RESEARCH PROJECT FOR THE DOCTORAL PROGRAMME IN RESEARCH METHODS IN SCIENCE AND TECHNOLOGY (XXXVIII CYCLE - ACADEMIC YEAR 2022/2023) WITH ADMINISTRATIVE OFFICE AT UNIVERSITÀ DEGLI STUDI DI URBINO CARLO BO

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Title: Moving towards developing near real-time landslide susceptibility integrated with early warning systems

Keywords: Landslide modelling, spatio-temporal statistics, cloud-based solutions

Research Area: Earth Sciences (Engineering Geology/Landslide Science)

Proposed project

With increasing frequency of extreme events, attributed to climate change, and urbanization without proper land management, landslide prone regions are becoming a bigger concern now more than ever. The proposed susceptibility models (Reichenbach et al., 2018) are mainly static in time, which means they do not account for the changing vegetation density, land use changes or the pattern of the triggering factors. Thus, the modelled susceptibility does not account for the changing characteristics which are responsible for spatio-temporal variations of landslide occurrence probability. Time-invariant landscape characteristics can indeed be used to capture the baseline susceptibility, but it is essential to integrate temporal triggering aspects to create operational landslide early warning system (EWS). Currently, few EWS for rainfall-induced landslides have already taken this route, being capable of coupling the static susceptibility signal together with rainfall thresholds. This is the case of the model developed at the Goddard Space Flight Center of National Aeronautics and Space Administration's (NASA). Their prediction tool, called Landslide Hazard for Situational Awareness (LHASA), functions on a global scale to provide real time landslide hazard forecast every 30 minutes using satellite based rainfall forecasts (Kirschbaum & Stanley, 2018). This model uses rainfall thresholds which are only specified for some countries with rich landslide studies, while the rest of the countries use a unified rainfall threshold. However, the global coverage of this model proves poor application and reliability with no accountability for uncertainty in the warning signals. LHASA also uses a static susceptibility map but has introduced time-invariant parameters including rainfall and, snow and soil moisture (Stanley et al., 2021). Though this is one step closer to developing a suitable EWS, it also excludes the interaction of rainfall and topographic effects in the initial susceptibility development, as LHASA combines these two signals through *a posteriori* operation such as intersection.

The proposed project thus focuses on the improvement of EWS methods, moving towards tools that can contextually model both susceptibility and rainfall patterns within the very same model. This will ensure that the uncertainty of each component will correctly propagate onto the final estimates. The model I envision, not only combines the susceptibility with the dynamic signal of the rainfall, but it also features other dynamic properties such as temperature, vegetation indices land use changes. All this will also be framed away from the global scale and at a level where the EWS results can be converted to meaningful information for local communities (e.g., catchment or regional scales).

The loss and damage brought by landslide hazards, among other geohazards, are often attributed to triggering event rather than the actual cause of damage. This underestimates the threat and danger of landslides a community is exposed to. Slope stability measures have taken place on smaller slopes with equipment insertion and costly lab experiments (Gian et al., 2017; Ha et al., 2020; Hidayat et al., 2019; Karnawati et al., 2011; Liao et al., 2010) which are not sustainable over a larger area. This research aims to utilize data-driven modelling which is cost-effective and can integrate multiple influencing factors into a single modelling framework. Early warning systems for slope failures have been developed in many areas around the world, to reduce losses and manage risk (Guzzetti et al., 2020) and have proven that timely warnings reciprocated with timely responses are the key action for disaster management in landslide prone regions.

Research objectives

The research objectives below are derived from the general aim of the proposed project to address the specificities of the integrated approach.

- Dynamic landslide prediction
- Development of a cloud-based solution in Google Earth Engine
- Development of a probability-threshold-based EWS rather than a rainfall-threshold one
- Testing the operational use of this new generation landslide EWS within the Marche region

Methodology and expected results

The proposed research aims to materialize these warnings which can be derived from spatial and temporal prediction of landslides through development of dynamic susceptibility maps. These maps will reflect the changing probabilities of failure as the triggering conditions change. The approach revolves around a data-driven model built in a Bayesian framework. Specifically, a Generalized Additive Model would allow incorporating the neglected uncertainty propagation in decoupled models like LHASA. Conversely, these elements will be modelled together, respecting the uncertainty, and carrying it into a single model where explanatory variables will be used both linearly and non-linearly. Contrary to decoupled models, a single unique model can estimate the susceptibility with landscape characteristics and rainfall patterns along with uncertainty in the model behaviour, which gives a richer insight regarding the reliability of the warning. Integrating trigger information while understanding the susceptibility patterns also means moving away from rainfall thresholds and moving towards a unified probabilistic threshold system.

Any Bayesian model naturally provides a summary of the mean behaviour together with an uncertainty estimation around it for each model component. Specifically, in the context of susceptibility modelling, this implies that the whole distribution of expected regression coefficients for each covariate under consideration can be retrieved (Luo et al., 2021). Based on these values, statistical simulations can be implemented. The statistical simulations are generated by randomly sampling values (regression coefficients) from the distribution for each model component (linear and non-linear) to be used as an input for retrieving a distribution of susceptibility (probabilistic estimates) for more accurate warnings.

The availability of vast global and local scale datasets (Gorelick et al., 2017; Kumar & Mutanga, 2018) which can be accessed through the Google Earth Engine (GEE) Catalog are available freely over multiple spatial and temporal resolutions if the region does not have a local and high-quality dataset. This offers sufficient support for the basic input of the model including proxy characteristics like that of the terrain extracted from a Digital Elevation Model as well as rainfall prediction estimates. Moreover, GEE supports Python and JavaScript Application Programming Interface (API) with integration of GEE API. The backbone of building a rich and informative model requires a detailed and dated inventory which, for the case of Italy, can be accessed through the FraneItalia (Calvello & Pecoraro, 2018) product, as well as the Italian Landslide Inventory (IFFI; Trigila et al., 2010). Both inventories can also shed light on landslide occurrences in areas which are most heavily affected by the shift in climate, thus can lead to improved and usable operation alarm systems. Introducing dynamic rainfall, especially in the model building phase with multi-temporal event-based inventories can allow integration of the trigger signal which marks the initialization of dynamic susceptibility.

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Work-plan

The first year would entail a focus on obtaining sufficient knowledge and training for spatio-temporal analysis and programming skills, especially programming languages like R and JavaScript (integrated with GEE API). Additional skills such as academic writing or advanced-scientific-illustration will also be developed on parallel. The second year would require construction of the web-based visualization for understanding near real-time (NRT) susceptibility. The final year(s) would move towards testing the model's predictability power for best implementation and completing the write-up for the thesis.

Table 1 Brief overview of the described workplan for this PhD research

Task/Date	Year 1	Year 2	Year 3
Scientific Background			
Skills Training			
Base Building			
NRT Susceptibility			
Web-visualization			
Prediction Check			
Thesis Writing			