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Unveiling the Complex Relationship Between Rainfall and Landslide Types Using a Transformer Neural Network

Rodolfo Rani[1], Ashok Dahal[2], Luigi Lombardo[2], Hakan Tanyas[2], and Matteo Berti[1]
[1]University of Bologna (UNIBO), Department of Biological, Geological and Environmental Sciences (BiGeA), Bologna (BO), Italy
[2]University of Twente, ITC, Applied Earth Sciences, Enschede, Netherlands

Landslides pose significant threats to human lives and economies, with their frequency and intensity increasingly exacerbated by climate change. This was demonstrated in May 2023 in the Emilia-Romagna region (northern Italy), where 80,000 landslides were triggered by two rare, high-intensity rainfall events with a return period of 300 years, occurring just 14 days apart. The landslides exhibited diverse types and materials, necessitating tailored risk management approaches due to differences in volume, velocity, and post-event behaviour. To address these complexities, susceptibility maps must integrate both static predictors and dynamic triggering factors to better understand the relationships between rainfall and landslide types.

Using a detailed landslide inventory developed through collaboration between the Emilia-Romagna Geological Service and the universities of Modena and Bologna, we analysed the relationship between rainfall and five distinct mapped landslide types: debris slide, debris flow, earth slide, earth flow, and rock slide. This study introduces a Transformer Neural Network (TNN) to integrate static predictors (e.g., slope, aspect, geology, land cover) with dynamic rainfall data from the 30 days preceding the second rainfall event (16th May), capturing the influence of antecedent wet/dry conditions. The TNN processes rainfall time series data similarly to speech recognition algorithms, allowing it to model temporal dependencies effectively.

We evaluated the TNN with rainfall data at different temporal resolutions (daily and hourly intervals) and compared its performance against models using only static predictors or cumulative rainfall. The TNN was trained on 70% of the dataset, targeting specific landslide types to generate susceptibility maps tailored for each type. Model performance was assessed using a comprehensive set of metrics, including Area Under the Curve (AUC), Accuracy, Recall, F1 and F2 scores, Matthew's Correlation Coefficient, and Kappa Coefficient. Additionally, we applied the SHAP (Gradient Explained) method to analyse the influence of rainfall on susceptibility values, revealing the model's internal decision-making processes.

The results demonstrate that integrating rainfall time series significantly enhances susceptibility mapping accuracy. The TNN using daily rainfall data produced the most reliable maps for all landslide types, except debris flows, where hourly intervals yielded slightly better results. SHAP analysis further illuminated the role of rainfall in susceptibility variations, providing valuable

insights into the TNN's functionality. Overall, the TNN outperformed models using only static predictors or cumulative rainfall, offering a robust framework for understanding and predicting landslide susceptibility in diverse scenarios.