Dear Reviewer,

We sincerely thank you for your careful reading of our manuscript and for your constructive and detailed comments. Your suggestions will help us improve the clarity, balance, and analytical focus of the review. Below, we respond to your comments paragraph by paragraph.

General comment

This review article evaluates rainfall-induced landslide early warning systems (LEWS) in the lens of the UN's Early Warnings for All (EW4All) framework. The authors reviewed 61 publications covering 23 countries looking at key gaps across the four EW4All pillars. The topic is relevant to NHESS. However, the manuscript in its current form has significant methodological, structural, and presentational weaknesses that must be addressed before it can be reconsidered for publication.

Answer:

We thank the reviewer for recognising the relevance of this study to NHESS and for highlighting the key areas requiring improvement. We will carefully revise the manuscript to address the methodological, structural, and presentational concerns raised.

Specific comments

On the paper selection and analysis

Query one:

My main concern regards the inclusions of forecasting systems in the analysis, which could be misleading and led to biased findings. Looking at Table 1, the vast majority of the 61 reviewed studies address only EW4All Pillars 1 and 2 (risk knowledge and detection/monitoring/forecasting). Very few address Pillars 3 and 4. This pattern is not incidental, indeed it directly reflects the inclusion of forecasting-only studies that, by the authors' own definition, are not EWS at all. As a matter of fact, the headline finding "14 of 61 LEWS are operational" is potentially misleading because it is unclear how many of the 61 are proper early warning systems versus forecasting tools that were included despite not meeting the paper's own definition of EWS. Moreover, the claim to evaluate LEWS "through the EW4All framework" is undermined because including forecasting-only systems guarantees that Pillars 3 and 4 will appear absent, not because they are genuinely missing from practice, but because the included studies were never designed to address them. Thus, I suggest to discard the forecasting systems from the review and focus only on proper LEWS, considering if necessary all LEWS already mentioned in the previous review articles (cited in the text). I think that including all LEWS in the review will

allow a more detailed evaluation of all EW4All Pillars. As an example, Hong Kong, Rio de Janeiro, Japan LEWS are left out from the main discussion, despite being consolidated systems with rich peer-reviewed and grey literature. I would suggest having a look also on the LEWS catalogue produced by LandAware, the international network on LEWS (https://www.landaware.org/glossary-and-catalog-of-lews/).

Answer: Thank you for this important comment. We agree that the previous wording could create confusion between full LEWS, forecasting systems, and LEWS-related technical studies. Our original intention was to examine how rainfall-induced landslide early warning systems are represented in recent academic literature. During the article selection process, records were initially screened from the selected academic databases using the title and abstract, particularly where the authors themselves described their work using terms such as “landslide early warning system” or “landslide early warning”.

However, we recognise that some of these publications describe only the technical forecasting, monitoring, or prediction component of a warning system, rather than a complete LEWS including dissemination, communication, preparedness, and response. We agree with the reviewer that treating all such studies as complete LEWS may bias the EW4All analysis towards Pillars 1 and 2. At the same time, we believe this is an important finding of the review: some recent academic publications often use LEWS terminology but provide detailed information mainly on forecasting and monitoring, while the operational, institutional, communication, and preparedness dimensions are much less frequently reported. We have indicated this in section 4.3. Therefore, in the revised manuscript, we will clarify that the observed lack of information on Pillars 3 and 4 should be interpreted primarily as a gap in academic reporting, not automatically as evidence that these components are absent in operational practice. To address the reviewer’s concern, we will revise the methodology and reclassify the selected records into clear categories: full LEWS and forecasting- or monitoring-only LEWS-related studies. Forecasting-only studies will no longer be counted as full LEWS or used to support the statement that Pillars 3 and 4 are absent. However, a few papers did not report their work as LEWS and will be excluded from the review. We will also revise the statement “14 of 61 LEWS are operational” to avoid implying that all 61 records describe full early warning systems.

We will also revise the temporal scope of the review. The revised manuscript will focus on LEWS-related publications from recent years, from 2015 to 2026. Our purpose is not to provide a complete inventory of all operational LEWS worldwide, including systems that may still be active but have not been discussed in recent publications. Because of limitations related to language, report type, open-access availability, and other factors, we believe it is difficult to identify information on all operational LEWS through academic databases or national agencies. In many cases, substantial work may be taking place on the ground under the supervision of relevant authorities, but this work may not be

documented in academic publications or publicly available agency reports. Therefore, considerable uncertainty remains regarding whether all operational LEWS have been included. We have already acknowledged this limitation in our study, but it may require further explanation. So, the revised aim is to more carefully examine how rainfall-induced LEWS are represented in recent academic and semi-academic literature and whether this recent literature provides sufficient evidence to evaluate LEWS through the EW4All framework. Therefore, LEWS with no relevant publication within recent years will not be included in the main dataset. We recognise that this may exclude some older but still operational systems. This limitation will be explicitly stated. Where such systems are mentioned in previous reviews or catalogues such as LandAware, they will only be discussed briefly (only if publicly available open access documents and written in English) as contextual examples, unless they have relevant publications within the revised recent-year window. This approach allows us to focus on current published evidence, recent methodological and operational challenges, and the gap between what is reported in recent literature and what is required for a complete EW4All-aligned LEWS.

Query two:

The 61 selected articles appear to include a wide range of publication types, from peer-reviewed empirical studies to conference proceedings and grey literature. The authors do not apply any quality assessment criteria to the included studies. Without this, high-quality national operational systems receive equal weight to conference papers describing prototype models.

Seven grey literature sources are included, but the selection criteria for these are vague. How were national websites identified? Was the search systematic or opportunistic? This needs clarification.

Answer: We agree with the reviewer. In the revised manuscript, we will add a transparent source-quality and evidence-strength classification to distinguish peer-reviewed operational LEWS studies from conference papers, prototype systems, methodological studies, and grey-literature sources. Each record will be coded by publication type, LEWS category, operational evidence, and evidence strength. We will also clarify the grey-literature search strategy. Grey literature will be treated as a targeted supplementary source, limited to LandAware and official agency/national websites where they provide identifiable information on rainfall-induced LEWS. This will prevent high-quality operational systems and prototype conference studies from being given equal analytical weight.

Query three:

Moreover, some papers are included in 61 selected papers (Table 1) even though they do not describe early warning systems or forecasting systems. As an example, the paper

by Guzzetti et al. (2024) describes a validation of a deep-learning model for landslide prediction; moreover, the three papers from Zhang et al. (2024) – which are wrongly cited as 2024, 2024a and 2024b – describe criteria for analyzing landslide displacements with the aim of early warning, but they do not describe a forecasting system; the article by Thomas et al. (2023) describes the application of a slope stability model in some locations, but is far from the definition of a comprehensive forecasting model.

Answer: We agree. We will exclude these from our database.

Query four:

The paper does not describe a structured data extraction protocol or inter-rater reliability process. Given that the review has a single primary analyst (RS), there is a risk of extraction bias, particularly for the EW4All pillar assignments in Table 1. Several pillar assignments appear to be inferred rather than explicitly reported in the source articles (as acknowledged in Section 3). This needs to be flagged more prominently as a limitation, and the basis for each assignment should be made transparent, perhaps via supplementary material.

Answer: We completely agree with the reviewer. The data extraction and EW4All coding were conducted by a single primary analyst using a structured coding protocol. A formal inter-rater reliability assessment was not undertaken. We mentioned in our work that the assignment of each pillar was based primarily on information reported in the relevant publications and other reliable sources like personal contact with the relevant authorities (which was limited to a few). Therefore, some coding decisions, particularly for EW4All pillar assignments, may involve interpretive judgement. To improve transparency, the revised review distinguishes between explicitly reported, inferred, and not reported/insufficient evidence, and provides the coding basis in supplementary material. Consequently, absence of information in the reviewed publications will be interpreted as a reporting limitation rather than definitive evidence that a component is absent in operational practice.

Query five:

- The paper does not dedicate any structured analytical section specifically to local-scale LEWS, despite them constituting nearly a third of the reviewed systems (19 of 61). Indeed, a previous review on local-scale LEWS (https://link.springer.com/article/10.1007/s10346-018-1068-z) is not mentioned. The gap analysis in Section 4.5 discusses challenges generically across all LEWS types without disaggregating by scale. There is no comparative discussion of how the challenges and EW4All pillar coverage differ between local, regional, and national systems — even though Table 1 encodes this information. The community-based LEWS literature is particularly relevant to EW4All's people-centred mandate but receives no dedicated treatment.

Answer: Thank you for this helpful comment. We agree that local-scale LEWS require a more explicit and structured treatment, especially because their operational characteristics differ from regional and national systems. In the original manuscript, the scale of the LEWS was reported in Table 1, illustrated in Figure 7, and discussed in the main text. The manuscript also briefly explains how local-scale LEWS differ from those operating at other spatial scales. However, a dedicated subsection on local-scale and community-based LEWS falls outside the scope of the present study, as such a discussion would require a different analytical approach that is not included in the current methodology. It is not feasible to address every possible dimension of LEWS analysis within a single study. Nevertheless, we will strengthen the discussion of local-scale LEWS by incorporating relevant information from other studies like https://link.springer.com/article/10.1007/s10346-018-1068-z.

Query six:

The novelty claimed in Section 1.4 is overstated. The authors assert that the distinct contribution lies in "reframing the field through the EW4All framework," yet the analytical application of the framework remains largely descriptive rather than evaluative. The paper identifies well-known gaps (data scarcity, lack of risk maps, limited community engagement) that have been extensively documented in prior literature. The authors do not demonstrate how the EW4All lens generates new insights beyond organising pre-existing knowledge under new headings. The theoretical contribution would be strengthened considerably if the authors more explicitly articulated what the EW4All framing reveals that prior frameworks did not. Section 1.4 should be improved to make a more defensible claim about novelty.

Answer: Thank you for this important comment. We agree that the novelty claim in Section 1.4 was overstated and that the previous version did not sufficiently demonstrate how the EW4All framework generated new analytical insight beyond organising known LEWS gaps under four headings. The revised manuscript will therefore make a more modest and defensible novelty claim.

In the original manuscript, we stated that the contribution was the reframing of rainfall-induced LEWS through the EW4All framework and the assessment of information shared in academic publications. We will revise this section to clarify that the novelty is not the identification of entirely new individual gaps such as data scarcity, limited risk mapping, or weak community engagement. Instead, the contribution is to evaluate how far recent LEWS publications provide evidence for the complete warning-system chain required by the current format of the EW4All.

On data analysis

Query seven:

The core analytical tool is a series of radial diagrams (Figures 7, 8, 9) that have serious readability problems. The analysis they represent is largely descriptive and categorical. The paper does not attempt any cross-tabulation, correlation, or comparative analysis between LEWS characteristics and operational status, geographic region, or EW4All pillar coverage. For example: Are LEWS that use susceptibility maps more likely to be operational? Do national-scale systems address more EW4All pillars than local ones? These questions are implied but never tested.

Answer: Thank you for this comment. We agree that the previous analysis was too descriptive. Although we think that the Figures are fine to read, in the revised manuscript, we will replace Figures 7–9 with clearer visualisations. There are some comparative discussions in the original manuscript without showing them on any Figure or Table. We will add simple comparative analysis outputs both in text and table/figure to make better use of the coded dataset. Specifically, we will examine relationships between LEWS characteristics and: operational status, scale, geographic region, and EW4All pillar coverage.

Query eight:

The distinction between operational and non-operational systems is central to the paper's argument but is applied inconsistently. The authors note (Section 3) that some LEWS in the "validated" stage are recommended for implementation, and that operational status does not necessarily mean full areal coverage. These nuances are important but are not systematically incorporated into the analysis.

Answer: Thank you for this important comment. We agree that the distinction between operational and non-operational systems was not applied consistently enough in the previous manuscript. In particular, systems that were validated or recommended for implementation should not automatically be treated as operational (which we also did not do in our original manuscript), and operational status should not be confused with full spatial or areal coverage.

In the revised manuscript, we will address this. In the current manuscript, a system is considered operational only where the source provides evidence that it is currently used for warning, decision-making, alert dissemination, or institutional response. This will be the same in the revised manuscript. However, systems described only as validated, tested, or recommended for implementation will be classified as non-operational, unless current operational use is explicitly reported.

We will also separate operational status from areal coverage. Some LEWS may be operational only for a specific slope, road corridor, municipality, city, or region, rather than for an entire administrative area or country. Therefore, the revised Table 1 will include separate fields for operational status and spatial/areal coverage.

Query nine:

Section 4.3 is, in my opinion, the weakest part of the paper. The authors essentially acknowledge that the literature review cannot address Pillars 3 and 4 because the academic publications do not cover them adequately. While this is an honest and valid observation, a paper claiming to evaluate LEWS "through the lens of the EW4All framework" cannot do so when two of the four pillars are almost entirely absent from the analysis. The authors should either supplement this section with a targeted review of grey literature, agency reports, and policy documents on warning dissemination and community preparedness, or clearly reframe the paper's scope in the title, abstract, and objectives to reflect that the analysis is primarily limited to Pillars 1 and 2.

Answer: Thank you for this important comment. We agree that Section 4.3 was not sufficiently framed in the previous manuscript. Our intention was not to claim that Pillars 3 and 4 are absent from operational LEWS practice. Rather, we aimed to show that many academic publications that describe their work as “landslide early warning systems” provide detailed information mainly on monitoring, forecasting, thresholds, or modelling, while providing limited or no information on warning dissemination, communication, preparedness, response, and institutional implementation. This is also an important finding of the present study. An early warning system (EWS) is generally understood as an integrated system comprising four interconnected pillars. The term EWS may therefore be used to describe studies or initiatives that address all four pillars. However, the absence of explicit discussion of one or more pillars in a particular study does not mean that the study cannot be assessed through the lens of the EW4All framework. Because the framework provides a structured basis for examining each pillar, it can still be used to evaluate the specific components reported in the study, even when the full EWS is not comprehensively described.

We agree that, without this clarification, the claim of evaluating LEWS through the EW4All framework could appear too broad. In the revised manuscript, we will therefore reframe Section 4.3 as a reporting-gap analysis rather than as direct evidence of absence in practice. The absence or limited discussion of Pillars 3 and 4 in the reviewed publications will be coded as “not reported”, not as “absent”.

We will also revise the other parts of the manuscript accordingly. The revised manuscript will focus on how rainfall-induced LEWS are represented in recent academic and selected grey literature, and whether these publications provide sufficient information to evaluate the full EW4All warning chain.

In addition, where available within the revised scope, we will use targeted grey literature, LandAware, and official/agency sources to contextualise Pillars 3 and 4. However, we will make clear that the paper does not aim to provide a complete global inventory of all operational LEWS or a full policy review of warning dissemination and preparedness systems. If we cannot get a considerable number of publications where the full LEWS is described, we will adjust the paper's scope in the title, abstract, and objectives.

Query ten:

The feasibility analysis in Section 4.6 is conceptually interesting but reads as opinion rather than evidence-based analysis. Several of the six feasibility concerns are presented without citation or empirical grounding. For instance, the claim that "ensuring complete inclusivity is practically impossible" is asserted without reference to any case studies or theoretical literature on emergency management and inclusivity. Similarly, the critique that the EW4All framework "emphasises the application of similar methods or models everywhere" is a characterisation that the authors do not substantiate with specific textual evidence from the EW4All documentation. These claims may be correct, but they must be supported.

Answer: Thank you for this comment. We agree that the feasibility analysis in Section 4.6 was not sufficiently evidence-based in the previous version. In the revised manuscript, we will either support each feasibility concern with relevant citations, case examples, or evidence from the reviewed LEWS literature, or soften/remove claims that cannot be adequately substantiated. We will also revise the discussion of EW4All to avoid implying that the framework promotes a uniform model everywhere unless this is directly supported by EW4All documentation.

On the presentation quality

Query eleven:

The radial diagrams (Figures 7, 8, 9) represent a major presentational problem. Each diagram attempts to display three or four variables simultaneously for 61 LEWS using country codes as labels around a crowded circle. The result is essentially not readable without extreme magnification. Individual labels frequently overlap, and the legend abbreviations require readers to cross-reference constantly. These figures, in their current form, do not meet minimum readability standards for a journal article. The authors should replace or substantially redesign these figures. Heat maps, grouped bar charts, or structured tables would convey the same information far more clearly. If the authors wish to retain the radial format as a visual overview, they should provide supplementary tables containing the underlying data in accessible form.

Answer: Thank you for this comment. We agree that the radial diagrams are overcrowded and difficult to read. In the revised manuscript, we will replace Figures 7–9 with clearer

visualisations. If any radial diagram is retained, it will be moved to the Supplementary Material only as an overview figure, and the underlying data will be provided in a supplementary table.

Query twelve:

Table 1 is comprehensive and generally well-constructed, though it is very long and would benefit from a brief inline summary noting the distribution of studies by continent and EW4All pillar coverage. Table 2 is useful for contextualising the additional LEWS from prior reviews.

Answer: Thank you for this positive and helpful comment. We agree that Table 1 is long and would benefit from a clearer summary before the detailed table. In the revised manuscript, we will add a brief inline summary highlighting the distribution of reviewed records by continent/region, LEWS scale, operational status, and EW4All pillar coverage before presenting Table 1. We will also revise Table 1, where necessary, to reflect the updated classification between full LEWS and forecasting-/monitoring-only LEWS-related studies.

Query thirteen:

The English writing is generally good. Given the authors' acknowledgement that AI tools were used for some paragraphs, the editors should be aware that several passages have a smoothed but imprecise quality that may have been introduced through AI assistance rather than corrected.

Answer: Thank you for this comment. We used AI tools to check for grammatical errors. In the revised manuscript, we will carefully edit the text to improve precision, specificity, and evidence-based wording.

Query fourteen:

The paper's structure is broadly logical, but the relationship between Sections 4.4 and 4.5 is confusing. Section 4.4 discusses "additional LEWS from review papers" using a different data source than the main 61 articles, while Section 4.5 analyses gaps in the 61 articles. The boundary between these sections is unclear, and the discussion of the additional 30 LEWS in Section 4.4 partially duplicates findings already made about the primary 61 in Sections 4.1–4.2. The authors should clarify how the findings from the two datasets are analytically distinguished and whether the additional 30 LEWS inform the gap analysis in Section 4.5.

Answer: Thank you for this comment. We agree that the relationship between Sections 4.4 and 4.5 was unclear in the previous manuscript. The gap analysis was based on the main set of reviewed publications, while the additional LEWS from previous review papers

were used mainly for contextual comparison. This distinction was not explained clearly enough.

In the revised manuscript, we will restructure these sections. The main analysis will focus only on LEWS-related academic and selected semi-academic recent publications published since 2015. The additional LEWS identified from previous review papers will not be treated as a second analytical dataset and will not be used to derive the main gap analysis. Instead, they will be used selectively to support the discussion, especially where they help contextualise operational practice or show how older/consolidated LEWS differ from recently published evidence. We will also remove duplicated discussion between Sections 4.4 and 4.5 and clarify the role of each evidence source.

Query sixteen:

I'd suggest to specify in the title that the review and analysis were done in the lens of EW4All framework.

Answer: We agree with the reviewer and will do so in the revised manuscript.

Other minor comments

Query seventeen:

Section 1.3: The claim that "88% of landslides are rainfall-triggered" (citing Haque et al., 2019 and Froude & Petley, 2018) should be contextualised. This statistic relates to fatal landslides in a specific database and time period, not to landslides in general. The generalisation as stated is imprecise.

Answer: Thank you for this clarification. We agree that the statement was too broad. In the revised manuscript, we will contextualise the statistic and avoid implying that 88% of all landslides globally are rainfall-triggered. We will clarify that this percentage refers to fatal landslides recorded in specific landslide inventories and time periods, not to all landslides in general.

Query eighteen:

Section 4.5.2.5: The claim that "there is no known standard methodology for developing LEWS" is an important finding that deserves more discussion. The authors could usefully reference the work of Calvello (2017) and Guzzetti et al. (2020) on performance evaluation frameworks, which represent partial steps toward standardisation.

Answer: Thank you for this helpful comment. We will expand Section 4.5.2.5 by discussing existing contributions, including Calvello (2017) and Guzzetti et al. (2020), particularly in relation to warning performance evaluation, threshold assessment, validation, and operational effectiveness. These works will be presented as important

steps toward standardisation, even if they do not yet constitute a single globally applicable LEWS development protocol.

Query nineteen:

Section 4.6: The six feasibility concerns should be structured and numbered consistently with the gap analysis in Section 4.5 for readability. Each concern should be supported by at least one citation or concrete example.

Answer: Thank you for this suggestion. We agree that Section 4.6 needs clearer structure and stronger evidential support. In the revised manuscript, we will restructure the six feasibility concerns so that they are numbered consistently with the gap-analysis section in 4.5. Each feasibility concern will be supported by at least one citation, case example, or evidence from the reviewed LEWS literature. We will also remove or soften any claims that cannot be adequately supported.

We are grateful for your constructive feedback, which will help us improve the manuscript substantially.

Sincerely,

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