PhD offer INRAE-BRGM : Design of integrated Territorial early-warning systems for shallow landslides

PhD 3 years position at **INRAE/IGE**, Grenoble, and **BRGM**, Orléans

Dates : Start between November 2023 and February 2024

Scientific context

Territorial **L**andslide **E**arly **W**arning **S**ystems (Te-LEWS) based on weather-induced landslide analysis are increasingly developed worldwide, allowing for improved landslide risk mitigation in order to reduce fatalities and economic losses. Most of them use information from rain gauge networks, meteorological models, weather radars, and satellite estimates, and their forecasting models are based on rainfall thresholds, distributed slope stability models, and soil water balance models. In France, few Te-LEWS have been developed, despite many landslide events leading to traffic interruption, village isolation, and casualties.

Landslide temporal triggering thresholds – Shallow landslide forecasting models are based on rainfall triggering thresholds. Since the pioneering work of Caine, many landslide triggering thresholds based on rainfall intensity and duration (referred as ID thresholds) have been reported worldwide at different spatial scales, from local to regional scales. An algorithm was developed to design thresholds considering input rainfall and landslide data. The algorithm is able to automatically reconstruct rainfall events, and to define ID thresholds. Results are satisfying, yet the input data and the method must still be improved. Indeed, some climatic parameters are not considered when ID thresholds are computed, or are taken into account but not known with sufficient accuracy.

As a matter of fact, the performance of Te-LEWS for landslides is strongly dependent on the quality and spatiotemporal resolution of real-time meteorological observations and forecast. Some works on EWS have demonstrated that regional rainfall thresholds based on corrected radar rainfalls (correction for atmospheric attenuation) are much more accurate than those based on rain gauge networks. Distributed rainfall fields at high spatial and temporal resolutions can be now correctly captured using weather radar networks. Yet, improvements need to be done, since convective cells are not always characterized with good accuracy. We argue that considering real-time lightning location systems as a complementary information to radar can be very useful for tracking convective cells. Moreover, snow melting constitutes a significant water supply for landslide triggering. It is proposed to analyze the snowmelt, considering delay of melt and infiltration in the soil. Finally, most systems consider only some parameters from rainfall data (such as Intensity and duration). Considering additional climatic parameters (e.g., evapotranspiration ratio, antecedent rainfall, antecedent soil wetness state, snow through antecedent conditions) might be a significant improvement into the quantification of the triggers.

Coupling triggering zones with local and regional landslide and propagation models - Once released, shallow landslides can display various propagation mechanisms, including flow-like movements. Therefore, LEWS need to estimate potential initiation zones and to include modelling approaches that consider both the release and the propagation phases. Yet, coupled models combining initiation and propagation of landslides are still scarce, and only few operational EWS effectively take flow propagation scenarios into account. Furthermore, when propagation is considered, it is often tackled through simple empirical or semi-empirical routing methods based on the angle of reach. These methods only partly reflect the complexity of propagation processes and often estimate only the travel distance, and not thicknesses or velocities of the flow. In comparison, physical-based numerical model can provide more detailed information, but require more computing power and are more difficult to parameterize (in particular for the choice of rheology and of associated parameters). Besides, contrary to more empirical methods, the initial mass geometry and volume must be precisely defined. This can be challenging for landslide hazard assessment at the local or regional scale, when only susceptibility maps are available. It is proposed here to develop a scenario-based methodology for real-time integration of triggering thresholds and advanced propagation models into EWS, while accounting for the various sources of uncertainties involved.

Spatial variability of shallow landslide triggering conditions - Another main drawback of landslide rainfall-based Te-EWS is their poor spatial prediction capacity: a threshold overcoming produces an alert for the entire area encompassing the events used for calibration, while the location of expected landslides is poorly constrained. This is related to the multifactorial character of landslide triggering, which is not only controlled by meteorological forcing, but also by local geological and geomorphological conditions. It is proposed to combine spatial and temporal conditions of landslides occurrence, by coupling susceptibility information with triggering conditions ; this can be done with developing methodological and probabilistic issues related to the crossing of data with different spatial scales and resolution and with different fluctuation timescales. The methodology used for defining susceptibility maps will depend on the scale of analysis ; indeed, at regional scale, statistics methods will be considered, with the comparison of the spatial distribution of the phenomena (i.e. landslide inventory) with the different environmental factors (in the form of a spatial variable). At local scale, a physically distributed model based on a limit equilibrium method will be used, computing Safety factor along 2D profiles over the entire area. This approach can integrate different landslide geometries, the spatial and inherent heterogeneity of the surficial deposits and geology and their geotechnical parameters, and triggering factors (such as water table level fluctuation).

Objectives

The objectives of this thesis are focused on :

i) The regional analysis of shallow landslide triggering thresholds. This task will focus on the back-analysis of landslide inventory linked with high-resolution radar rainfall observations, among other climatic data ;
ii) Computing susceptibility maps, and then coupling them to landslide triggering thresholds, to get spatialized triggering thresholds ;
iii) Coupling landslide triggering thresholds and susceptibility maps with propagation models to generate real-time scenarios of exposed areas. The coupling methodology and propagation model type will be adapted to the scale of the analysis.

Two embedded scales will be considered. At a regional scale, the project will be implemented in the **Southern Alps**. At a local scale, a few sites will be selected based on the availability of data concerning previous events for which a retrospective analysis can be carried out. In particular, municipalities affected by the storm Alex will be involved in the project.

Role of the PhD student

The PhD student will be in charge of the following scientific tasks:

i) **The regional analysis of shallow landslide triggering thresholds** will be based on back-analyses of landslide inventory linked with high-resolution radar rainfall observations. Some improvement will be considered, by considering additional climatic parameters (e.g., evapotranspiration ratio, antecedent rainfall, antecedent soil wetness state, snow through antecedent conditions). From a methodological point of view, the testing of recently developed machine learning techniques combined with appropriate training and validation procedures will also be considered to improve the framework.

ii) **Combining spatial and temporal conditions – Te-L**EWS can be made spatially explicit when spatial and temporal conditions of occurrence are combined in the operational framework. This implies the integration of landslide susceptibility information in the EWS, with methodological issues related to the crossing of data with different spatial scales and resolution and with different timescales.

iii) **Coupling landslide triggering thresholds and susceptibility maps with propagation models.** To better evaluate in real-time hazard levels in the downstream parts of the catchments, the statistical landslide susceptibility model will be coupled to flow propagation models. Depending on the scale of study and the available data, models of different complexities can be considered. In a first approach, empirical routing algorithms will be used to make a demonstrator of real-time updated landslide hazard mapping tool at the regional or local scale. A more complex approach will then be investigated at the site / catchment scale using physical-based models (e.g. thin-layer models), and taking into account uncertainties on the input parameters (volume, geometry and location of initial mass, rheology, etc). These models can provide access to time-resolved evolution of flow height and velocity over complex topographies. In that way, preexisting scenarios databases spanning the expected range of possible processes will be constituted for incorporation into LEWS.

Profile sought

We are looking for a highly-motivated student with a Master's or engineering degree in Earth sciences or mechanics. Solid skills in at least one of the following domains are mandatory, while the student will be expected to acquire the complementary skills during the PhD:

- geomatics (Arcgis or Qgis) & statistical analysis;
- mechanical modelling;
- scientific programming (for instance Python, R);

Knowledge on soil mechanics, geotechnics, geomorphology, natural hazards and, if possible, landslide hazard and/or meteorological data will be appreciated. Organizational skills, sense of initiative and autonomy are also required.

Candidates should be motivated by a multidisciplinary work at the interface between several teams.

Context and working environment

This thesis is part of the **ANR VIGIMONT** project (Mountain Vigilance : Forecasting the risk of landslides and debris flows in mountainous areas, 2023-2027)

The PhD candidate will be jointly hosted at INRAE/IGE (Grenoble) and at BRGM (Orléans), and will spend approximately half of its time in both laboratories.

Host laboratories and teams:

The IGE/ECRINS team implements research programs related to the prevention of natural hazards in mountain environments. The team has a wide expertise in geomechanical modelling, hydraulics of complex fluids, geomorphology, hazard and risk assessment, hazard mitigation strategies, and decision science. The Institute of Environmental Geosciences (IGE) is a joint research unit of the CNRS, Grenoble Alpes University, INRAE, Grenoble INP and IRD.

BRGM is a public institute in applied earth sciences. Its fields of activity encompasses hazard assessment to support for decision-making in the contexts of climate change adaptation, warning systems, and crisis management. It has a high expertise in landslide characterisation and modelling.

Team description :

This PhD will be co-supervised by G. Chambon (INRAE, IGE) and S. Bernardie (BRGM) in close collaboration with S. Chave (Predict).

General information

To apply: send an e-mail before the **23th of September**, to guillaume.chambon@inrae.fr and s.bernardie@brgm.fr with your CV and an explanation of why you are applying.