Response letter

Dear Editors and Reviewers:

Re: egusphere-2025-3004

We sincerely thank you and reviewers for providing us with such a valuable revision opportunity. Thus, we can further improve and present our studies. The comments from you and the reviewers were highly insightful and enabled us to greatly improve the quality of our manuscript. We have carefully reviewed the feedback and made corrections that we hope will be met with approval. Revised portions are marked on the revised manuscript. Please note that these resulting revisions did not change the paper's findings.

In the response letter to editor and reviewers, we firstly summarized the major changes in a cover letter to editors, and we then itemized response to editors and reviewers, **in which the blue font indicates the response to each comment and the black font presents the revision from the revised manuscript.**

We hope that the revisions in the revised manuscript and the responses to the comments will suffice to allow our manuscript to be suitable for publication in ***Natural Hazards and Earth System Sciences*****.**

Sincerely regards,

Songtang He (hest@imde.ac.cn)

Institute of Mountain Hazards and Environment, Chinese Academy of Science

Response to Reviewer #1

[Comment 1] The following studies cited are older than 10-15 years: Regmi et al., 2010; Yilmaz, 2009, Fell et al., 2008; Hürlimann et al., 2008; Sezer et al., 2010; Hu & Bentler, 1999; Goren et al., 2010; Manzella et al., 2008. It is preferable to cite recent articles in a manuscript, and only in exceptional circumstances should references going back more than 10-15 years be cited. It is preferable to cite recent articles because older references may be irrelevant given more recent advancements in the field of study. Exceptions to this rule should be reserved for seminal works directly relevant to the topic of research. Citing recent articles also helps journal editors see that there is a potential audience for your topic of research.

Response:

Thank you for your valuable suggestion. To ensure that the cited literature reflects the most recent advances in landslide susceptibility research, we have carefully reviewed and updated the references. Older citations have been removed and replaced with more recent and relevant studies to strengthen the scientific foundation of the manuscript(Delete the redundant literature："Fell et al., 2008; Hürlimann et al., 2008; Hu & Bentler, 1999; Goren et al., 2010; Manzella et al., 2008."). The revisions have been made in the Introduction (line 82) and Methods Section 2.3.2 of the revised manuscript, as shown below.

Introduction（Revised manuscript line 82）

"*Substantial efforts have been made to assess landslide susceptibility using various methodologies, including geoscience factor weighting, statistical models, machine learning, and Geographic Information Systems (GIS)-based spatial analysis (Abay et al., 2019; Gebrehiwot et al., 2025; Guo et al., 2023; Pham et al., 2018; Sun et al., 2024; Wang et al., 2024).*"

2.3.2 Rationality validation of susceptibility assessment results (Revised manuscript line 246)

"In this study, Receiver Operating Characteristic (ROC) curves and area under the curve (AUC) values were used for validation. ROC curves provide a representation of the specificity and sensitivity of an analytical method (Khosravi et al., 2019; Gebrehiwot, et al., 2025). The AUC measures model accuracy, ranging from 0.5 to 1, with values closer to 1 indicating higher accuracy (Wendim et al., 2025)."

References:

Abay, A., Barbieri, G., & Woldearegay, K. (2019). GIS-based Landslide Susceptibility Evaluation Using Analytical Hierarchy Process (AHP) Approach: The Case of Tarmaber District, Ethiopia. *Momona Ethiopian Journal of Science*, 11(1), 14–36. https://doi.org/10.4314/mejs.v11i1

Gebrehiwot, A., Berhane, G., Kide, Y. *et al.* Landslide susceptibility mapping in Lesalso (Laelay Maichew), Northern Ethiopia: a GIS approach using frequency ratio and analytical hierarchy process methods. *Model. Earth Syst. Environ.* **11**, 421 (2025). https://doi.org/10.1007/s40808-025-02578-7

Wendim, S., Mebrahtu, G. & Woldearegay, K. GIS-based landslide susceptibility mapping using Analytical Hierarchy Process method along Gedo-Dilb asphalt road section, Northern Ethiopia. *Bull Eng Geol Environ* **84**, 440 (2025). https://doi.org/10.1007/s10064-025-04455-0

[Comment 3] There is some repetition in the introduction, which can be frustrating for your readers; The last paragraph is so long, please split into two part.

Response:

Thank you for this helpful comment. We agree that the original Introduction contained some repetitive descriptions, which may reduce readability, and that the final paragraph was overly long.

In response, we carefully revised the Introduction to eliminate redundant statements and improve conciseness, particularly in the discussion of vegetation-related effects on landslide processes. Overlapping explanations were streamlined or merged to avoid repetition while preserving the necessary scientific context.

In addition, the original final paragraph has been reorganized and split into two shorter paragraphs. One now focuses on summarizing the research background and motivation, while the other clearly presents the study objectives and overall contribution. This restructuring improves readability and allows the logical progression of the Introduction to be more clearly conveyed.

We believe these revisions have enhanced the clarity, conciseness, and overall structure of the Introduction. We thank the reviewer for this constructive suggestion, which has helped improve the quality of the manuscript.

Introduction（Revised manuscript）

"*Landslides represent a significant geological hazard in mountainous regions worldwide, causing substantial loss of life, infrastructure damage, and economic disruption (Alvioli et al., 2024; Zhang et al., 2025). In areas with dense vegetation cover, the relationship between vegetation and slope stability is particularly complex and non-linear (Deng et al., 2022; Medina et al., 2021). While vegetation is traditionally regarded as a stabilizing agent through root reinforcement, soil moisture regulation, and erosion control (He et al., 2017; Lan et al., 2020; Rey et al., 2019), shallow landslides frequently occur even in densely vegetated landscapes (Xu et al., 2024). This paradox underscores the dual—and often contradictory—role of vegetation in landslide processes, acting as both a mitigating and a predisposing factor depending on environmental context and trigger conditions.*

The stabilizing function of vegetation is well-documented. Root systems enhance soil cohesion and shear strength, while canopy and litter layers reduce rainfall impact and surface runoff (Gonzalez-Ollauri & Mickovski, 2016; Murgia et al., 2022; Vergani et al., 2017). However, under certain conditions, vegetation can exacerbate slope instability. The added weight of trees, especially on steep slopes, increases gravitational driving forces (Schmaltz & Mergili, 2018). Vegetation can also alter soil hydrological properties, increasing infiltration and soil moisture content, which in turn reduces effective stress and shear resistance during rainfall events (Qin et al., 2022). Furthermore, wind forces acting on tall vegetation can transmit dynamic loads to the slope, while root wedging in thin soils may promote fracture development (Bordoloi & Ng, 2020; Liu et al., 2020). Rainfall remains the primary trigger of landslides in *vegetated areas, as it saturates the soil, elevates pore water pressure, and reduces slope stability (Dhanai et al., 2022; Li et al., 2025). Therefore, landslide initiation in vegetated terrain is not governed by vegetation alone but results from the intricate interplay among vegetation characteristics, rainfall intensity, slope gradient, lithology, and other environmental factors.*

Substantial efforts have been made to assess landslide susceptibility using various methodologies, including geoscience factor weighting, statistical models, machine learning, and Geographic Information Systems (GIS)-based spatial analysis (Abay et al., 2019; Gebrehiwot et al., 2025; Guo et al., 2023; Pham et al., 2018; Sun et al., 2024; Wang et al., 2024). These approaches have improved our understanding of the spatial distribution of landslides and the relative importance of conditioning factors. However, several critical gaps remain. First, many studies provide qualitative descriptions of factor influences but lack quantitative analysis of spatial correlations and interactive effects among multiple driving factors (Shu et al., 2025; Triplett et al., 2025). Second, while rainfall-landslide relationships have been extensively studied using spatial autocorrelation and clustering techniques (Chen et al., 2024; Liu et al., 2024; Ortiz-Giraldo et al., 2023; Pokharel et al., 2021; Wang et al., 2020), the moderating role of vegetation in these relationships is poorly quantified. Specifically, how vegetation mediates the effects of rainfall, lithology, slope, and wind on slope stability coefficients remains unclear (Lan et al., 2020). Third, most susceptibility models operate at a single spatial scale, either regional/watershed or site-specific, with limited integration across scales. This hampers a holistic understanding of how macro-scale predisposing factors translate into micro-scale failure mechanisms.

To address these research gaps, this study investigates the dual-edged role of vegetation in landslide susceptibility by integrating watershed-scale statistical analysis with site-specific geomechanical modeling. We selected the Jinkouhe District in Southwest China—a region with high vegetation cover (⩾65.5%) and frequent landslide activity—as our study area. The research aims to (1) Quantify the individual and interactive effects of key environmental factors (rainfall, vegetation, wind speed, slope, lithology, etc.) on landslide susceptibility at the watershed scale using Geodetector and Structural Equation Modeling (SEM). (2) Analyze the mechanical role of vegetation weight and its coupling with rainfall and anthropogenic loading in triggering a typical shallow landslide through slope stability calculations. (3) Integrate *findings from both scales to elucidate how vegetation mediates landslide processes under different environmental conditions, thereby providing a multi-scale perspective on its "double-edged sword" function. By bridging macroscopic susceptibility patterns with microscopic failure mechanisms, this study offers novel insights into the complex vegetation–landslide interplay. The results are expected to enhance the accuracy of landslide risk assessments and inform sustainable slope management strategies in densely vegetated mountainous regions.*"

References:

Abay, A., Barbieri, G., & Woldearegay, K. (2019). GIS-based Landslide Susceptibility Evaluation Using Analytical Hierarchy Process (AHP) Approach: The Case of Tarmaber District, Ethiopia. Momona Ethiopian Journal of Science, 11(1), 14–36. https://doi.org/10.4314/mejs.v11i1.

Alvioli, M., Loche, M., Jacobs, L., Grohmann, C. H., Abraham, M. T., Gupta, K., Satyam, N., Scaringi, G., Bornaetxea, T., Rossi, M., Marchesini, I., Lombardo, L., Moreno, M., Steger, S., Camera, C. A. S., Bajni, G., Samodra, G., Wahyudi, E. E., Susyanto, N., Sinčić, M., Gazibara, S. B., Sirbu, F., Torizin, J., Schüßler, N., Mirus, B. B., Woodard, J. B., Aguilera, H., & Rivera-Rivera, J. (2024). A benchmark dataset and workflow for landslide susceptibility zonation. *Earth-Science Reviews*, 258, 104927. https://doi.org/10.1016/j.earscirev.2024.104927

Bordoloi, S., & Ng, C. W. W. (2020). The effects of vegetation traits and their stability functions in bio-engineered slopes: A perspective review. *Engineering Geology*, 275, 105742. https://doi.org/10.1016/j.enggeo.2020.105742

Chen, C., Liu, Y., Li, Y., & Guo, F. (2024). Mapping landslide susceptibility with the consideration of spatial heterogeneity and factor optimization. *Natural Hazards* http://doi.org/10.1007/s11069-024-06955-w

Deng, J., Ma, C., & Zhang, Y. (2022). Shallow landslide characteristics and its response to vegetation by example of July 2013, extreme rainstorm, Central Loess Plateau, China. *Bulletin of Engineering Geology and the Environment*, 81(3), 100. http://doi.org/10.1007/s10064-022-02606-1

Dhanai, P., Singh, V.P. & Soni, P. Rainfall Triggered Slope Instability Analysis with Changing Climate. *Indian Geotech J* **52**, 477–492 (2022). https://doi.org/10.1007/s40098-021-00581-0

Gebrehiwot, A., Berhane, G., Kide, Y. *et al.* Landslide susceptibility mapping in Lesalso (Laelay Maichew), Northern Ethiopia: a GIS approach using frequency ratio and analytical hierarchy process methods. *Model. Earth Syst. Environ.* **11**, 421 (2025). https://doi.org/10.1007/s40808-025-02578-7

Gonzalez-Ollauri, A., & Mickovski, S. B. (2016). Using the root spread information of pioneer plants to quantify their mitigation potential against shallow landslides and erosion in temperate humid climates. *Ecological Engineering*, 95, 302-315. https://doi.org/10.1016/j.ecoleng.2016.06.028

Guo, Z., Guo, F., Zhang, Y., He, J., Li, G., Yang, Y., & Zhang, X. (2023). A python system for regional landslide susceptibility assessment by integrating machine learning models and its application. *Heliyon*, 9(11) https://doi.org/10.1016/j.heliyon.2023.e21542

He, S., Wang, D., Fang, Y., & Lan, H. (2017). Guidelines for integrating ecological and biological engineering technologies for control of severe erosion in mountainous areas – A case study of the Xiaojiang River Basin, China. *International Soil and Water Conservation Research*, 5(4), 335-344. https://doi.org/10.1016/j.iswcr.2017.05.001

Lan, H., Wang, D., He, S., Fang, Y., Chen, W., Zhao, P., & Qi, Y. (2020). Experimental study on the effects of tree planting on slope stability. *Landslides*, 17(4), 1021-1035. http://doi.org/10.1007/s10346-020-01348-z

Li, Z., Guo, J., Li, T. *et al.* Influence of topography on the fragmentation and mobility of landslides. *Bull Eng Geol Environ* **84**, 73 (2025). https://doi.org/10.1007/s10064-025-04095-4

Liu, W., Yang, Z., & He, S. (2020). Modeling the landslide-generated debris flow from formation to propagation and run-out by considering the effect of vegetation. *Landslides*, 18, 43-58. https://doi.org/10.1007/s10346-020-01478-4

Medina, V., Hürlimann, M., Guo, Z., Lloret, A., & Vaunat, J. (2021). Fast physically-based model for rainfall-induced landslide susceptibility assessment at regional scale. *Catena*, 201, 105213. https://doi.org/10.1016/j.catena.2021.105213

Murgia, I., Giadrossich, F., Mao, Z., Cohen, D., Capra, G. F., & Schwarz, M. (2022). Modeling shallow landslides and root reinforcement: A review. *Ecological Engineering*, 181, 106671. https://doi.org/10.1016/j.ecoleng.2022.106671

Ortiz-Giraldo L, Botero BA and Vega J (2023) An integral assessment of landslide dams generated by the occurrence of rainfall-induced landslide and debris flow hazard chain. *Front. Earth Sci.* 11:1157881. http://doi.org/10.3389/feart.2023.1157881

Pham, B. T., Prakash, I., & Tien Bui, D. (2018). Spatial prediction of landslides using a hybrid machine learning approach based on Random Subspace and Classification and Regression Trees. *Geomorphology*, 303, 256-270. https://doi.org/10.1016/j.geomorph.2017.12.008

Pokharel, B., Althuwaynee, O. F., Aydda, A., Kim, S., Lim, S., & Park, H. (2021). Spatial clustering and modelling for landslide susceptibility mapping in the north of the Kathmandu Valley, Nepal. *Landslides*, 18(4), 1403-1419. http://doi.org/10.1007/s10346-020-01558-5

Qin, M., Cui, P., Jiang, Y. et al. Occurrence of shallow landslides triggered by increased hydraulic conductivity due to tree roots. Landslides 19, 2593–2604 (2022). https://doi.org/10.1007/s10346-022-01921-8

Rey, F., Bifulco, C., Bischetti, G. B., Bourrier, F., De Cesare, G., Florineth, F., Graf, F., Marden, M., Mickovski, S. B., Phillips, C., Peklo, K., Poesen, J., Polster, D., Preti, F., Rauch, H. P., Raymond, P., Sangalli, P., Tardio, G., & Stokes, A. (2019). Soil and water bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration. *Science of the Total Environment*, 648, 1210-1218. http://doi.org/https://doi.org/10.1016/j.scitotenv.2018.08.217

Schmaltz, E. M., & Mergili, M. (2018). Integration of root systems into a GIS-based slip surface model: computational experiments in a generic hillslope environment. *Landslides*, 15(8), 1561-1575. http://doi.org/10.1007/s10346-018-0970-8

Shu, H., Qi, S., Liu, X., Shao, X., Wang, X., Sun, D., ... & He, J. (2025). Relationship between continuous or discontinuous of controlling factors and landslide susceptibility in the high-cold mountainous areas, China. Ecological Indicators, 172, 113313. https://doi.org/10.1016/j.ecolind.2025.113313

Sun, D., Wang, J., Wen, H., Ding, Y., & Mi, C. (2024). Landslide susceptibility mapping (LSM) based on different boosting and hyperparameter optimization algorithms: A case of Wanzhou District, China. *Journal of Rock Mechanics and Geotechnical Engineering*, 16(8), 3221-3232. https://doi.org/10.1016/j.jrmge.2023.09.037

Triplett, L.D., Hammer, M.N., DeLong, S.B. et al. Factors influencing landslide occurrence in low-relief formerly glaciated landscapes: landslide inventory and susceptibility analysis in Minnesota, USA. Nat Hazards 121, 11799–11827 (2025). https://doi.org/10.1007/s11069-025-07262-8

Vergani, C., Giadrossich, F., Buckley, P., Conedera, M., Pividori, M., Salbitano, F., Rauch, H. S., Lovreglio, R., & Schwarz, M. (2017). Root reinforcement dynamics of European coppice woodlands and their effect on shallow landslides: A review. *Earth-Science Reviews*, 167, 88-102. http://doi.org/https://doi.org/10.1016/j.earscirev.2017.02.002

Wang, Y., Feng, L., Li, S., Ren, F., & Du, Q. (2020). A hybrid model considering spatial heterogeneity for landslide susceptibility mapping in Zhejiang Province, China. *Catena*, 188, 104425. http://doi.org/https://doi.org/10.1016/j.catena.2019.104425

Wang, Y., Ling, Y., Chan, T. O., & Awange, J. (2024). High-resolution earthquakeinduced landslide hazard assessment in Southwest China through frequency ratio analysis and LightGBM. *International Journal of Applied Earth Observation and Geoinformation*, 131, 103947. https://doi.org/10.1016/j.jag.2024.103947

Xu, Y., Luo, L., Guo, W., Jin, Z., Tian, P., & Wang, W. (2024). Revegetation Changes Main Erosion Type on the Gully–Slope on the Chinese Loess Plateau Under Extreme Rainfall: Reducing Gully Erosion and Promoting Shallow Landslides. *Water Resources Research*, 60(3), e2023WR036307. https://doi.org/10.1029/2023WR036307

Zhang, Y., Li, y., Tom Dijkstra., Janusz Wasowski., Meng, X., Wu, X., Liu, W., Chen, G. (2025). Evolution of large landslides in tectonically active regions - A decade of observations in the Zhouqu County, China. Engineering Geology, 348, 107967. https://doi.org/10.1016/j.enggeo.2025.107967

[Comment 4] Line 67, “reposted” should be “reported”.

Response: Thank you for pointing out this inappropriate expression. It has been corrected in the revised manuscript.

[Comment 5] Figures 1,2 and 4 were referenced in the text after the appearance of the figure. Please amend;

Response: Thank you for pointing out the issue regarding the citation order of Figures 1, 2, and 4. We have adjusted the paragraph structure and the placement of the figures accordingly in the revised manuscript.

[Comment 6] Clarify why the specific study area (Jinkouhe District) was chosen—how do its characteristics contribute to the relevance of this research?

Response:

Thank you for your valuable comment regarding the selection of the study area. The Jinkouhe area was chosen based on the following scientific considerations:

1. High vegetation coverage and complex landslide mechanisms

The Jinkouhe area has a high vegetation coverage (≥65.5%) yet frequently experiences shallow landslides, indicating that the effects of vegetation on landslides are complex and not unidirectionally stabilizing (He et al., 2017; Xu et al., 2024). Previous studies have shown that while vegetation can reduce soil erosion and enhance slope stability, it may also increase landslide susceptibility due to tree weight or changes in soil properties (Lan et al., 2020; Qin et al., 2024). Therefore, this area provides an ideal setting to investigate the interactive effects of vegetation with rainfall, slope gradient, lithology, and wind forces on landslide susceptibility, thereby revealing the "double-edged sword" role of vegetation.

2. Feasibility of multi-scale analysis

The region's complex topography, diverse geology, and variable hydrological and climatic conditions make it highly suitable for coupled watershed- and point-scale analyses. By applying structural equation modeling (SEM), the Geodetector method, and slope stability coefficient calculations, the influences of individual factors and their interactions on landslide occurrence can be quantified, providing insights into the concealed mechanisms of landslides in highly vegetated areas.

3. Scientific significance

Selecting the Jinkouhe area not only facilitates the investigation of complex landslide mechanisms in regions with dense vegetation but also provides theoretical reference and practical experience for landslide risk assessment and disaster prevention in similar ecological settings. This contributes significantly to understanding the dual role of vegetation in landslide control and the interactive effects of multiple environmental factors.

In addition, to highlight the scientific rationale for this selection, we have supplemented the *Study Area* section with the following statement.

2.1 Study Area（Revised manuscript line 120）

"*It provides a representative setting for investigating the dual role of vegetation in landslide occurrence and the coupled influences of multiple environmental factors in highly vegetated mountainous terrains.*"

References:

He, S., Wang, D., Fang, Y., & Lan, H. (2017). Guidelines for integrating ecological and biological engineering technologies for control of severe erosion in mountainous areas – A case study of the Xiaojiang River Basin, China. *International Soil and Water Conservation Research*, 5(4), 335-344. https://doi.org/10.1016/j.iswcr.2017.05.001

Lan, H., Wang, D., He, S., Fang, Y., Chen, W., Zhao, P., & Qi, Y. (2020). Experimental study on the effects of tree planting on slope stability. *Landslides*, 17(4), 1021-1035. http://doi.org/10.1007/s10346-020-01348-z

Qin, M., Cui, P., Jiang, Y. et al. Occurrence of shallow landslides triggered by increased hydraulic conductivity due to tree roots. *Landslides* 19, 2593–2604 (2022). https://doi.org/10.1007/s10346-022-01921-8

Xu, Y., Luo, L., Guo, W., Jin, Z., Tian, P., & Wang, W. (2024). Revegetation Changes Main Erosion Type on the Gully–Slope on the Chinese Loess Plateau Under Extreme Rainfall: Reducing Gully Erosion and Promoting Shallow Landslides. *Water Resources Research*, 60(3), e2023WR036307. https://doi.org/10.1029/2023WR036307

[Comment 7] Provide more detailed descriptions of the modeling processes, especially SEM, including assumptions made during factor selection.

Response:

Thank you for your insightful comment. We have expanded the description of the Structural Equation Model (SEM) to provide a clearer explanation of the modeling process, including the assumptions underlying factor selection and the relationships among key variables.

2.4 (2) Structural equation model（Revised manuscript line 303）

“*The SEM comprises two components: the measurement model, which defines relationships between observed and latent variables, and the structural model, which illustrates relationships among latent variables (Fan et al., 2016; Wang & Rhemtulla, 2021). Based on the GeoDetector results and previous research findings (Chicas et al., 2024; Pourghasemi et al., 2018; Segoni et al., 2024), key factors representing topographic, hydrological, and environmental characteristics were selected to capture the main drivers of landslide susceptibility. The selection of these factors was guided* *by the assumption that each variable has a direct or indirect physical relationship with landslide occurrence, possesses sufficient explanatory power in the GeoDetector analysis, and reflects geomorphological and ecological processes under high-vegetation conditions. Accordingly, the following hypotheses were proposed:*"

References:

Chicas, S. D., Li, H., Mizoue, N., Ota, T., Du, Y., & Somogyvári, M. (2024). Landslide susceptibility mapping core-base factors and models' performance variability: a systematic review. *Natural Hazards*, 120(14), 12573-12593. http://doi.org/10.1007/s11069-024-06697-9

Fan, Y., Chen, J., Shirkey, G., John, R., Wu, S. R., Park, H., & Shao, C. (2016). Applications of structural equation modeling (SEM) in ecological studies: an updated review. *Ecological Processes*, 5(1), 19. http://doi.org/10.1186/s13717-016-0063-3

Pourghasemi, H. R., Teimoori Yansari, Z., Panagos, P., & Pradhan, B. (2018). Analysis and evaluation of landslide susceptibility: a review on articles published during 2005–2016 (periods of 2005–2012 and 2013–2016). *Arabian Journal of Geosciences*, 11(9), 193. http://doi.org/10.1007/s12517-018-3531-5

Segoni, S., Ajin, R. S., Nocentini, N., & Fanti, R. (2024). Insights Gained from the Review of Landslide Susceptibility Assessment Studies in Italy. *Remote Sensing*, *16*(23), 4491. https://doi.org/10.3390/rs16234491

Wang, Y. A., & Rhemtulla, M. (2021). Power Analysis for Parameter Estimation in Structural Equation Modeling: A Discussion and Tutorial. *Advances in Methods and Practices in Psychological Science*, 4(1), 1403230957. http://doi.org/10.1177/2515245920918253

[Comment 8] please redraw the Fig. 6.

Response:

Thank you for your suggestion. We have redrawn and optimized Figure 6 by adding a sloping background, illustrating the distribution of shrubs, trees, and grasses on the slope, and incorporating a rainfall scenario at the top of the figure. These elements were integrated with the original schematic to more clearly depict the conceptual processes, resulting in the revised Figure 6 presented in the manuscript.

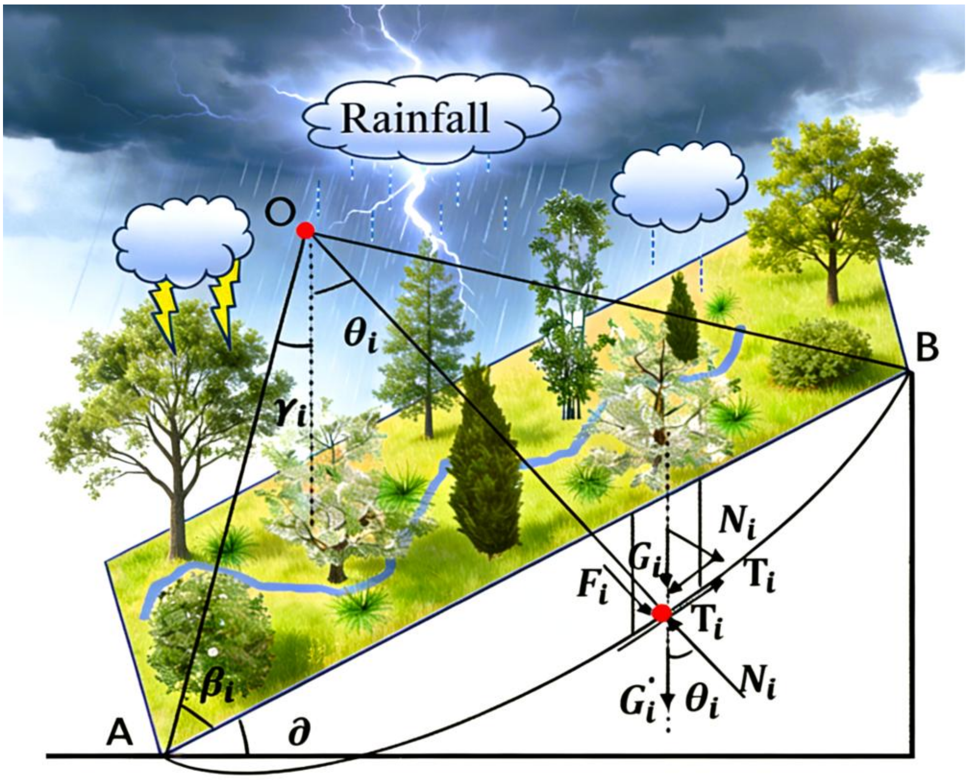

Fig.6. Slope Stress Analysis Diagram

Furthermore, to comply with the journal's publication requirements, we have also refined several other figures to achieve a consistent style and improved graphical quality across the manuscript. For Figure 1, we added a new basemap for panels (a) and (b). In (a), the names of other provinces were removed, while Sichuan Province was retained and highlighted. Panel (b) now more clearly shows the location of the study area. In (c), the color scheme and north arrow were updated for better visual clarity. In addition, panels (d–h) were supplemented with partially interpreted landslides in densely vegetated areas based on visual interpretation.

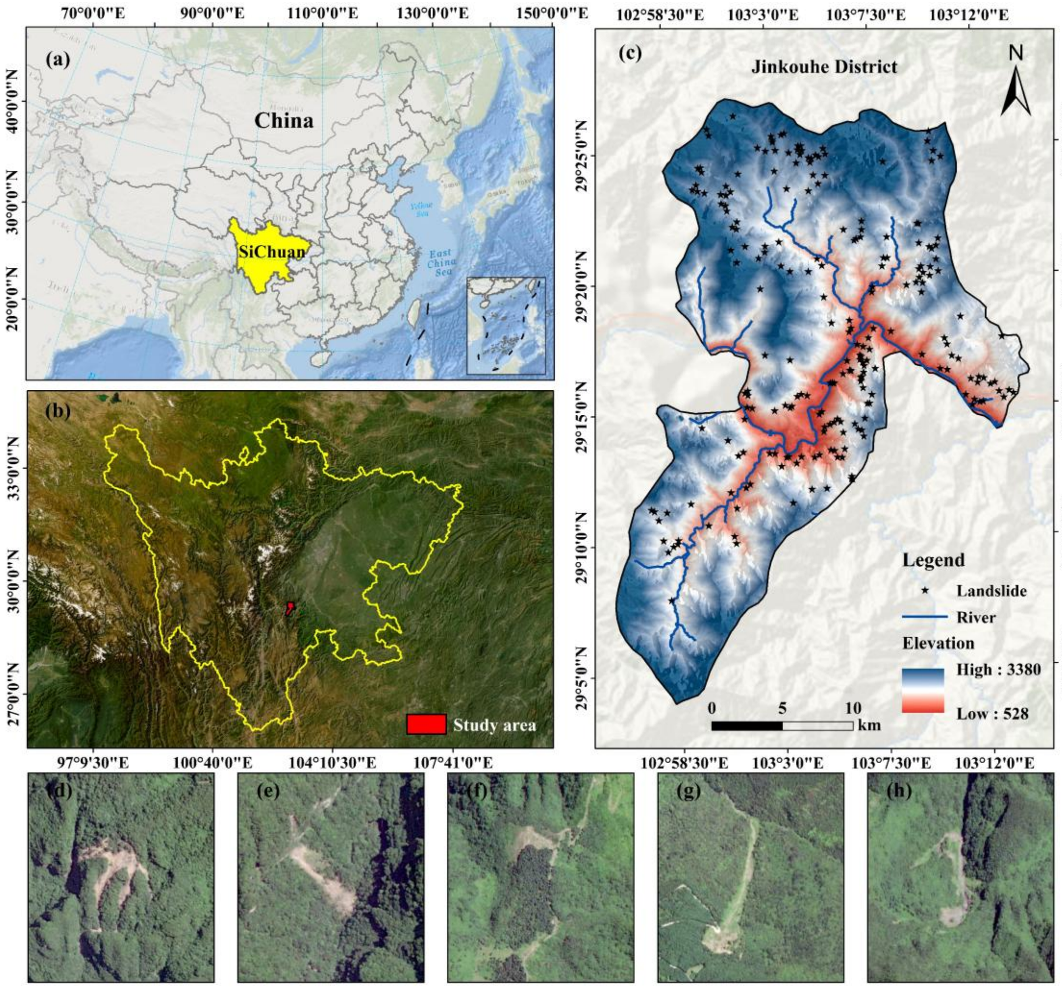

Fig. 1. Location map of Jinkouhe District

For **Figure 7**, the north arrow was replaced, and a new layer title "LSI" was added to improve the figure's interpretability.

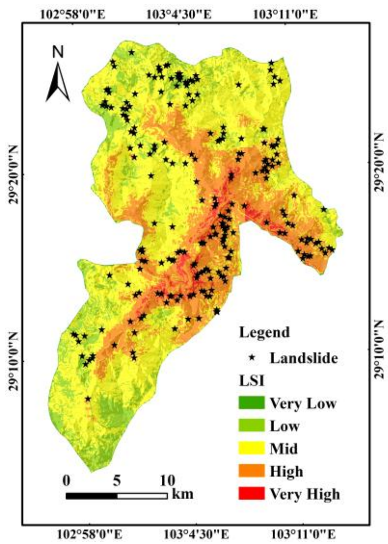

Fig. 2. Landslide susceptibility assessment map

For **Figure 9**, the image was simplified by replacing the previously cluttered multicolor layout with a yellow-and-blue scheme. Yellow arrows represent the total effects of conditioning factors on landslide susceptibility, while blue dashed lines indicate the indirect interactions among factors.

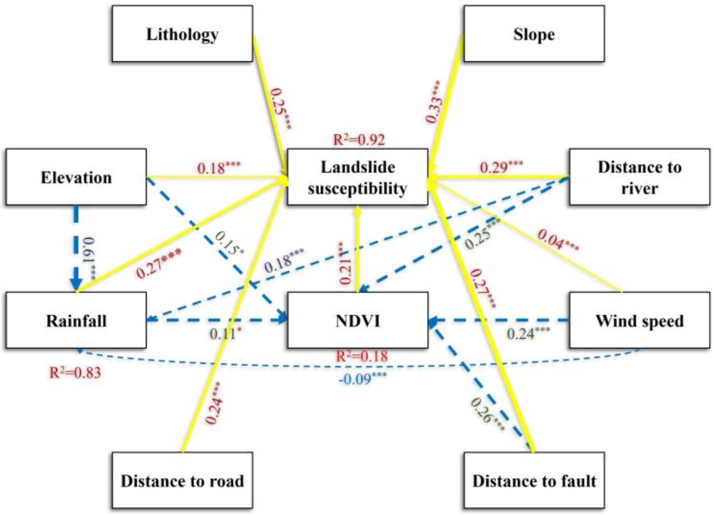

Fig. 3. SEM of landslide susceptibility.

For **Figure 10**, we removed the landslide point distribution to make the map clearer, and added a legend, scale bar, and north arrow for each scenario to improve consistency and clarity.

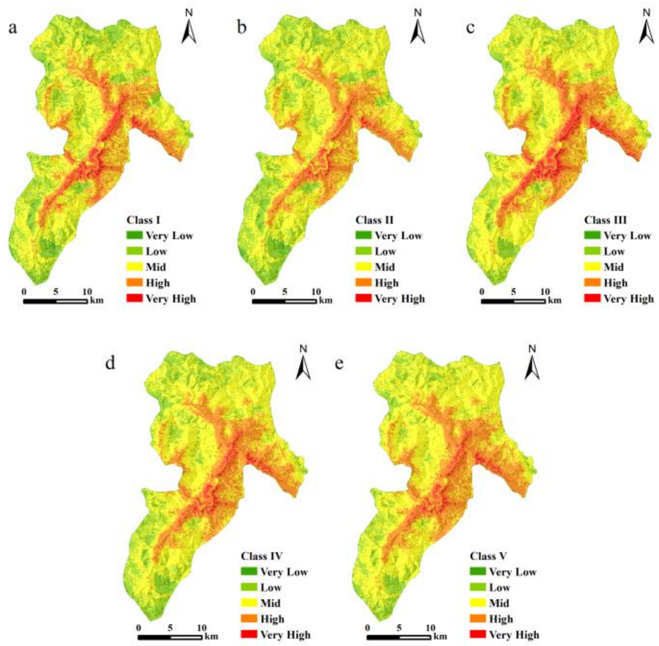

Fig. 4. Landslide Susceptibility Distribution Map for Five Scenarios

[Comment 9] Lines 330-332, It would be useful to give the areas (north, southwest, etc.);

Response:

Thank you for your insightful comment. We have adjusted the sentence order in this section and re-added directional information to clarify the distribution of high and very high susceptibility zones. The revised text is as follows:

3.1 Landslide susceptibility mapping and distribution characteristics （Revised manuscript line 369）

"*Moderate susceptibility zones are widespread across the northern, western, and southwestern regions. High and very high susceptibility zones, though smaller in coverage, exhibit a "cross-shaped" spatial distribution, primarily located in the central-eastern and northeastern parts of the study area, with a small portion in the southwest. Very high susceptibility zones are scattered within the high susceptibility areas*."

[Comment 10] Line 335, please left a space between Fig.7.landslide……

Response: Thank you for pointing out this error. We have corrected it in the revised manuscript.

[Comment 11] Lines 352-353, the title 3.3 can be revised as "Slope stability calculation considering artificial waste sediment and vegetation self-weight".

Response: Thank you for your precise comment. We agree with your suggestion and have revised the original subsection title accordingly.

[Comment 12] This section provides a thorough discussion of the results-based part and the differences and improvements compared to previous studies, and also offers an outlook on future work. However, it is necessary to more clearly point out the unique aspects of this research (for example, "integrating macroscopic susceptibility with microscopic mechanics"). The outlook for future research can be more specific, for example: how to utilize interpretable machine learning and multi-source data fusion, rather than just making general statements:

Response: Thank you very much for this valuable and constructive comment. We appreciate the reviewer's recognition of the comprehensive discussion of our results and agree that the unique aspects and future perspectives of this study should be stated more clearly. In the revised manuscript, we emphasize that the novelty of this research lies in revealing that even areas with dense vegetation coverage, which are often considered stable, can still experience shallow landslides under the combined influence of rainfall, vegetation weight, and human disturbances. By integrating macroscopic susceptibility analysis with microscopic mechanical interpretation, our study connects regional-scale assessments with field-scale processes and provides new insight into the dual role of vegetation in slope stability.

In addition, the Outlook section has been refined to include more targeted content. Future research could consider applying optical remote sensing image classification and InSAR deformation monitoring to identify potentially unstable slopes. At the same time, interpretable machine learning models, such as SHAP-based approaches, could be used to quantify the nonlinear interactions, threshold effects, and spatial heterogeneity among key conditioning factors. These methods would improve the interpretability of susceptibility assessments and enhance the temporal and spatial resolution of landslide prediction and early warning in densely vegetated mountainous regions. These additions make the outlook more specific and provide feasible directions for extending the current research.

4.4 Comparison with previous studies and scope for future research（Revised manuscript line 593）

"*Existing studies on landslides have predominantly focused on rainfall-related triggering mechanisms, such as rainfall intensity, duration, and antecedent moisture conditions (Gatto et al., 2025; Zhang et al., 2025). For example, Cui et al. (2024) analyzed the characteristics and causes of a similar landslide in this area using Massflow V2.8 simulations. They identified rainfall and human activities as key triggers, but insufficiently addressed interactions between soil, moisture, and external forces (such as natural wind and human mining activities) under high vegetation* *conditions. This limited simulation accuracy. In these studies, vegetation is often treated as a background environmental condition or a stabilizing factor, while its mechanical and hydrological roles are rarely quantified explicitly. As a result, landslides occurring in highly vegetated areas are commonly interpreted primarily as a response to extreme rainfall, with comparatively limited attention paid to vegetation-related processes themselves. Consequently, from the perspective of vegetation as an active influencing factor, research addressing why landslides still occur in areas with dense vegetation coverage remains relatively scarce.*

Furthermore, An et al. (2025) investigated the mechanisms of landslide occurrence in densely vegetated areas by examining the interactions between terrain and lithological properties. They highlighted that in natural forests, landslides tend to initiate along the soil–bedrock interface. Owing to the shallow soil layer and pronounced permeability contrast, perched water readily accumulates above this interface, thereby reducing shear strength and triggering slope failure. Their work underscores the significant role of vegetation as a key intermediary that links various environmental factors in shaping landslide susceptibility. Nevertheless, their study treated terrain and lithology primarily as background environmental conditions and did not account for slope damage induced by wind drag on trees. In contrast, the present study incorporates wind forces both in the macroscopic assessment of landslide susceptibility and in the stability analysis of specific slopes.The results of our study support and extend these findings by demonstrating that high vegetation coverage does not necessarily imply low landslide susceptibility.

Our study integrates regional-scale susceptibility assessment with site-scale mechanical interpretation. This multi-scale framework bridges macroscopic statistical patterns and microscopic physical processes, providing a more comprehensive understanding of vegetation's "double-edged" effect on landslide development. The novelty of this work lies not only in identifying the limitations of vegetation's stabilizing role, but also in clarifying the conditions under which its negative effects may become significant. But research on vegetation types, height, and growth conditions (such as thickness and types of soil and human activity disturbances) in relation to landslide risks remains limited. Future research could apply optical remote sensing image classification and InSAR deformation monitoring to identify potentially unstable slopes and capture temporal deformation characteristics (Li et al., 2025). When combined *with interpretable machine learning approaches, such as SHAP-based models, together with analytical tools like GeoDetector and SEM, these methods can quantify nonlinear interactions, threshold effects, and spatial heterogeneity among conditioning factors (Sun et al., 2024; Wen et al., 2025), thereby improving the interpretability of susceptibility evaluation and enhancing the prediction capability for landslides in densely vegetated areas.*"

References:

An, N., Dai, Z., Hu, X., Wang, B., Huo, Z., Xiao, Y., ... & Yang, Y. (2025). Comparing landslide patterns and failure mechanisms in restored and native forest ecosystems: Insights from geomorphology, lithology and vegetation. Catena, 260, 109452. https://doi.org/10.1016/j.catena.2025.109452

Cui, Y., Qian, Z., Xu, W., & Xu, C. (2024). A Small-Scale Landslide in 2023, Leshan, China: Basic Characteristics, Kinematic Process and Cause Analysis. Remote Sensing, 16(17), 3324. http://doi.org/10.3390/rs16173324

Gatto M P A, Misiano S, Montrasio L. Space-time prediction of rainfall-induced shallow landslides through Artificial Neural Networks in comparison with the SLIP model[J]. Engineering Geology, 2025, 344: 107822. https://doi.org/10.1016/j.enggeo.2024.107822

Li, Q., Li, X., Zhao, C., & Zhang, S. (2025). Back analysis key parameters of Scoops3D model using SBAS-InSAR technology for regional landslide hazard assessment. Landslides, 22(12), 4097-4112. https://doi.org/10.1007/s10346-025-02578-9

Sun, D., Wang, J., Wen, H., Ding, Y., & Mi, C. (2024). Landslide susceptibility mapping (LSM) based on different boosting and hyperparameter optimization algorithms: A case of Wanzhou District, China. Journal of Rock Mechanics and Geotechnical Engineering, 16(8), 3221-3232. https://doi.org/10.1016/j.jrmge.2023.09.037

Wen, H., Yan, F., Huang, J., & Li, Y. (2025). Interpretable machine learning models and decision-making mechanisms for landslide hazard assessment under different rainfall conditions. Expert Systems with Applications, 270, 126582. https://doi.org/10.1016/j.eswa.2025.126582

Zhang L M, Lü Q, Deng Z H, et al. Probabilistic approach to determine rainfall thresholds for rainstorm-induced shallow landslides using long-term local precipitation records[J]. Engineering Geology, 2025: 108139. https://doi.org/10.1016/j.enggeo.2025.108139

[Comment 13] Line 364, the title should be changed to "Analysis of landslide driving factors and their interaction pathways". This part, the authors mainly emphasize the factors and the interactions.

Response: Thank you for your valuable comment. We agree with your suggestion and have revised the subsection title accordingly.

[Comment 14] Line 453, the title should be precise. This part mainly compared the landslide susceptibility under different factors combination, so maybe this title will be more suitable: "differences and explanations of landslide susceptibility results under different factor combinations".

Response: Thank you for pointing out this inappropriate expression. It has been corrected in the revised manuscript.

Thank you again for the reviewer's constructive comments. We hope the revisions and responses will make our manuscript suitable for publication in ***Natural Hazards and Earth System Sciences.***