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From Hazard Assessment to Action: National Landslide Susceptibility to Rainfall and Early Warning in Nepal

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Abstract: Nepal experiences frequent rainfall-induced landslides due to steep terrain, fragile geology, and intense monsoon storms. This study develops a national-scale landslide susceptibility and early warning framework by integrating statistical modeling, machine learning, and satellite-based rainfall analysis. Slope-unit-based susceptibility was mapped using GAMI-Net with terrain and environmental factors, yielding 84 percent accuracy and demonstrating strong spatial consistency with observed landslides. Susceptibility outputs were coupled with rainfall thresholds derived from IMERG satellite data and DHM gauges to support near-real-time monitoring. The system was deployed in Google Earth Engine as LhamNepal, providing dynamic hazard updates for decision makers. Results confirm the value of localized thresholds and interpretable models for advancing operational landslide early warning in Nepal.

Keywords: ***Landslide, Nowcast, Nepal Himalaya, Early warning.***

Introduction

Landslides are becoming increasingly frequent in Nepal due to intensifying precipitation patterns and the expansion of rural road construction. These factors significantly enhance the risk to both lives and livelihoods in the affected areas. To address this pressing issue, this study presents an integrated methodology that combines two advanced modeling techniques aimed at predicting landslide probabilities. The first technique focuses on analyzing historical data and covariates to identify areas prone to landslides. The second technique employs real-time data collection and machine learning algorithms to continuously update and refine the predictions. By merging these two approaches, more accurate and timely forecasts of landslide occurrences can be provided. Additionally, the study proposes the establishment of a near-real-time warning system for landslides. This system is designed to alert communities and authorities about imminent landslide threats, allowing for swift evacuation and disaster response measures. The integration of these modeling techniques and the warning system aims to mitigate the adverse impacts of landslides, enhancing the resilience of communities in Nepal to such natural disasters. Through this comprehensive approach, we hope to safeguard lives and livelihoods against the growing threat of landslides. This research deals with landslide analysis and subsequent development and implementation of local and regional nowcast early warning systems in the Nepal Himalaya.

Methodology

In this study, an integrated process based on two different modelling approaches has been applied. First, a probabilistic approach of landslide susceptibility modelling. The initial method employed a probabilistic, explainable artificial intelligence (XAI) strategy, amalgamating Generalized Additive Models with Structured Interactions (GAMI-Net), to forecast the probability of landslide events within geomorphic slope units. These models integrate various causative factors (CFs) and leverage data on geo-environmental factors associated with landslide occurrences. Second, developed a near-real-time landslide warning system coupling the result of landslide susceptibility and decision tree-based selection criteria. Terrain analysis-derived independent variables were incorporated to bolster the modeling procedures in this study. Moreover, the adoption of a global Landslide Hazard Assessment model for Situational Awareness (LHASA) (Kirschbaum and Stanley, 2018) aided in pinpointing areas and timeframes with heightened landslide potential within the study region.

The modelling procedures have been supported throughout this research by including independent variables obtained from terrain analysis. All morphometric variables were derived from a detailed Digital Elevation Model (DEM) in 30 × 30 m scale. A LHASA has been used to provide an indication of where and when landslides may be likely around in the study area.

Results and discussion

The result of landslide susceptibility map is presented in Figure 1, which includes the spatial distribution of mean probability for landslide susceptibility across slope units based on 5-fold random cross validation process. The landslide susceptibility map was classified using natural break algorithm in GIS platform. A total of 69.72% of the area was categorized as having a very low susceptibility, 16.01% as low susceptible, 6.84% as

moderate, 4.07% as high and the remaining 3.36% was considered to have very high susceptibility. About 81.51% of landslide data were in the very-high-susceptibility class, demonstrating the reliability of the map. This map shows the average likelihood of landslide occurrence for different regions.

The receiver operating characteristic (ROC) curve was used to evaluate the model and the accuracy of the model was found to be 84%. After preparing the final landslide susceptibility maps, a landslide Nowcast system was developed in Google Earth Engine (GEE) platform and a name "Landslide Hazard Assessment Model LhamNepal) was assign to the developed Application. LhamNepal is an open-access application developed in Google Earth Engine for the rapid characterization of near real time landslide hazard detection to both the scientific and the emergency management communities.

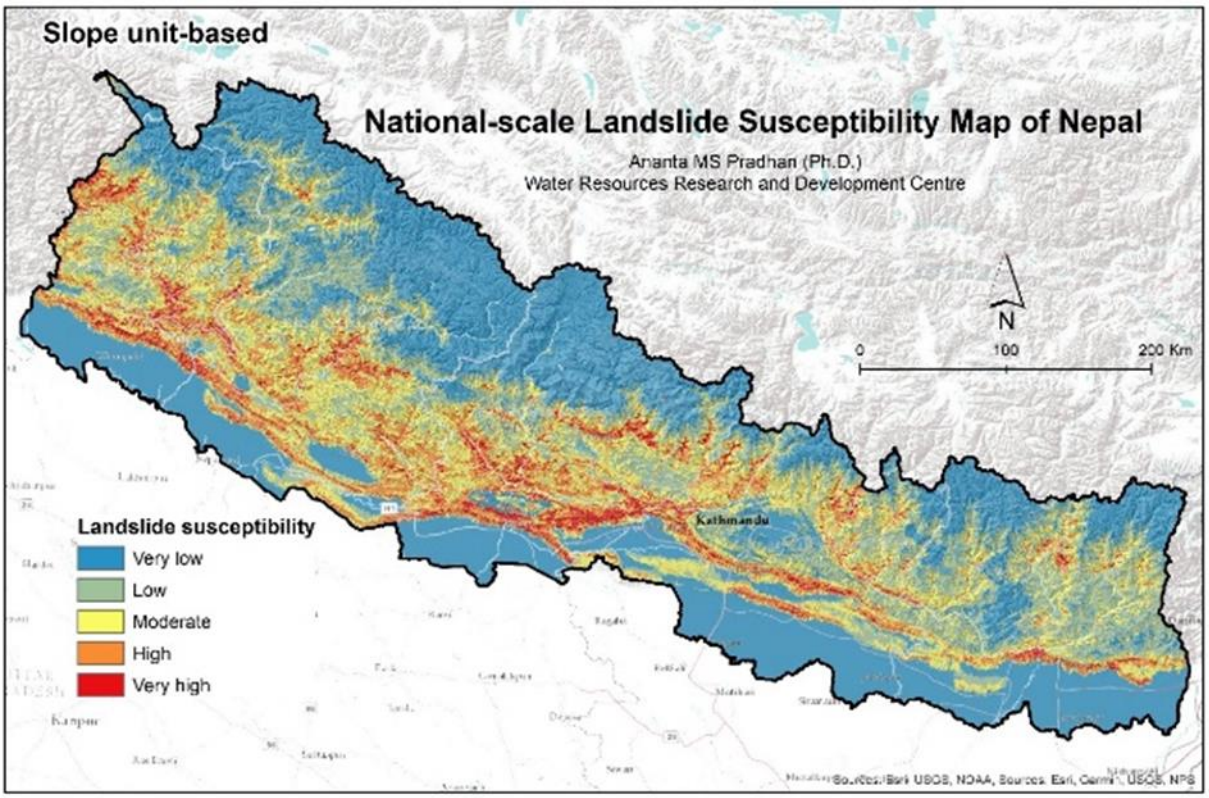

Figure 1, Landslide susceptibility map of Nepal.

References

Kirschbaum, D., and Stanley, T. (2018). Satellite-based assessment of rainfall-triggered landslide hazard for situational awareness. Earth's Future, 6(3), 505–523. https://doi.org/10.1002/2017EF000715