A Soil Moisture-Informed Seismic Landslide Model Using SMAP Satellite Data

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Motivation

- Earthquake-triggered landslides pose serious threats to lives and infrastructure worldwide
- Existing seismic landslide models emphasize seismic shaking and terrain, while relying on static hydrologic proxies rather than direct observations of pre-event soil moisture

Approach

- Compiled landslide inventories from five major earthquakes and developed a balanced dataset of landslide and non-landslide cases
- Conducted exploratory analysis to evaluate relationships between pre-event soil moisture, seismic, terrain, and hydrologic variables
- Integrated satellite-based soil moisture from NASA's SMAP mission into a Random Forest seismic landslide model
- Evaluated performance using leave-one-earthquake-out testing and benchmarked against the USGS landslide model

Landslide Inventories

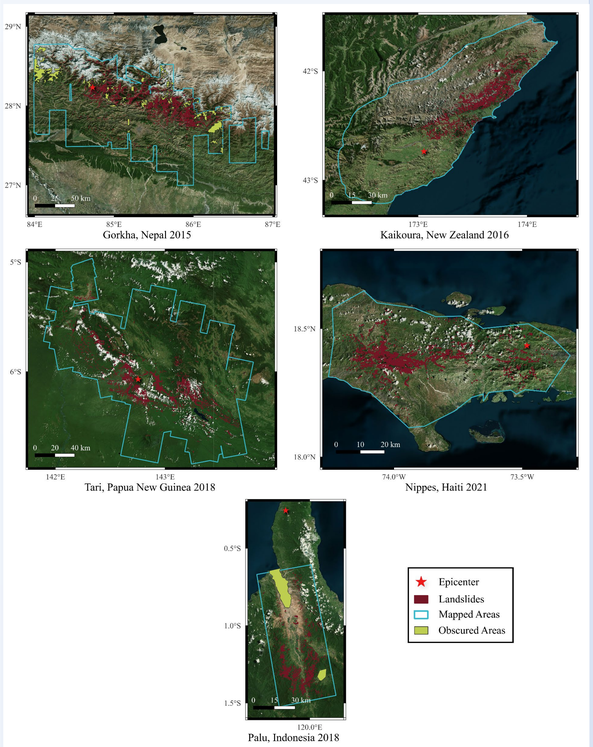

Fig. 1. Landslide inventories used in this study.

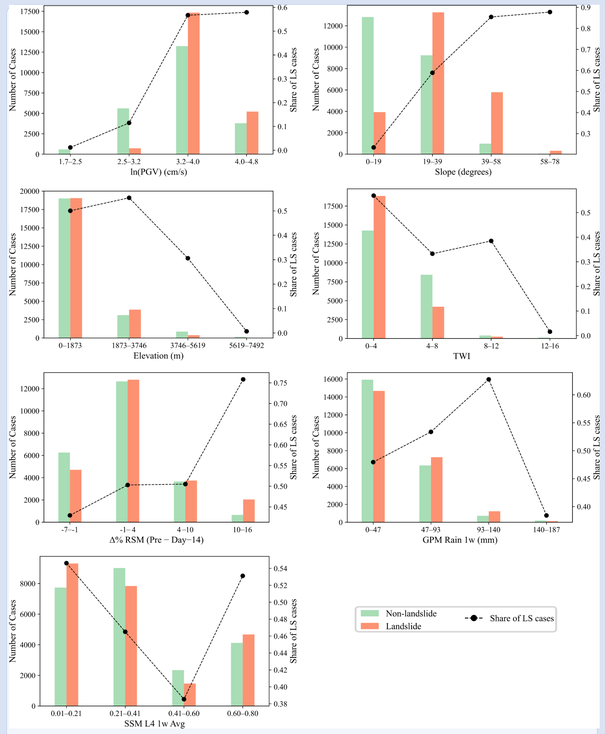

Fig. 2. Distribution of landslide and non-landslide cases across binned intervals of selected key variables.

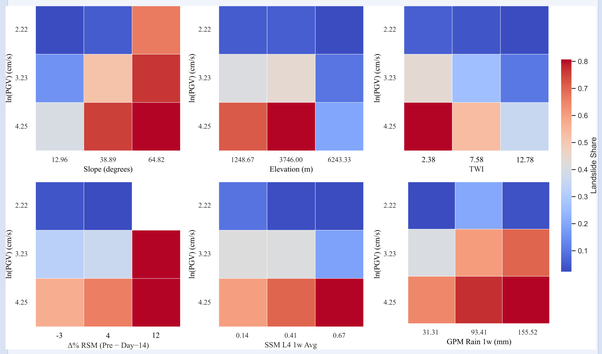

Fig. 3. Stratified bivariate heatmaps showing the proportion of landslide cases across combinations of PGV and other selected key variables. Warmer colors indicate a higher share of landslide events.

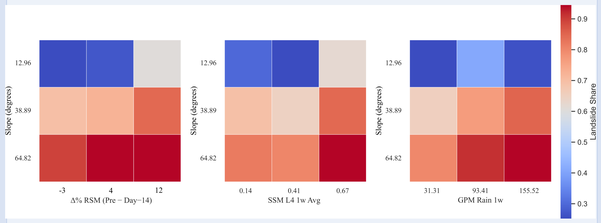

Fig. 4. Stratified bivariate heatmaps showing the proportion of landslide cases across combinations of Slope and hydrological variables: Δ% SSM L4 (Pre − Day−7), SSM L4 1w Ave, and GPM Rain 1w.

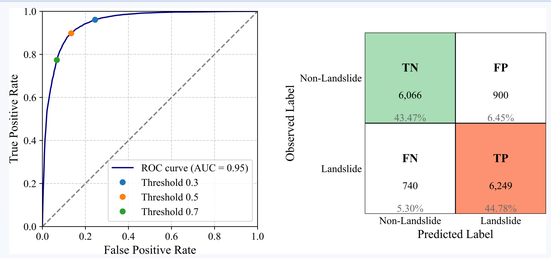

Fig. 5. ROC curve of the global model, accompanied by the confusion matrix at a 0.5 threshold. The matrix displays the distribution of true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN).

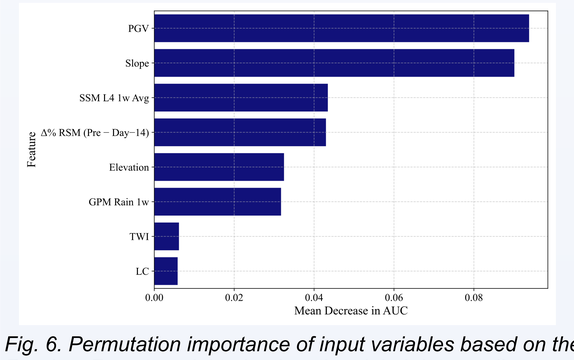

Fig. 6. Permutation importance of input variables based on the Random Forest model trained on the global dataset. Scores represent the mean decrease in AUC when each variable is randomly shuffled, reflecting its contribution to predictive performance.

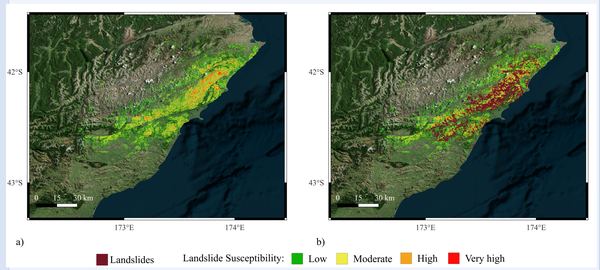

Fig. 7. Landslide susceptibility maps for the Haiti 2021 event generated using the leave-Haiti-out model: (a) model output, (b) with observed landslides for validation.

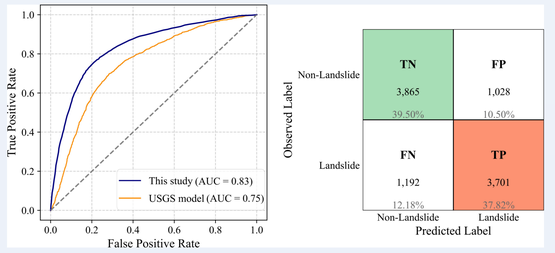

Fig. 8. ROC curve and confusion matrix (threshold = 0.5) for Haiti 2021 as the test dataset, using a model trained on the other four earthquake inventories.

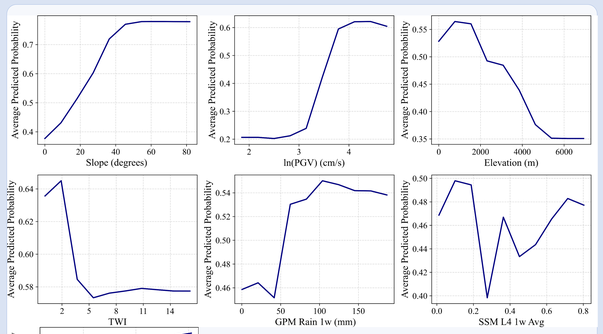

Fig. 9. Partial Dependence Plots showing how individual input variables influence the predicted probability of landslide occurrence, while other variables are held constant.

Conclusions

- Elevated pre-event soil moisture is strongly associated with increased landslide occurrence, highlighting the role of hydrologic preconditioning in co-seismic slope failures
- SMAP surface and root-zone soil moisture significantly improve seismic landslide prediction and rank among the top predictors
- The SMAP-informed Random Forest model achieves high predictive accuracy (LOEO validation; AUC ≈ 0.86) and outperforms the USGS landslide model across unseen earthquakes
- Dynamic hydrologic variables (SMAP soil moisture and GPM rainfall) provide more predictive insight than static proxies such as TWI
- The framework demonstrates strong transferability across five diverse earthquakes, supporting near-real-time, satellite-based landslide hazard assessment

Acknowledgments

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