Revision Notes of the Revised Manuscript

Manuscript NO.: Egusphere-2026-160

Title: Integrating multidimensional factors through Bayesian Belief Networks for landslide and debris-flow risk reduction in subtropical zones

Submitted to: Natural Hazards and Earth System Sciences (NHESS)

Letter to editors and reviewers:

Dear editors and reviewers,

Thank you very much for your useful comments, we are now pleased to resubmit the revised version of Egusphere-2026-160 title: "*Integrating multidimensional factors through Bayesian Belief Networks for landslide and debris-flow risk reduction in subtropical zones".* Based on the comment of the first reviewer, the authors changed the title to: *"Integrating multidimensional factors through Bayesian Belief Networks for landslide risk reduction in subtropical zones".*

We would like to thank the reviewers for careful and thorough reading of this manuscript and for your suggestions, which helped us to improve the manuscript. We have carefully considered all the suggested changes and revised the manuscript accordingly.

Please refer to "Detailed response to reviewers' comments" below for studying the changes.

Yours Sincerely,

On behalf of all authors who read and agreed on the revised manuscript.

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Detailed response to reviewers' comments:

---------- **Reviewer #2** ----------

1. The concept of "multidimensional factors" needs to be more clearly defined from the outset, including the scope of variable groups and selection criteria, to avoid the perception of the concept being purely qualitative.

Answer: In the revised manuscript, the authors explicitly define this term as the integration of four main groups of variables*: "(i) geomorphological factors (e.g., slope, curvature, drainage characteristics), (ii) geological and material properties (e.g., soil and rock types, pre-transported materials), (iii) triggering factors (e.g., rainfall intensity and duration), and (iv) exposure-related variables (e.g., population, infrastructure, land use). The selection of these variables was based on a combination of statistical validation (SEM and multivariate regression), data availability, and their demonstrated relevance in previous studies..."*.

This clarification has been added to the Introduction and Methodology sections to ensure that the concept is quantitatively grounded and consistently applied throughout the study.

2. The choice of the BBN model is reasonable, but the presentation doesn't clearly explain why this method is preferred over other popular machine learning models like Random Forest or Neural Networks.

Answer: In the revised manuscript (section 2.2), the authors clarified that:

"... the BBN approach is preferred due to its ability to explicitly represent causal relationships among variables and to integrate heterogeneous data sources (environmental, geological, and socio-economic) within a unified probabilistic framework. Unlike black-box models such as Random Forest or Neural Networks, BBN provides transparent and interpretable results, which are particularly important for risk communication and decision-making.

In addition, BBN can also be used to perform probabilistic inference in the face of uncertainty, and scenario-based analysis (e.g., with different rainfall conditions), which are necessary to landslide hazard and risk assessment. The following benefits make BBN

more appropriate in this research where both interpretability and combining various groups of factors are needed. This description has been included in the revised version…"

This explanation has been added to the revised manuscript.

3. The combination of BBN and SEM is a strength, but the specific role of SEM in the network structure construction process (e.g., determining causal relationships or parameter adjustment) needs to be clarified to avoid misunderstandings about the level of integration between the two methods.

Answer: In the revised manuscript, the authors explicitly state that:

"…SEM is used as a preliminary statistical analysis tool to identify and validate the relationships among variables, as well as to assess their relative influence. The results of SEM (together with multivariate regression) are used to support the selection of variables and the definition of network structure (i.e., directional relationships between nodes) in the BBN.

However, SEM is not directly integrated into the probabilistic inference process of the BBN. The conditional probability tables (CPTs) are constructed independently based on observed data and statistical relationships, rather than being directly parameterized from SEM outputs…"

This clarification has been added to the methodology section (section 2.2 – step 4) to clearly distinguish the complementary roles of SEM and BBN and to avoid any misunderstanding regarding their level of integration.

4. Although the paper emphasizes the integration of socio-economic factors, the specific role of this group of factors is not clearly demonstrated in the results section. The author could add a brief statement to clarify the extent of the influence of these factors in the model, thereby highlighting the significance of the multidimensional approach the study aims for.

Answer: In the revised manuscript, the authors have included a very short explanation in Results section in the revised manuscript to point out how socio-economic variables (e.g., land use, population, and infrastructure) contribute to the model. The findings suggest that

although these factors do not directly influence the occurrence of landslides (hazard), they have a major influence in the risk formation especially in the distribution of risk in space through exposure-related aspects.

This difference underlines the fact that the socio-economic factors integration is critical to the shift between the hazard assessment and the risk assessment approach, thus supporting the idea of the multidimensional character of the suggested approach.

5. The scenario analysis is a strong point; however, the logic behind constructing the scenarios (combining rainfall, land use, and protective structures) is not clearly explained. Adding a short paragraph explaining the reasons for choosing these combinations would help readers understand the representativeness and practical significance of the constructed scenarios.

Answer: To clarify that the scenarios are meant to reflect real world combinations of the important controlling factors in landslides, the have included a brief paragraph in the revised manuscript. In particular, rainfall can be chosen as the major triggering factor (on the basis of observed thresholds and short-term accumulation), land use as human-induced alterations of slope stability, and protective measures can be represented by protective structures (e.g., embankments) as the mitigation measures that can alter the vulnerability and exposure.

Additionally, the authors provided one more result related to probability maps of landslide occurring in different rainfall scenarios based on the BBN (Figure 7). Such combinations are not arbitrary, but are meant to model common and policy-relevant conditions that are faced within the study area and, in this way, the model can assess the level of hazard and risk responsiveness to different environmental and management conditions. This explanation has been added to enhance the clarity and practical application of the scenario design.

6. The role of reinforcement structures such as gabion embankments is presented in a very positive light. To achieve better academic balance, the author could add a brief statement

about the application conditions, scope of effectiveness, or potential limitations (e.g., cost, suitable terrain), thereby making the conclusions more objective.

Answer: In the revised manuscript, the authors have added a brief statement clarifying that while reinforcement structures such as gabion embankments are effective in reducing landslide risk, their applicability depends on site-specific conditions, including slope geometry, material properties, and hydrological context. In addition, practical considerations such as construction cost, maintenance requirements, and accessibility in mountainous terrain may limit their widespread implementation.

7. One of the advantages of BBN is its ability to handle uncertainty, but this aspect is not clearly emphasized in the methods section. Adding a sentence explaining how the model reflects and propagates uncertainty would further highlight the advantages of the methodology used in the study.

Answer: The authors explained more in the Methods and Discussion section about how uncertainty is explicitly modelled in the BBN by having probabilistic states of variables and conditional probability tables (CPTs). The model spreads uncertainty by revising posterior probabilities as the evidence varies so that the effect of uncertain or incomplete input data can be manifested in the final hazard and risk estimates. This addition underscores one of the major benefits of the BBN approach especially in complex environmental systems where data uncertainty and variability cannot be avoided.

8. Field data is mentioned as an important input source; however, its specific role in the model (calibration, validation, or structural construction) is not clearly presented. The author could clarify this point with a brief statement, thereby increasing the reliability and transparency of the study

Answer: In the revised manuscript, the authors explained in step 4 of section 2.2 that:

"… Five field trips were procedure from 2023 to 2025 to employ in three aspects: (i) to aid in the construction of the BBN structure by confirming the significance and orientation of relationships among variables; (ii) to instruct and calibrate CPTs where observational

data exist (e.g., by relating rainfall, slope, land use conditions to observed landslides); and (iii) to provide an independent validation check of the model, by comparing model. …"

This has been explained in the Methods section to enhance trustworthiness and transparency of the study.

9. The conclusion currently mainly summarizes the results but does not truly emphasize a key scientific message. The author could add a highly generalized summary sentence clarifying the core contribution of the study to the field of landslide and mudflow risk assessment, thereby increasing the academic weight of the paper.

Answer: In the revised manuscript, the authors indicated that the main contribution of this paper is the formulation of a probabilistic and multidimensional model integrating environmental, geological, and socio-economic factors to analyze the landslide hazard and risk together. In addition to improving the knowledge of landslide processes under uncertainty, this method also increases the relevance of risk assessment with the help of the analysis via scenarios and spatial representation.

Please check the revised manuscript to see all changes.

Thank you so much!