Department of Earth Sciences
Ph.D. School ''Vito Volterra" of Astronomy, Chemistry,
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Research proposal - Ph.D. in Earth Sciences

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ANALYSIS OF EARTHQUAKE – INDUCED LANDSLIDE SCENARIOS UNDER CHANGING ENVIRONMENTAL CONDITIONS

Candidate:
Ramaz Koberidze
Ramaz.koberidze@uniroma1.it

Internal Tutor:
Professor Salvatore Martino

External-Tutor:
George Gaprindashvili -
Professor of Geography Department of Tbilisi State University

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1 Introduction

Earthquakes are one of the most destructive natural phenomena, capable of causing extensive damage to infrastructure and environment. Among the several ground effects triggered by earthquakes triggered landslides (EqTLs) pose a significant risk, particularly in mountain and hill areas. These landslides not only worsen the impact of seismic events but also lead to long-term environmental and economic consequences. Understanding the mechanisms of (EqTLs) is crucial for creating scenario maps that inform effective hazard assessment, urban planning, and disaster mitigation strategies.

The interplay of different factors, such as soil moisture conditions, rainfall, together with seismic shaking, also understanding the role of individual factors is essential to predicting earthquake-induced landslide scenarios. Initial soil moisture distribution, for instance, can greatly influence slope stability (especially in soil slopes), playing the role of preparatory factors as well as the cumulative rainfall which can anticipate ground shaking creating over time conditions more adapt for trigger efficence.

Despite advancements in understanding these processes, significant gaps remain in our knowledge, particularly regarding how preparatory and climate factors—such as increased rainfall, temperature fluctuations, and soil moisture—interact to predispose slopes to failure.

1.1 State of the Art

Recent research has highlighted the complexity of the factors influencing earthquake-triggered landslides. Studies show that different levels of soil saturation significantly affect the stability of weathered slopes during seismic events [1]. For instance, saturated conditions can decrease the effective stress within soils, making them more susceptible to failure under seismic shaking [2]. Furthermore, EqTLs are identified as critical geological hazards, particularly in regions with steep topography and loose, unconsolidated materials [3]. Degree of slope stability can be categorized into three stages: first, the predisposing factors (i.e., time independent) second, the preparatory factors that develop over a middle to long time frame, and finally, the triggering factors that act in a more immediate, short-term window. Impulsive triggers, such as the intense shaking from an earthquake, can push a slope beyond its stability threshold. In contrast, preparatory conditions, such as prolonged rainfall or soil saturation, can gradually weaken slope stability over time. However, while much is known about individual triggers, the interaction between these factors remains substantially unexplored [4].

The reconstruction of landslide scenarios is crucial for managing risk assessment. Scenario maps provide spatial distributions of potential landslide impacts under various environmental conditions, helping to inform urban planning and emergency response strategies [5]. Nonetheless, traditional parametric models often overlook the complexities of soil behavior under dynamic conditions, leading to insufficient predictions [6]. The focus of this resarch proposal is on creating scenario maps rather than hazard maps for landslides. This means we may establish the hazard of a specific trigger (like an earthquake) and instead model the resulting distribution of landslide effects ("induced scenario"). In some cases, it’s also necessary to consider "hazard-independent" scenarios, such as worst-case scenarios, that do not rely on a specific hazard. Understanding the distinction between hazard maps (probability-based) and scenario maps (impact-based) is crucial for effective risk management.

Recent literature has begun to explore the role of preparatory factors in landslide dynamics. For example, cumulative rainfall can significantly affect soil moisture content, influencing slope stability prior to seismic events [7]. However, there is a notable lack of studies addressing the specific contributions of rainfall and soil moisture conditions in the context of earthquake-induced landslides [8]. The state of the art indicates a need for a more integrated approach to understanding the interplay of environmental factors and seismic activity. Future researches should aim to fill these gaps by investigating the roles of soil saturation, rainfall, and seismic shaking as interconnected elements in landslide and rockfall initiation.

Open Questions:

How do preparatory factors primarily linked to meteo-climatic conditions, such as soil moisture and rainfall, influence the stability of slopes and the potential for rockfalls before seismic shaking will occur? And how can be distinguished a preparatory from a triggering role of rainfall (as one of the meteo-climatic factor) in providing landslide scenarios?

2 Research objectives

2.1 General objective

To explore landslide scenarios within a multirisk framework and in climate-controlled conditions to understand their collective impact on the environment.

2.2 Specific objectives

Use of quantitative tools to analyze how preparatory factors, specifically related to rainfall and soil moisture, affect slope stability by reinstating different scenarios of landslide distribution in selected case study areas.

3 Implications and applications

By employing specific quantitative analysis tools such as GI (ground instability) and (PARSIFAL), I'm aiming to reinstate potential landslide scenarios in these regions and improve the accuracy of our assessments. The research will focus on different methodologies and tools in three case study areas: Choirokoitia (Cyprus), Montecilfone (Molise, Italy), and Racha (Racha-Lechkhum and Lower Svaneti, Georgia). A tailored risk assessment framework will be developed, integrating geological, and environmental data, including critical preparatory factors such as soil moisture and rainfall, to better identify vulnerable areas.

The insights gained from this research will inform disaster preparedness strategies and recovery planning, ultimately enhancing community resilience to seismic events. Furthermore, the study will provide recommendations for sustainable land use policies and infrastructure design that consider landslide and rock fall risks associated with varying levels of soil moisture and rainfall.

Lastly, learning approaches will be made to raise awareness and inform communities about the impacts of these preparatory factors on landslide (including earth or rock-slides and rockfalls) risks and preparedness measures, empowering residents to take proactive steps to mitigate their vulnerability. These results will help make communities safer in areas with earthquakes. They will provide important information to manage risks better.

4 Work plan

- In year 1st: of PhD research, I will focus on the engineering geological modeling of three case study areas. The plan includes the following components: I will begin with a comprehensive literature review to establish a theoretical foundation (1-3 months). Next, I will conduct data collection, field surveying and conceptualization of quantitative tools (e.i., PARSIFAL) in each case study area (4-9 months). Additionally, begin the susceptibility analysis during (10-12 months).

- In Year 2nd: I will analyze the preparatory factors influencing susceptibility in my case study by integrating datasets into a GIS framework for susceptibility analysis (13-18 months). Start monitoring data collection and analysis during (19-21 months); develop strategies for soil moisture distribution using (remote sensing) and visualization in (22-24 months).

- In Year 3d: Develop and create scenario maps for the case study areas (25-30 months); I will begin writing my thesis (31-34 months); Finally, I will prepare for thesis defense (35-36 months).

5 Milestones

In three years, I expect to have achieved significant personal and professional growth, including enhanced skills in my field, a strong network of connections, and a clear pathway toward my long-term goals. Each year, my outcomes will be as follows:

By the end of Year 1, I will have completed a comprehensive literature review, conducted data collection and field surveys, refined quantitative tools for analysis, and initiated the susceptibility analysis for the three proposed case study areas.

By the end of Year 2, I will have established a centralized database for geological and geotechnical data, initiated monitoring and analysis of susceptibility factors, and developed strategies for soil moisture distribution through remote sensing.

By the end of Year 3, I will have developed scenario maps for the three proposed case study areas, completed the initial draft of my thesis, and prepared thoroughly for my thesis defense.

6 Dissemination plan

During my Ph.D. I will outline a strategy for disseminating the results of my research through various channels, including peer-reviewed publications, conference presentations, and university seminars. Additionally, I will participate in workshops organized by the TRIQUETRA and RETURN projects to share my findings and foster collaboration within the academic community. This comprehensive approach will ensure that my research reaches a wide audience and contributes to ongoing discussions in the field.

During my PhD studies, I plan to participate in the following conferences and forums:

- International Conference on Landslides (ICL)
- European Geosciences Union General Assembly (EGU)
- International Symposium on Landslides (ISL)
- World Landslide Forum (WLF26)
- Living Planet Symposium 2025 (LPS2025)

7 Training activities

Over the next three years, I will enhance my skills in data analysis, modeling, risk assessment, and science communication through various workshops, seminars, and courses.

Over the next three years, I plan to actively participate in various training activities and conferences, particularly those associated with the European project-TRIQUETRA (https://triquetra-project.eu/), for which, also Sapienza University became a scientific partner and RETURN (https://www.fondazionereturn.it/) in the framework of the National Plan for Recovery and Resilience (PNRR) projects.

Additionally, I will participate in university seminars on topics like environmental modeling and data collection techniques to stay updated and gain diverse perspectives.

I plan to participate in a research methodology course to build foundational skills and a statistical analysis workshop to enhance my proficiency in data analysis software. I will also pursue workshops on field data collection techniques and geographic information systems (GIS) to support my data gathering and analysis needs. refining quantitative tools, specifically PARSIFAL and Ground Instability (GI), to enhance my data analysis and decision-making processes.

8 Mobility abroad

I will explore opportunities for collaboration and knowledge exchange with researchers at Sapienza University of Rome, Department of Earth Science and considering a potential co-tutoring agreement (cotutelle) with Tbilisi State University or another institutions, which would enhance the support for the doctoral study process. Potential activities include short-term visits, joint research projects, conference participation, and collaborative publications.

9 GAANT chart - Time schedule

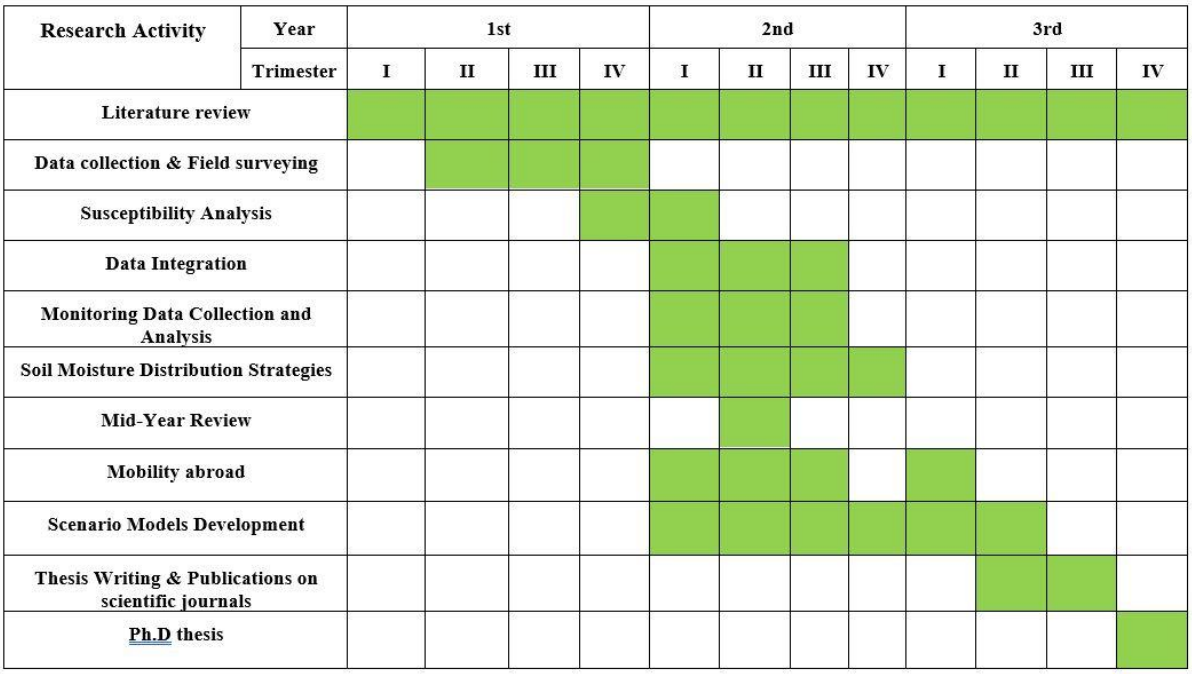

Figure 1: Proposed Gantt chart for the present project

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