

Dear Reviewer,

We sincerely thank you for your careful reading of our manuscript and for your constructive and detailed comments. We appreciate your positive assessment of the manuscript's potential, the literature coverage, the EW4All perspective, and the PRISMA 2020-based methodological framework. Your suggestions have helped us improve the clarity, balance, and analytical focus of the review. Below, we respond to your major comments paragraph by paragraph, followed by a response to the minor comments.

Major Comments

Comment 1: The Introduction is informative but somewhat heavier than necessary. The transition toward the research gap is somewhat delayed. The manuscript would benefit from bringing forward more explicitly the limitations of existing LEWS reviews and the specific added value of adopting an EW4All-based analytical perspective. The main contribution is not the compilation of published LEWS studies, but rather their reinterpretation through operational and governance dimensions. This is an important point that deserves importance. The methodological framework based on PRISMA 2020 is appropriate and adds transparency to the review.

Answer: We thank the reviewer for this helpful comment. We have revised the Introduction to make the transition toward the research gap clearer and to bring forward the added value of adopting an EW4All-based analytical perspective. The revised text now explains that previous LEWS reviews have mainly focused on technical dimensions, such as rainfall thresholds, spatial scale, monitoring approaches, and modelling methods, while less attention has been given to operational and governance dimensions. We now state more explicitly that the main contribution of this review is not only the compilation of published rainfall-induced LEWS studies; rather, it is their reinterpretation through the EW4All framework, including institutional responsibility, warning dissemination, community preparedness, response capability, and implementation feasibility. We retained the PRISMA 2020-based methodological framework, as it provides transparency in the identification, screening, and selection of the reviewed literature.

Comment 2: The Results and Discussion section contains a large amount of relevant material, but its presentation is often more descriptive. The literature is well covered, yet many findings are reported rather than interpreted. For NHSS, a stronger effort to extract meaning from the observed patterns would be expected. Implications for operational reliability, scalability, and governance could be developed more systematically.

Answer: We thank the reviewer for this important suggestion. We have revised several parts of the Results and Discussion section to strengthen interpretation rather than only reporting findings. In particular, we expanded the discussion of operational LEWS, slope-specific systems, susceptibility mapping, monitoring strategies, AI, and Pillars 3 and 4. The revised manuscript now links the observed patterns more directly to operational reliability, scalability, institutional responsibility, communication pathways, and governance constraints. These revisions help clarify what the observed patterns reveal about the transition from technical LEWS development to sustained operational implementation.

Comment 3: For instance, the discussion on susceptibility mapping could be strengthened by moving beyond the simple observation of its limited use. The more interesting point is what these reveals about the persistent dominance of rainfall-threshold-based approaches compared to more spatially distributed risk modelling strategies. Similarly, the distinction between local and broader scale systems would benefit from a more explicit reflection on the trade-offs between accuracy, transferability, and operational scalability.

Answer: We agree with the reviewer that the susceptibility mapping discussion should move beyond the observation of limited use. We revised this section to explain that the limited integration of susceptibility maps reflects the continued dominance of rainfall-threshold-based approaches over more spatially distributed and impact-based risk modelling strategies. The revised text now explains that rainfall thresholds are often easier to develop, communicate, and operationalise, especially where data availability, technical capacity, and institutional resources are limited. However, without susceptibility or risk information, LEWS may provide more generalised warnings and may not adequately represent spatial variation in landslide susceptibility. We also strengthened the discussion of local, regional, and national LEWS by explaining the trade-offs between accuracy, transferability, and operational scalability. Local LEWS can generate more precise warnings for specific slopes or communities; however, they are less transferable because they require slope-specific monitoring instruments, regular updating, technical expertise, funding, and long-term maintenance. Regional and national LEWS are more scalable and easier to operationalise; however, they may lose some local accuracy. This revision makes the operational trade-offs clearer.

Comment 4: The section on artificial intelligence is relevant and up to date, but the framing is sometimes slightly unbalanced. While limitations are correctly identified, the discussion would be stronger if it more clearly acknowledged the parallel potential of AI-based approaches, particularly in data-scarce environments, alongside their well-known constraints in terms of interpretability.

Answer: We thank the reviewer for this useful comment. We revised the AI section to provide a more balanced discussion. The revised text now acknowledges the potential of AI-based approaches for data-gap filling, satellite-data integration, pattern recognition, susceptibility mapping, and large-area analysis, particularly in data-scarce environments. At the same time, we retain the discussion of key limitations, including data quality requirements, transferability challenges, limited interpretability, and the risk of overlooking local knowledge, cultural context, communication preferences, and social vulnerability. We now frame AI as a complementary tool within hybrid LEWS approaches, where AI-supported analysis is combined with expert interpretation, local validation, transparent decision-making, and communication planning.

Comment 5: In particular, the idea that only effective LEWS can reduce landslide impacts should be softened, as risk reduction is inherently multi-dimensional and depends on land use planning, also governance structures, exposure and vulnerability conditions.

Answer: We agree with this comment and have revised the relevant statement. The manuscript now clarifies that an effective LEWS can contribute significantly to reducing potential loss and damage from rainfall-induced landslides; however, its effectiveness depends on wider risk reduction measures, including land-use planning, governance structures, exposure reduction, vulnerability reduction, and preparedness planning. This revision clarifies that LEWS are an important component of landslide risk reduction, while recognising that risk reduction is inherently multi-dimensional.

Comment 6: One of the strongest contributions of the manuscript is the identification of the limited attention given to Pillars 3 and 4 of the EW4All framework. This is a particularly relevant finding and could be more strongly emphasized, as it highlights a clear structural imbalance in the current LEWS literature between technical forecasting components and communication.

Answer: We thank the reviewer for highlighting this point. We have strengthened the discussion of Pillars 3 and 4 to emphasise that the limited reporting of warning dissemination, communication, preparedness, and response capability is one of the main findings of the review. The revised manuscript now identifies this as a structural imbalance in the current LEWS literature, where technical forecasting components are reported more frequently than the communication and response processes required for people-centred early warning. We also emphasised this point in the Conclusion, where we now identify the underreporting of Pillars 3 and 4 as a key gap between technical LEWS development and the operational requirements of EW4All.

Comment 7: The discussion on operational systems is also valuable. The observation that only a small fraction of systems described in the literature are actually operational is an important point. However, the explanation of this phenomenon would benefit from a more integrated interpretation.

Answer: We have expanded the discussion of operational systems to provide a more integrated interpretation of why only a small fraction of LEWS described in the literature are operational. The revised text now explains that operationalisation requires more than a forecasting model or monitoring method. It also depends on continuous data streams, maintenance capacity, institutional responsibility, legal authority to issue warnings, adequate funding, skilled personnel, communication and response protocols, and appropriate mandates. We therefore frame the limited number of operational LEWS as a broader implementation challenge across the full warning value chain, rather than as a purely technical limitation.

Comment 8: The manuscript also appropriately highlights the gap between academic publications and operational reality, particularly regarding the lack of detailed implementation information in scientific articles. This is an important methodological limitation and could be further developed, as it directly affects the robustness of global comparisons.

Answer: We agree that this is an important methodological limitation and have further developed it in the manuscript. The revised text now clarifies that the review is based on information explicitly reported in the selected publications. We also explain that some studies provide detailed technical forecasting information, while others provide limited information on institutional mandates, warning dissemination, preparedness actions, operational status, or community engagement. For this reason, comparisons among LEWS developed across countries and scales may partly reflect differences in reporting practices, rather than only differences in actual LEWS performance or maturity. This addition makes the limitation of global comparison more explicit.

Comment 9: For the conclusions section, in its current form, it would be preferable to focus more clearly on the main scientific messages, the key gaps identified, and the most relevant priorities for future LEWS development within the EW4All framework.

Answer: We have revised the Conclusion to focus more clearly on the main scientific messages, key gaps, and priorities for future LEWS development within the EW4All framework. The revised conclusion now highlights the imbalance between Pillars 1–2 and Pillars 3–4, the limited number of operational LEWS, the absence of landslide risk maps, the gap between academic publications and operational reality, and the need to prioritise operational governance, risk- and impact-based information, last-mile communication,

preparedness, and locally adapted scalability. This makes the Conclusion more closely aligned with the main findings of the review and the EW4All framework.

Comment 10: In summary, the manuscript has strong potential as a review article for NHESS. The literature coverage is extensive and the EW4All perspective represents a clear added value. However, the manuscript would benefit from a more analytical structure, reduced redundancy, and a stronger effort to synthesize rather than describe.

Answer: We thank the reviewer for this overall assessment. Across the revised manuscript, we have worked to reduce redundancy, improve readability, and strengthen synthesis. The revisions aim to make the manuscript more analytical by interpreting what the reviewed evidence reveals about operational reliability, scalability, governance, communication, preparedness, and implementation feasibility. We believe these changes strengthen the contribution of the review for NHESS by moving the manuscript beyond a descriptive synthesis toward an EW4All-based interpretation of current LEWS practice and gaps.

Minor comments

We also addressed the minor comments as follows:

Lines 327–334: The clarification regarding the limitations of the reviewed literature is appreciated and improves the transparency of the study. However, this paragraph could be shortened slightly to avoid interrupting the transition into the Results and Discussion section.

Answer: We shortened and clarified the paragraph explaining the limitations of the reviewed literature so that it does not interrupt the transition into the Results and Discussion section.

Lines 338–344: The discussion introducing Pillar 1 is clear and well contextualized. Nevertheless, some sentences are somewhat repetitive, particularly regarding the concept of “awareness” and “knowledge” of landslide risks.

Answer: We revised the introductory paragraph for Pillar 1 to reduce repetition around “awareness” and “knowledge”.

Lines 345–352: The finding that only 14 out of 61 LEWS are operational is highly relevant. It would be useful to elaborate more on the reasons preventing the transition from prototype systems to operational implementation.

Answer: We elaborated on why many systems remain at the prototype or experimental stage rather than becoming operational.

Lines 366–374: The discussion on slope-specific LEWS is interesting and highlights an important operational limitation. However, the argument on cost–benefit analysis could be supported with a more critical perspective on scalability and long-term maintenance requirements.

Answer: We expanded the slope-specific LEWS discussion to include scalability and long-term maintenance requirements.

Lines 385–406: The section discussing susceptibility maps is very informative. In particular, the explanation of how susceptibility mapping may reduce false alarms is well presented. However, some parts could be reduced in order to improve readability.

Answer: We revised the susceptibility mapping discussion to improve readability and to strengthen the interpretation of rainfall-threshold dominance.

Lines 407–417: The discussion on data scarcity is highly relevant, especially for data-sparse regions. Nonetheless, similar arguments appear repeatedly throughout the manuscript.

Answer: We reduced repeated discussion of data scarcity where appropriate.

Lines 432–439: The introduction to Pillar 2 is generally clear, although the paragraph would benefit from a more direct connection to the operational implications of monitoring strategies.

Answer: We revised the Pillar 2 introduction to connect monitoring strategies more directly with operational reliability, lead time, maintenance, and scalability.

Lines 473–478: The role of additional meteorological variables is mentioned appropriately; however, the statement that these variables are “less crucial” may be simplified, particularly in complex hydrometeorological environments.

Answer: We softened the statement about additional meteorological variables and clarified that rainfall remains the primary trigger, while other variables may provide supporting information in complex hydro-meteorological environments.

Lines 481–497: The discussion regarding piezometers and inclinometers is valuable and technically well explained. However, some sentences are long and could be divided to improve readability.

Answer: We divided long sentences in the discussion of piezometers and inclinometers to improve readability.

Lines 578–600: The manuscript correctly highlights the lack of information regarding Pillars 3 and 4 in the reviewed literature. This represents one of the most important findings of the study and deserves further emphasis in the Conclusions section.

Answer: We further emphasised the limited reporting of Pillars 3 and 4 in the Conclusion.

We are grateful for your constructive feedback, which has helped us improve the manuscript substantially.

Sincerely,

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On behalf of **Bayes Ahmed** and **Peter Sammonds**