the correct information.

Reply: thank you for your comments; the references have been updated

The terms "Flush flood" and "flash flood" are both used. Please make it consistent by using the standardized term" flash flood."

Reply: The authors have made sure to use the standardized term "flash flood" throughout the manuscript.

Lines 52 and 53: Please review the sentence for clarity.

Reply: The authors have revised the sentence to improve clarity. (Please see lines 53-54 of the revised manuscript)

L56 to L58, please make it clear the sentence is confusing

AR: The authors have revised the sentence to improve clarity. (Please see lines 58-61 of the revised manuscript).

"Since 1959, Pakistan has contributed only 0.4% of global carbon dioxide emissions—the primary greenhouse gas—compared to 16.4% from China and 21.5% from the United States (Handley, E. 2022). Yet, Pakistan remains among

the countries most severely impacted by catastrophic mega-floods, experiencing these devastating events nearly every decade."

Study Area: The section briefly overviews the Swat River's course and surrounding geography. However, more detail on the Swat Valley's specific topographic and hydrological characteristics would help readers better understand the context of the floods and geological hazards. For example, how do elevation changes and river gradients influence flow patterns and flood risks?

Reply: Thank you for your suggestion. The authors have expanded the study area section to provide more detailed information on the Swat Valley's topographic and hydrological characteristics, including elevation changes and river gradients, to clarify their influence on flow patterns and flood risks. (Please see section 2 of the revised manuscript).

The text mentions that the Swat River is nourished year-round by glacier streams. Can you elaborate on how? seasonal variations and climatic factors, such as monsoon rainfall and glacial melt, affect the river's flow patterns and potential for flooding? How do these factors vary throughout the year, and what are the regional disaster preparedness implications?

Reply: Thank you for your valuable comment. To answer your query about the seasonal variations and climatic factors influencing the flow patterns of the Swat River and their implications for flooding, we have provided additional insights and details below.

The flow of the Swat River is influenced by both seasonal glacial melt and monsoon rainfall. In spring and summer, particularly between May and August, the melting of glaciers in the higher altitudes of Swat Kohistan contributes significantly to river discharge. As the temperature rises, glaciers in the Usho and Gabral valleys begin to melt, providing a continuous source of water to the river, which increases its flow volume. This meltwater is particularly significant during warm months when river levels can rise rapidly, increasing the risk of flash floods, especially in the narrow gorges around Kalam and Madyan.

During the monsoon season, typically from July to September, rainfall exacerbates the discharge from the river. The combination of heavy monsoon rains and glacier melt results in elevated river levels, which increases the potential for flooding, particularly in the lower Swat Valley. The river's behavior heightens the flood risk as it flows across broad plains, which can overflow and inundate nearby settlements. This dynamic interplay between rainfall and glacial melt can lead to sudden, large-scale flooding events in areas like Madyan, where the river passes through narrow gorges, intensifying the danger of flash floods.

The variability of these climatic factors, including fluctuating rates of snowmelt and varying rainfall patterns, makes it difficult to predict flood events. Local disaster preparedness plans must account for this unpredictability, especially considering the increasing impacts of climate change on glacier dynamics and weather patterns. Given this variability, early warning systems and effective flood control measures are essential to mitigate flood risks, particularly in vulnerable areas such as the Kalam and Madyan valleys. Proper flood management strategies should include considering the timing of glacial melt and the intensity of seasonal rainfall to enhance disaster resilience in the region.

Methodology: The methodology outlines using GPS to document landslides and debris flow locations with an accuracy of 1m. How was this accuracy verified? Were any challenges encountered in ensuring this precision in rugged and inaccessible terrain? Additionally, what measures ensured the consistency and reliability of data collected from different sites?

Reply: Thank you for your questions. To ensure GPS precision, we calibrated the devices against benchmarks and verified accuracy with high-resolution satellite imagery. Multiple devices were used for redundancy and cross-checking. Challenges such as signal obstruction, terrain errors, and weather conditions were addressed through calibration, cross-verification, device maintenance, and the use of backup technologies like GIS to improve data reliability. In order to inform the reader, the authors have added these details in the revised manuscript. (Please see lines 144-152 of the revised manuscript)

L130: "The positions of each debris flow dam and meticulously measured the dimensions" to "The dimensions of each debris flow dam were also measured and documented comprehensively."

Reply: Corrected. (Please see lines 153 of the revised manuscript)

L136: conducted to performed

Reply: Corrected. (Please see lines 158 of the revised manuscript)

L163: for "Land Use and Land Cover (LUC)" throughout the section using consistent terminology and format. The study spans 20 years and is divided into four intervals for LUC mapping. Can you provide more detail on how the specific intervals (2002, 2009, 2016, and 2022) were chosen?

Reply: In the study "Land Use and Land Cover (LUC)," terminology and format are consistently used to maintain clarity. The specific intervals of 2002, 2009, 2016, and 2022 were chosen based on the availability of high-quality satellite imagery data, enabling consistent LUC mapping over time. These intervals represent key stages in the region's land cover changes, allowing for the assessment of long-term trends and periodic shifts in LUC due to natural and anthropogenic influences. Additionally, each interval aligns with significant regional environmental or policy changes, providing insight into the factors influencing LUC patterns over the past two decades.

Results: Section 4.1: The results highlight the role of rainfall intensity and antecedent rainfall in triggering debris flows. Can you elaborate on how these factors were quantified and analyzed to establish a correlation with debris flow events? How did the return period of the flood (estimated at 425 years) influence the interpretation of the data and flood risk assessment in the study area?
Reply: Thank you for your insightful feedback. We have refined Section 4.1 to clarify how rainfall intensity and antecedent rainfall were quantified and correlated with debris flow events. The revised text now emphasizes the cumulative effect of antecedent rainfall and daily rainfall intensity as key factors in triggering debris flows, supported by empirical rainfall data from Kalam Valley. We also addressed the significance of the 425-year return period, highlighting how such rare events should inform flood risk assessment and preparedness strategies in the study area.

Figure 1: Please check the X-axis of the panel (d). What does "Dig." mean? Please explain in the caption.
Reply: Corrected. (Please see Fig. 2 revised manuscript)
Section 4.2: Please state how flood levels were measured at different locations in one sentence. The results show a decline in vegetation cover and an increase in barren land. How do these changes correlate with the increase in debris flow events? Were any specific land use practices or human activities identified as key contributors? How do fluctuations in cropland affect slope stability and the likelihood of landslides or debris flows?
Reply: Flood levels at different locations along the Swat River were measured using hydrological gauges set up at key points to capture the height of water flow during peak flood events. The gauges also identified the flood level from the flood marks. This setup enabled accurate tracking of flood intensity and distribution across varied terrain and riverbank structures, such as urbanized areas and natural river sections.
The decline in vegetation cover has a direct correlation with the increased occurrence of debris flow events. Vegetative cover, especially in mountainous regions, is critical for stabilizing the soil and reducing surface runoff. The observed reduction in forest and grassland cover has led to higher soil erosion rates and increased vulnerability to debris flows. Additionally, land use changes, including expanding barren land and urban development, have increased susceptibility to debris flows by reducing natural resistance to flow, increasing water runoff, and accelerating erosion.
Human activities, particularly deforestation and urban expansion, were identified as significant contributors to land degradation in the study area. These practices decrease the landscape's ability to absorb rainfall, making slopes more prone to erosion and landslides. Furthermore, fluctuations in cropland affect slope stability, as seasonally abandoned or poorly maintained agricultural land can lose vegetation cover, reducing soil cohesion and stability. This makes these areas more prone to debris flows and landslides than areas with dense, stable vegetation cover.

Section 4.3: Along with topographic factors, consider discussing how geological factors contribute to the occurrence of hazards in the region.
Reply: Thank you for your insightful feedback regarding Section 4.3. We appreciate your suggestion to include a discussion on how geological factors contribute to the occurrence of hazards in the region alongside the topographic factors already presented. In response, we have revised Section 4.3 to incorporate a comprehensive analysis of the geological characteristics influencing debris flow occurrences. Specifically, we believe these additions enrich the section by providing a more holistic understanding of the factors contributing to geological hazards in the Swat Valley. (Please see section 4.3 of the revised manuscript)

Line 193: Please correct the sentence.
Reply: Corrected. (Please see line 220 of the revised manuscript)
Line 197: Please review this sentence.
AR: Revised. (Please see line 224 of the revised manuscript)
Ensure consistent terminology throughout the manuscript when numbering debris flows. Some sections refer to "DF 1," while others use "DF 01."
Reply: The authors have ensured to use of consistent terminology DF for debris flow throughout the manuscript.
Line 220: Please review this line.
Reply: The authors have revised the sentence for clarity. (Please see line 224 of the revised manuscript)

The font size in Figure 4 is inconsistent. The Y-axis in panel (b) looks narrow—please revise. Also, in the DEM panel, the names of the catchments and debris flows are cluttered; please check and enlarge the font size.
Reply: Thank you for your feedback. We have adjusted the font size in Figure 4 for consistency, widened the Y-axis in panel (b), and enlarged the font size in the DEM panel to improve clarity for the catchment and debris flow names. (Please see Fig. 4 of the revised manuscript)

Figure 4: Panel (a) has no heading, while panel (b) does. Consider adding more photos of the debris flow fan. Overall, the quality of the figure should be improved.
Reply: The authors have improved the quality of the figure. (Please see Fig. 4 of the revised manuscript)
Figure 5 (b and c): The font size is unreadable—please review. Also, add a north-direction indicator.
Reply: Thank you for your comment. We have increased the font size in Figure 5 (b and c) for readability and added a north-direction indicator for clarity. (Please see Figure 5 (b and c) of the revised manuscript)

Figures 6 and 7: The font size is also unreadable—please check and improve it.
Reply: The authors have improved the quality of the figure. (Please see Fig. 6 and 7 of the revised manuscript)
Section 4.7: The results show significant changes in debris flow depth and velocity over time, particularly when merging with the Swat River. How do these variations impact downstream flood dynamics and hazards? Can you explain the factors contributing to the rapid increase in velocity and depth, especially in residential areas?
Reply: The increase in debris flow depth and velocity significantly impacts downstream flood dynamics by accelerating flood flow and intensifying damage, particularly in residential areas. The rapid increase in velocity and depth, especially after merging with the Swat River, is primarily driven by land use changes, such as vegetation loss and the expansion of barren land, which reduce natural barriers and increase flow speed. This leads to larger, faster debris flows that exacerbate flooding. Additionally, the merging of debris flows with the river causes blockages that, when breached, lead to catastrophic downstream flooding, damaging infrastructure and land.

L325 and 326: the lines should need to be rephrased
Reply: The authors have rephrased the sentence to improve clarity. (Please see lines 375-377 of the revised manuscript)
L334 and 335: replace to "The debris flow depth reaches its peak between 45 and 60 minutes, ranging from 36 to 40 m, while the velocity reaches a maximum of 17 to 18 m/s, as shown in panels d-e and i-j, respectively."
Reply: Replaced. (Please see lines 385-386 of the revised manuscript)

Section 4.8: The section presents the information well. However, given the damage to infrastructure, particularly bridges and buildings, what specific design flaws were identified as contributing to their failure during the floods? How can future constructions in the Swat region be improved to withstand such events, especially considering lessons from previous incidents like the 2010 flood?
Reply: Thank you for your insightful comment. In response, we have expanded Section 4.8 to address specific design flaws that contributed to the failure of infrastructure. We also discuss recommendations for future constructions in the Swat region, focusing on design improvements like reinforced foundations and elevated structures, incorporating lessons learned from previous incidents, including the 2010 flood**.** (Please see lines 412-416 of the revised manuscript)
"Structural failures in the Swat region largely result from critical design flaws that overlook the impact of debris and flash floods, especially in bridges and buildings. Field observations highlight issues like inadequate lap splice length at column bases, narrow pier spacing, low bridge clearance, and construction near riverbanks, all of which contribute to structural vulnerability. To improve resilience, future construction should adopt flood-resilient building practices such as proper lap splice positioning, wider pier spacing, increased bridge clearance, and reinforced approaches in flood-prone areas."

L522: change was observed to was recorded.
Reply: Changed. (Please see line 595 of the revised manuscript)
L524: change "catalyzed" to triggered
Reply: Changed. (Please see line 598 of the revised manuscript)
Figure 9: Please add an overview map as panel (a) to indicate the damage locations. This will improve readability, as shown in Figure 10, where locating damaged sites is easy. Consider doing the same for Figure 9. Why are some panel legends in Figure 10 bold while others are not? Please ensure consistency.

AR: Thank you for your helpful suggestions. We have added an overview map as panel (a) in Figure 9 to indicate the damage locations, improving readability similar to Figure 10. Additionally, we have ensured consistency in the panel legends in Figure 10 by adjusting all text to the same font style. (Please see Fig. 9 and Fig. 10 of the revised manuscript)

Discussion: The discussion is thorough and well-structured, connecting the key findings to broader literature and contextualizing them within global climate change and local environmental challenges. The clear presentation of data, particularly the integration of meteorological factors, deforestation, and land use, strengthens the argument. Can you elaborate on how the numerical simulation data was validated, particularly regarding the debris flow velocities and depths? Clarifying this would enhance the reliability and accuracy of the findings.
Reply: thank you for your question and to address the reviewer's question on the validation of the numerical simulation data for debris flow velocities and depths, the validation was based on both observed field data and previously established models for similar environments. The model's outputs, including debris flow depths and velocities, were cross-checked against real-world measurements, such as those recorded at various locations along the Swat River and its tributaries, including data from gauge stations at Kalam Valley and other nearby monitoring sites. In addition, the model was compared with other simulation studies on debris flows in similar terrains (e.g., Iverson et al., 2010; García-Ruiz, 2010). These comparisons were used to ensure that the model adequately captured the observed dynamics of debris flows. By aligning the model's results with real-world flood and debris flow events, including the merging of debris flows with the Swat River, the validity of the numerical simulations was further supported. The consistency between observed and modeled data reinforces the reliability and accuracy of the findings in terms of debris flow dynamics and their impact on downstream hazards. The main modification in the discussion is as follows;
"Integrating real-time satellite precipitation products and radar-based rainfall monitoring, such as data from NASA's Global Precipitation Measurement (GPM), could significantly enhance the accuracy of rainfall forecasts and early warnings. Additionally, machine learning models could analyze historical data on precipitation, land cover, and debris flow incidents, enabling more predictive, location-specific alerts. These predictive models could refine warnings by incorporating specific thresholds for rainfall and runoff, thus reducing false alarms and enhancing local responsiveness."
And
"In addition to short-term mitigation measures, long-term strategies are essential to build resilience against these hazards. Reforestation, especially with native or drought-resistant species, emerges as a critical solution for stabilizing soil, reducing runoff, and enhancing ecosystem health in landslide-prone areas. Integrating climate-resilient infrastructure—such as permeable pavements, bio-retention systems, and strategically placed vegetation—into land use plans can complement traditional engineering methods, providing additional stability and reducing the strain on infrastructure during extreme weather events.
The study also underscores the importance of policy initiatives that support sustainable land use practices, particularly in vulnerable regions. These could include policies that incentivize reforestation, restrict deforestation in high-risk areas, and promote green infrastructure investments. By aligning practical, evidence-based recommendations with broader climate adaptation strategies, this study reinforces the need for holistic and proactive approaches in disaster management. Together, these measures can address the complex challenges posed by geological hazards in the face of climate change and ensure a more resilient future for affected communities."