Facoltà di Scienze Matematiche Fisiche e Naturali

Dipartimento di Scienze della Terra

Progetto di ricerca – Dottorato di ricerca in Scienze della Terra

XXXIX ciclo

Set-up of a comprehensive framework for geo-hydrological hazard and risk assessment for statutory purposes

A.A. 2023 – 2024

Candidato

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Carlo Esposito

Introduction

Geo – hydrological hazard is related to the occurrence of landslide and flood events that threaten the built and natural environments, causing socio-economic losses for communities. The entity of damages is related to the territory's susceptibility and the community resilience to these events. Prevention and mitigation of such a risk starts from the better knowledge of geo-hydrological hazard conditions. As recalled also by the Italian law, a Civil Protection System has to include the Scientific Community as it can provide effective and up-to-date methods for risk management, from the hazard analysis to the emergency management, thus addressing disaster risk reduction policies implemented by public administrations acting at different levels (i.e., from the municipal up to the national scale) and with different purposes. Thus, an effective transfer of knowledge from the Scientific Community to the Administrations as well as continuous feedback from the latter to the former should represent an essential step. Notwithstanding, putting science into practice (i.e., taking into account the actual applicability of rigorous methods in relation to the actual availability of data as well as financial resources) can be a challenging task. For these reasons, the goal of this research project is to review the existing methods for geo-hydrological hazard assessment, improving their applicability in practice, even by tailoring them to the extent which is necessary for exploiting available data sources but still fitting the requirements of rigorous results for statutory purposes. Such a goal is among the objectives of the ''RETURN'' (Multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate) research project funded by the PNRR – National Plan of Recovery and Resilience (https://www.fondazionereturn.it/). Specifically, Spoke 7 - TS3 (Communities' resilience to risks: social, economic, legal and cultural dimensions) promoted the scholarship ''Responsibility on action of mitigation/prevention in the Civil Protection System'' that funds the hereby presented proposal.

State of the art

Many regions are prone to events that impact the same location at same time period [9] increasing in such a way the overall impacts [2]. Depending on the type of processes, the scale of the analysis, the availability of input data, and, on overall goal, the presence of different (and potentially interacting) hazards can be dealt with "multi-layer single hazards" or proper "multi-hazard" approaches [14], the latter being more challenging. Geo-hydrological hazards derive from the interaction between meteo-hydrological and geological conditions of a region, that potentially lead to losses [6]. Italy is exposed to several geohazards. Geo-hydrological phenomena (i.e., floods and slope failures) are the most common [12] (e.g., events of Toscana, November,2023; Emilia – Romagna, May 2023; Ischia, November 2022). Furthermore, the natural predisposition to geo-hydrological hazards is enhanced by still inadequate governmental investments for risk prevention and mitigation with respect to the actual need [11]. Prevention and mitigation of natural disasters should be implemented on different spatial (from national to site-specific) and temporal (from differed time to real time, as stated in the "Directive 27 February 2004: operational guidelines for the management of the national alert system for hydrogeological and hydraulic risk" released by the Presidency of the Council of Ministers [5]) scales. As regards the large spatial scale and the differed-time horizon, the main non-structural actions encompass hazard and risk analyses, i.e. basic knowledge of the territory that can be turned into land-use planning and related regulations. Several methods, both qualitative and quantitative, nowadays exist to assess susceptibility and/or hazard from geo-hydrological processes (e.g., Maranzoni et al., 2022 [10]; Corominas et al, 2014 [4]). Whatever the method applied, hazard (and related risk) assessment requires a huge amount of data to train and test proper "forecasting" functions [1]. Moreover, a multi-hazard approach is required to provide a synthetic information for administrations dealing with land-use planning [3]. Nevertheless, one of the first issues affecting the feasibility or reliability of such analyses consists in the availability and the quality of databases regarding the process itself (inventories of past events) and the independent controlling factors [15], as well as the exposed elements, especially in terms of economic worth and vulnerability. Unfortunately, available information is often incomplete, fragmented and unsuitable for reliable quantitative analysis [7; 13]. Therefore, governmental authorities before defining the objectives of the zoning of territory have to consider the availability of existing input data and assess the implications for the acquirement of new dataset; considering timeframes, budgets and resources limitations [8]. In Italy the official land-use planning tools for the geohydrological risk reduction are implemented by the "Piani di Assetto Idrogeologico" (PAI) (supplied by River Basin District Authorities) and "Vincolo Idrogeologico" (VI) (this last one defined by the ''R.D.L. 30/12/1923 n° 3267'' and ''R.D. 16/05/1926 n° 1126''). Furthermore, the PAI provide guidelines for the structural interventions to reduce the damages due to landslides and/or flood events, as well as zoning landslides and flood hazard and risk areas. However, some critical issues affect these products. The present River Basin District Authorities replaced and aggregated the territories previously governed by former River Basin Authorities; as a result, many District PAI are the mosaic of former Basin PAI, each one conceived and elaborated according to different methods and approaches (mainly of qualitative type). A standardization of dataset should be implemented to ensure a homogeneous risk evaluation and subsequent regulations and decision making also at the national level (e.g., governmental investments for prevention and mitigation). VI is still in force after one century, but most of the Regions (in charge to manage this disposition) inherited the zonation originally performed, without never updating the following land-use change, as well as new analysis methods. It is worth noting that against the above-mentioned issues, both PAI and VI strongly impact (and limit the use of) the territory and human activities, thus reminding the need for an upgrade and update of the related products, taking into account financial and temporal limits that do not allow for a rapid improvement and refinement of ancillary data bases.

General objective

Based on the premise, the general objective is to set – up a comprehensive framework for strengthening the resilience to geo-hydrological hazard by means of effective land-use planning tools by accounting for scientific standards, actual availability of ancillary data and their practical application for statutory purposes.

Specific objectives

The research has multifold specific objectives:

a) Development of a multi-hazard analysis method to support the large-scale zoning of the territory based on open-data availability and multi-criteria approaches, with a specific focus on the role of land covers in preventing geo-hydrological issues
b) Set-up of a comprehensive framework to provide multi-risk estimations for ranking criticalities in the built environment and regulating future urban development
c) Critical comparison of the research products and analogue institutional planning tools to provide a suggestion on the type of legal constraints (i.e., prohibitory vs. prescriptive) consistent with the quality and quantity of ancillary data for such large-scale products.

Applications and implications

A principal implication deriving from this project is to provide a tool for updating and customizing, to statutory purposes, existing data and methods for geo – hydrological hazard assessment. Moreover, by the integration of the outcome of multi – hazard scenarios with official socio – economic data (e.g. ''Italian National Institute of Statistics'' – ISTAT dataset), it will be possible to perform a preliminary multi – risk map accounting for both structural and socio-economic vulnerability. This research also aims to: enhance the evaluating of the flood susceptibility within secondary river basins, where it is not possible to retrieve information by PAI products, overcome the differences between the methodologies implemented by the District Authorities and make more efficient the non-structural measure for regulating land use, by the identification of the protecting areas that contribute to the prevention of slope instabilities and/or flooding in the related "physiographic units". Therefore, the innovations of this project compared to previous studies lies in the attempt to implement a new comprehensive and replicable method for objective evaluation of damages due to geohazard. In this way, the final product would become a fundamental tool for a more practical evaluation of the intervention to adopt, in real time, and a more efficient management of the socio-economic investment for the risk prevention and reduction, in differed time.

Work plan and milestones

The experimental activity will be conducted in the territory of Lazio Region, which encompasses two District Authorities and 6 former River Basin Authorities and promoted a regional law for the update of VI. In the first semester of the PhD, the aim is to deepen the knowledge of multi – hazard and risk approaches, theory of DBMS and ML algorithms. In the second and third semesters the single landslides and flood hazard models will be implemented. In the fourth semester, the multi – hazard risk model will be defined, from the assimilation and fusion of the previous product obtaining the geohydrological (multi – hazard) map. The fifth semester will be focused on the comparison and critical evaluation of outcomes of the research and current land planning tools adopted for large scale policies. For sake of clarity and synthesis, the main activities are illustrated below as a bulleted list.

WP 0 - Bibliographic study and update

- Study of thematic bibliography, attendance of courses and seminars, abroad mobility

WP 1 - Collection, Organization and pre - processing of basic data

- GeoDB design and implementation for the collection and storage of open-source data
    - Optimization of available data (MILESTONE 1): standardization of topology and attributes, pre-processing to extract relevant information

WP 2 - Analysis of the spatial components of geo - hydrologic hazard

WP 2A – Slope stability

- For each landslide type:
    - Evaluation of landslide detachment scenarios by means of ML algorithms; comparison of prediction performances and selection of the appropriate one
    - Data-driven or knowledge-based multi-criteria rating of soil cover classes based on the role of contrast to geo-hydrological instability
    - Identification of optimal terrain units for the implementation of downscaled analyses aimed at defining an "influence" area where variations of predisposing factors (i.e., land cover) can impact on slope dynamics
- Final comprehensive zoning in terms of landslide proneness based on a multi-criteria fusion of results for each landslide type (MILESTONE 2)

WP 2B – Flooding

- Set-up of customized hybrid (i.e., morphological and hydrological) methods to outline potentially flooded areas, in particular within secondary river basins where it is not possible to retrieve information by the PAI products
- Calibration on available products (i.e., Basin River Authority plans) for different scenarios in terms of frequency (and, thus, severity)
- Zoning of the territory (MILESTONE 3) to define:
    - Potentially flooded areas
    - Watershed sections contributing to natural reservoir capacity

WP 3 - Multi – hazard risk frameworks

- Set-up and tuning of a methodological framework for the assimilation, fusion and synthetic multi-hazard assessment and mapping over large areas, by means of semi-quantitative approaches
- Design and test of a methodological framework for the implementation of preliminary, index-based multi-risk assessment based on official data sources, such as ISTAT databases, trying also to incorporate metrics of the social vulnerability (<u>MILESTONE 4</u>)

WP 4 - From theory to practice

- Comparison and critical evaluation of outcomes of the research and current land planning tools adopted for large scale policies (i.e., PAI and "hydrogeological constraint") to get insights on:
    - Contrast between severity of regulations and robustness of related zoning
    - The extent to which large-scale analyses can be reliably transferred in regulations
    - Possible transfer of the newly refined methodologies to risk management policies as a non-structural measure (<u>MILESTONE 5</u>) for: regulating land use in areas over given (multi)hazard thresholds, protecting areas that contribute to the prevention of slope instabilities and/or flooding in the related "physiographic unit" and providing a more downscaled zonation in term of criticalities to allow a more efficient emergency intervention from the Civil Protection.

Dissemination plan

Publication of scientific articles and participation in conferences and seminars.

- ✓ World Landslide Forum
- ✓ BeGEO
- ✓ International Symposium on Landslides
- ✓ MYRIAD – EU
- ✓ 8° Congresso Nazionale AIGA

Training activities

- ✓ Data Analytics for Earth Sciences - Prof. Ghaderpour, Sapienza Università di Roma;
- ✓ Application in GIS enviroment - Prof. Delchiaro, Sapienza Università di Roma;
- ✓ Suggestions on how to write a scientific paper, set – up a presentation and write a research project; Prof. Collettini, Prof. Scuderi, Prof. Andreozzi, Prof.ssa Strani, Sapienza Università di Roma.

Abroad mobility

University of Twente - Department of Applied Earth Sciences (Prof. L. Lombardo)

Time schedule

PhD Activities	First year				Second year				Third year			
	I semester		II semester		III semester		IV semester		V semester		VI semester	
Literature Review and Courses attending	■	■	■	■	■	■	■	■	■	■		
Geospatial Database Construction	■	■	■	■								
Single Hazard Analyses			■	■	■	■	■	■				
Construction of Multi - hazard risk model							■	■	■	■		
Comparison with offical product and outcomes validation										■	■	
Dissemination Activities					■	■	■	■	■	■	■	■
Abroad mobility					■	■	■	■				
Thesis Writing											■	■

Figure 1 - Gantt chart.

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