Natural Hazard Event Dataset for the Garrotxa Region (Catalonia, Spain): A Foundational Step Toward Multi-Hazard Risk Assessment

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Abstract. Data-driven approaches are increasingly essential for understanding complex, interacting natural hazards. We present a natural hazard event dataset compiling all documented occurrences of earthquakes, landslides, rockfalls, floods, wildfires, and ground subsidences in the Garrotxa region (Catalonia, Spain) between 1900 and 2023. The dataset integrates inventoried, written, and oral sources, including official inventories, historical press, scientific literature, and citizen-science contributions, which were processed and cross-~~cross-~~validated to remove duplication and inconsistencies. A total of 1049 events were compiled. A simple~~ynthetic~~ exploratory analysis illustrates the potential of the dataset for multi-hazard interaction and hazard–meteorological association~~s studies~~. Comparison with national and international repositories (e.g., EM-DAT, SHELDUS, Risk Data Hub) shows that this dataset provides higher spatial resolution and includes locally validated records absent elsewhere. The study~~work~~ therefore contributes ~~establishes both a~~ both a new regional data resource~~data resource~~ and a workflow for compiling and validating heterogeneous hazard data, supporting future susceptibility and multi-hazard risk analyses in this and other regions.~~methodological framework for future susceptibility and multi-hazard risk analyses applicable to other regions.~~

1 Introduction

Understanding natural-hazard risk requires consistent knowledge of where and when past hazard events have occurred. While risk represents the potential for losses arising from the interaction of hazards, exposure, and vulnerability, hazard events are the observable manifestations, such as earthquakes, floods, wildfires, etc, that underpin quantitative and qualitative risk analyses. Global frameworks such as the United Nations Office for Disaster Risk Reduction (UNDRR) Sendai Framework (2015) emphasize multi-hazard perspectives, yet implementation at local scales remains limited by the scarcity of harmonized event data (e.g., Hewitt and Burton, 1971; Kappes et al., 2012; Gill and Malamud, 2014; United Nations Office for Disaster Risk Reduction [UNDRR], 2016; Tilloy et al., 2019; de Ruiter et al., 2020; Gill et al., 2022).

In regions like Garrotxa (Catalonia, Spain), environmental, geological, and climatic diversity leads to the occurrence of multiple hazards that may interact temporally or spatially. However, the available information is typically fragmented among institutions, stored in incompatible formats, and rarely cross-validated. This fragmentation hinders both single-hazard and multi-hazard risk assessments.

The present study aims to contribute to the improvement of multi-hazard risk assessments by enabling future data-driven analyses. For this, it addresses three main questions: (1) What is the historical record of natural-hazard events that have affected the Garrotxa region between 1900 and 2023? (2) How do these events relate spatially and temporally, indicating potential interactions (e.g., rainfall-induced landslides or earthquake-triggered rockfalls)? (3) How does the resulting dataset compare with existing national and international repositories, and what added value does it offer for future multi-hazard risk assessment? By answering these questions, the work provides a bridge between data compilation and applied risk-analysis frameworks.

This paper introduces a hazard event dataset, instead of a probabilistic hazard model. A hazard map quantifies the probability of an event of given magnitude within a specific period (e.g., Calder et al., 2015; Lindell, 2020; MacPherson-Krutsky et al., 2020), whereas a hazard event dataset records the actual, observed occurrences over time (e.g., St. Denis et al., 2023; Bisquert et al., 2025). Both are complementary: the latter supplies empirical evidence necessary to calibrate, validate, and contextualize the former.

Existing open datasets such as EM-DAT (Centre for Research on the Epidemiology of Disasters [CRED], n.d.), SHELDUS (Center for Emergency Management and Homeland Security [CEMHS], n.d.), or Risk Data Hub (Disaster Risk Management Knowledge Centre [DRMKC], n.d.) operate at national or continental scales but often lack spatial precision or local validation. At the regional scale of the Garrotxa region, no integrated repository of natural-hazard events across multiple hazard types previously existed., multi-hazard event repository previously existed. The dataset presented here therefore fills a critical resolution gap, enabling finer-scale analyses of hazard frequency, clustering, and potential interrelationships. In this sense, the present study contributes methodologically by integrating heterogeneous data sources (official, historical, and citizen-science), outlining a reproducible workflow for data processing and validation, defining a reproducible workflow for data validation, and outlining demonstrating how such data can inform susceptibility and multi-hazard risk modelling.

The following sections describe the study area, data-identification and processing methods, the resulting dataset structure, and a preliminary exploration of hazard interrelationships in the Garrotxa region.

2 Case study: the Garrotxa region

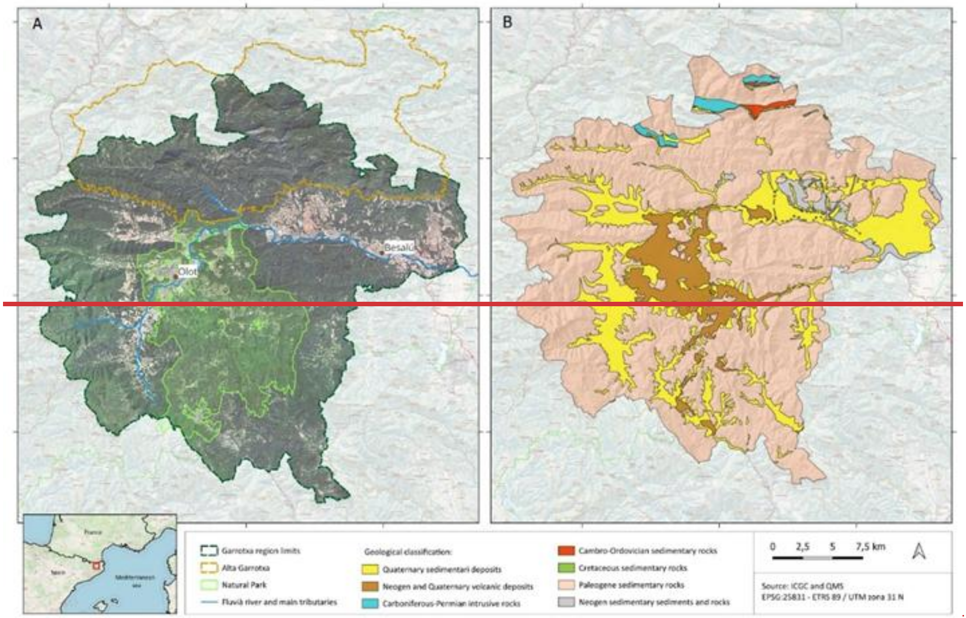
2.1 Geographical, geological and socio-economical setting

The Garrotxa region is located in the northeastern part of Catalonia, within the province of Girona, Spain (Fig. 1A). It is characterized by a mountainous landscape and significant geological diversity, with the most distinctive feature being the Garrotxa Volcanic Zone Natural Park. This protected area represents the most well-preserved volcanic landscape in the Iberian Peninsula, comprising over fifty volcanic cones and extensive lava flows (Martí et al., 2016). Two different relief units can be distinguished in the Garrotxa region (Fig. 1A, 1B) and the limit between the two sectors is marked by the Vallfogona thrust that runs from west to east (Martínez-Rius et al., 1990) (Fig. 1).

The Alta Garrotxa is part of the pre-Pyrenees mountain range. It covers the northern part of Garrotxa and extends beyond it. It is formed by cliffs and karstic relief originating from the east–west Alpine antiforms with Eocene limestones and Garumnian lutites. In the core of the folds, granites and schists outcrop the Paleozoic. In this area, the valleys are very closed and steep, with canyons produced by karstic erosion and mainly dominated by tectonic structures in the form of folds and thrusts in an east–west direction produced by the Alpine orogeny (65 Ma to 35 Ma).

The center and the south of the Garrotxa region are part of the Transversal mountain range of Catalonia, here composed of Eocene marls and sandstones. They are faulted by the Neogene (20 Ma to present) tectonic structures that form part of the European Rift. This area shows a flatter bottom and less abrupt reliefs as a result of the Quaternary volcanism and sedimentation (0.3 Ma to early Holocene) (Martí et al., 2025). The different lava flows and sediments accumulated by the past volcanic eruptions have formed the valleys of Bas, Olot, Santa Pau and Brugent. The Fluvià River traverses the region from west to east, playing a crucial role in shaping the local environment and hydrological dynamics.

The climate conditions of the Garrotxa region are classified as Mediterranean with montane influences, characterized by cold winters and mild summers. Precipitation levels are relatively high, which, together with the fertile volcanic soils, fosters the development of extensive forests, such as the beech forest of La Fageda d'en Jordà, one of the most ecologically significant ecosystems in the region (Garrotxa Tourism, 2025).



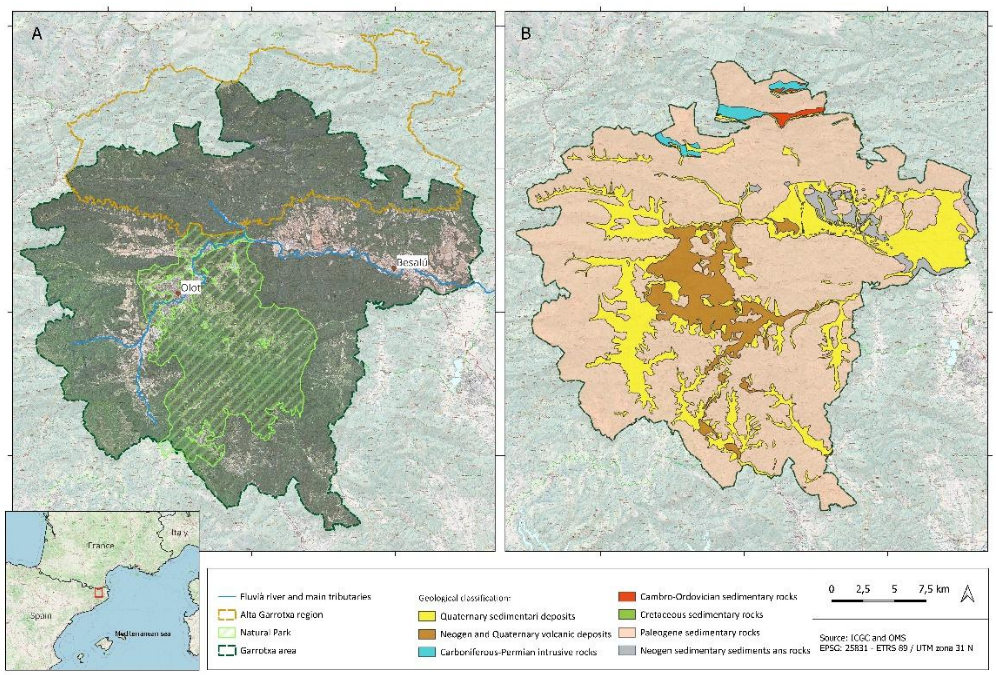


Figure 1: Study area. A) Location and geographical map of the Garrotxa region. B) Lithological map of the Garrotxa region. Base map service of the Cartographic and Geological Institute of Catalonia (ICGC), under a CC BY 4.0 license.

Beyond its geological and geographical characteristics, the Garrotxa region also possesses distinct socio-economic features that make it particularly suitable for a study like this. First of all, Garrotxa is the only mountainous administrative region of Catalonia with more than 20.000 inhabitants (GarrotxaDigital, 2022). Additionally, with a total area of 734.5 km², the region is highly accessible, and numerous scientific work has been conducted there, providing valuable knowledge of the zone (e.g., Bartolini et al., 2015; Varga et al., 2018; Revelles et al., 2023). 91 % of the residents of the Garrotxa region live in urban settlements (Garrotxa Environment and Public Health Consortium [SIGMA], 2023). Olot, the regional capital, is home to 38.836 people (Institut d'Estadística de Catalunya [Idescat], 2025a), accounting for more than half of the total population of Garrotxa. The second most populated municipality, La Vall d'en Bas, has only 3,221 inhabitants (Idescat, 2025b). Therefore, although Olot is a small to mid-sized city, it functions as a metropolitan hub for the region. The remaining 9 % of the population resides in dispersed settlements (SIGMA, 2023). This population distribution reflects a broader trend in Catalonia, where only the province of Barcelona accounts for almost 73 % of the total population (Gencat, 2023).

Thus, Garrotxa serves as a valuable study area, representing a larger demographic pattern. Additionally, Garrotxa has a strong economic activity. Despite being a mountainous area, 42 % of the workforce is employed in industry, making it the second-largest economic sector of the region (SIGMA, 2023). As a result, the unemployment rate remains below 10 %, slightly lower than the Catalonian average (SIGMA, 2023). Industrial growth has driven the development of major road infrastructure in the region, creating strong connections to key destinations such as Barcelona, the French border, the high-speed train station in Figueres-Vilafant, and Girona-Costa Brava Airport. Both industrial and transport infrastructure in Garrotxa can be treated as vulnerable elements, which have to be included in risk assessment and management studies.

Moreover, tourism is another important income for Garrotxa, which is attracted by its great natural beauty. In 2023, Garrotxa welcomed 192.109 tourists (overnight stays), while 559.515 people visited the Garrotxa Volcanic Zone Natural Park (Turisme Garrotxa, 2023). However, the growing number of visitors has raised concerns about overcrowding in natural areas of Garrotxa, especially in water ponds during summer and in La Fageda d'En Jordà during autumn.

2.2 Natural hazards in the Garrotxa region

The Garrotxa region, characterized by its volcanic geomorphology, mountainous terrain, and Mediterranean climate, is exposed to multiple natural hazards. Although the volcanic activity in the region remains dormant (Martí et al., 2025), other geological and hydrometeorological threats, including seismicity, landslides, flooding, and wildfires, present ongoing risks to both the environment and local communities (Vilaplana et al., 2008; Ajuntament d'Olot, 2022).

Seismic activity, while generally moderate, is influenced by the proximity to the Pyrenean tectonic boundary and the presence of Neogene-Quaternary active normal faults (Institut Cartogràfic i Geològic de Catalunya [ICGC], 2006; Bolós et al., 2015). Despite large-magnitude earthquakes in the region are relatively infrequent, moderate and low seismicity located along the main Neogene faults that cross the study area are common (Secanell et al., 2004; Ajuntament d'Olot, 2006; Jiménez and García, 2008; Departament d'Interior i Seguretat Pública, 2021). This seismicity, while rarely destructive, highlight the underlying geodynamic instability of the region (Instituto Geográfico Nacional [IGN], 2017; ICGC, 2020).

The steep topography, combined with intense seasonal precipitation and soil saturation, contributes significantly to landslide susceptibility (Palau et al., 2023). The many slopes, composed of weathered volcanic materials and unconsolidated sediments, are particularly prone to mass-wasting events following prolonged rainfall or seismic activity (ICGC, n.d.; Copons, 2008a). Landslides can disrupt transportation infrastructure, alter river courses, and threaten residential areas in both the highlands and foothill zones. Additionally, rockfall hazard is well-established at Castellfollit de la Roca. This municipality is characterized by a prominent, columnar-jointed basalt cliff standing above less cohesive alluvial and pyroclastic layers, whose differential erosion and fractures contribute to frequent rockfall hazards (Abellán et al., 2011; Bassols and Calm, 2018; Janeras et al., 2023).

Hydrometeorological hazards, particularly flooding, represent another major concern. The Fluvià River and its tributaries frequently experience episodes of rapid water level rise, particularly during extreme precipitation events (Escuer, 2008; Departament d'Interior i Seguretat Pública, 2015; SIGMA, 2017). The combination of steep catchments and variable rainfall patterns promotes flash flooding, which can impact urban areas such as Olot and pose significant threats to agricultural productivity (Agència Catalana de l'Aigua [ACA], n.d.). The increasing incidence of extreme weather events, attributed to ongoing climatic shifts, has further exacerbated flood risks in recent decades (Barriendos et al., 2019; Llasat, 2021; Sharma et al., 2021).

Soil erosion, closely linked to hydrological instability, is particularly pronounced in the volcanic soils of Garrotxa, which are highly susceptible to weathering and displacement (Palou et al., 2010; Planagumà-Guàrdia et al., 2022). Factors such as deforestation, changes in land-use practices, and overgrazing have intensified soil degradation, especially on inclined terrain, leading to loss of arable land and increased sedimentation in river systems.

Wildfires remain a persistent risk, particularly in densely forested areas dominated by Mediterranean oak and beech woodlands (Consell Comarcal de la Garrotxa, 2021; Consorci de l'Alta Garrotxa, 2024; Departament d'Interior i Seguretat Pública, 2024). The dry summer season, coupled with increased temperatures and periodic droughts, creates favorable conditions for fire ignition and rapid spread (Pausas and Fernández-Muñoz, 2012; Turco et al., 2019; Duane et al., 2021). The expansion of forested areas due to rural depopulation has further increased fuel availability, heightening wildfire risks (Vila-Subirós et al., 2014).

Ground subsidences are concentrated in the eastern part of the study area, particularly in the municipality of Besalú. This trend has been documented by previous investigations on the evaporite karst system developed within the geological complex of the Fluvià Valley (Copons, 2008b; Gutiérrez et al., 2016).

Regarding volcanic hazard in the Garrotxa volcanic field, the area is considered active, with the most recent period of volcanic activity covering the last 250 ka (Martí et al., 2025). The most recent eruption in this zone has traditionally been dated to the early Holocene (11–13 ka), although recent studies suggest it may have occurred as recently as ~8 ka (Revelles et al., 2023; Martí et al., 2025). Volcanic activity in Garrotxa has ranged from effusive Hawaiian-style eruptions to more explosive Strombolian episodes, with numerous phases of phreatomagmatic activity (Martí et al., 2011). This volcanism is structurally controlled by the main regional normal faults formed during the Neogene extensional phase that affected the area (Bolós et al., 2015). Bartolini et al. (2015) identified five distinct hazard levels in the Garrotxa volcanic field, based on simulations of lava flows, pyroclastic density currents (PDCs), and fallout scenarios.

In recent years, climate change has played a significant role in amplifying the frequency and intensity of extreme weather phenomena in the region, including heatwaves, droughts, strong wind events, and intense rainfall episodes while at the same time contributing to a marked decline in snowfall events (Observatori Pirinenc del Canvi Climàtic [OPCC] and Comunitat de Treball dels Pirineus [CTP], 2018; Cortès et al., 2019; Servei Meteorològic de Catalunya [METEOCAT], 2024). These changes have compounded existing hazards, necessitating a more comprehensive approach to risk assessment and mitigation strategies in the Garrotxa region.

3 Methodology

3.1 Data identification

The dataset spans 1 January 1900–31 December 2023, chosen to ensure a century-scale temporal window suitable for trend and recurrence analysis while maintaining reliable documentation. Six hazard types were included: earthquakes, landslides, rockfalls, floods, wildfires, and ground subsidences. Selection was guided by (1) their risk relevance in Garrotxa, (2) data availability within the study period, and (3) their potential interactions in a multi-hazard framework. In reference to this last criterion, relevant scientific literature was reviewed (e.g., Gill and Malamud~~et al.~~, 2014; Zscheischler et al., 2020; López-Saavedra and Martí, 2023; Lee et al., 2024; UNDRR and International Science Council [ISC], 2025) to identify cascading or triggering relationships that could plausibly occur in a region with the characteristics of Garrotxa, such as earthquake-induced landslides, rainfall-triggered landslides, or landslide-induced flooding resulting from the formation of natural dams and subsequent overbank flow. ~~–~~Volcanic activity, though geologically important, was excluded because its most recent eruption (~8 ka BP;~~,~~ Revelles et al., 2023) falls outside the historical timeframe.

The dataset was intentionally structured using a single-hazard approach, in which each hazard occurrence is recorded individually rather than being classified a priori as part of a multi-hazard event. This design choice minimizes subjective interpretation during data compilation and preserves event-level information, allowing potential hazard interrelationships to be explored subsequently through data-driven analyses of temporal and spatial co-occurrence.

To guide the data collection strategy, we first identified the main variables commonly used to characterize the selected natural hazards. This step aimed to ensure that the dataset would be compatible with existing hazard modelling approaches and could support future analyses.

The identification of relevant variables was based on three complementary sources: (1) a review of existing hazard models to identify commonly used input parameters ~~Rather than deriving descriptive variables solely from historical records, we first reviewed existing hazard models~~ (e.g., IBER for floods [Bladé et al., 2014], RockGIS for rockfalls [Matas et al., 2017], Cell2Fire for wildfires [Pais et al., 2019], FSLAM for landslides [Medina et al., 2021; Guo et al., 2022], and the Peak Ground Acceleration QGIS plugin [Núñez-Murillo, 2017])~~.~~; (2) a review of scientific literature and additional expert consultation; and (3) the previous experience of the authors in natural hazard research.

Once the relevant variables had been identified, they were conceptually classified into four analytical categories (Table 1): (1) internal or constitutive variables, representing intrinsic physical or geological properties influencing hazard occurrence; (2) external or environmental variables, describing external conditions that may trigger or modulate events; (3) process-development variables, capturing the temporal or dynamic evolution of events; and (4) non-influential or meta variables, corresponding to descriptive or administrative attributes related to data documentation.

This classification was used as a conceptual framework to guide the compilation of the historical dataset. However, during data collection it became evident that many theoretically relevant variables were not consistently reported in historical sources such as press archives or oral testimonies. As a result, the final dataset includes a combination of theoretically informed variables and surrogate variables (e.g., "affected_municipality", "np_ini_date", "np_fin_date") adapted to the level of detail available in the available sources.

This model-first approach ensured that our variables list would be compatible with future numerical modeling, allowing seamless integration of our event data into susceptibility or hazard simulations. During data collection we observed discrepancies between model-defined variables and historical documentation: for example, early-century press articles rarely reported quantitative rainfall totals or precise coordinates, so surrogate variables (e.g., "affected_municipality", "np_ini_date", "np_fin_date") were introduced.

3.2 Variable classification

Each variable was assigned to one of four analytical categories (Table 1) to structure subsequent statistical or network analyses. This typology links observational data to process understanding and helps prioritize which parameters can inform susceptibility or inter-hazard modeling.

Table 1. **Conceptual classification of hazard-related variables used to guide dataset compilation.** **Illustrative classification of analytical categories applied to dataset variables.**

Categories	Definition / Role	Example variables from the dataset	Utility for analysis
Internal (constitutive)	Intrinsic physical or geological properties influencing event generation	Lithology class, slope angle, soil type	Used in susceptibility modelling (e.g., landslide potential)
External (environmental)	External conditions triggering or modulating events	Daily rainfall, maximum wind speed, temperature anomaly	Supports correlation or co-occurrence analysis (e.g., rainfall-triggered failures)

Process-development	Variables describing temporal or dynamic evolution	Duration of rainfall episode, propagation direction of fire	Inputs for dynamic modelling or hazard-cascade simulations
Non-influential (meta)	Descriptive or administrative attributes	Data source, event ID, reporter type	Used for traceability, quality assessment, bias evaluation

~~This classification provides a conceptual bridge between raw observations and modeling frameworks, clarifying which variables act as drivers versus descriptors.~~

3.2~~3~~ Data collection

Data were collected from three complementary source categories (Tables 2 to 4): (1) i~~I~~nventoried datasets from official institutions (e.g., ICGC seismic catalogues, ACA flood inventories, and the wildfire database of the Catalan Government), obtained via formal data-sharing requests; 2) w~~W~~ritten sources, including historical newspapers and scientific literature, retrieved through digital archives (e.g., Arxiu Municipal de Girona, ReGira) using bilingual keyword searches (Catalan / Spanish); and 3) o~~O~~ral and citizen-science sources, gathered through two workshops (Montagut and La Vall d'en Bas) involving several participants with local and technical knowledge. Participants annotated printed maps and provided recollections, particularly regarding major floods and slope instabilities.

Table 2: Summary of the different inventory sources and methodologies used to collect the natural hazard events occurred in the Garrotxa region (1900-2023).

Natural hazard	Inventory source	Methods and Actions
Earthquakes	Cartographic and Geological Institute of Catalonia (ICGC): public institution responsible for geodesy, cartography and the spatial data infrastructure of Catalonia.	Data were obtained through a formal online request: https://www.icgc.cat/ca/LICGC/Contacte/Bustia-de-contacte. Two different datasets were provided: 1) Earthquakes felt in the Garrotxa region, with epicenters both inside and outside the region. 2) Earthquakes with epicenters located within the Garrotxa region.
Landslides and Rockfalls	ICGC	Data were obtained through a formal online request: https://www.icgc.cat/ca/LICGC/Contacte/Bustia-de-contacte. A dataset with 15 records was provided.
Floods	Portal Àgora, managed by: 1) the Analysis of Adverse Meteorological Situations Group (GAMA), a research group of Barcelona University (UB) in charge of studying adverse meteorological situations and their associated natural risks; and 2) the Catalan Water Agency (ACA), a public institution in charge of water resource management and flood risk planning in Catalonia.	Data were retrieved from the online software Portal Àgora (Llasat et al., 2022), which is publicly available and free.
	Garrotxa Environmental and Public Health Consortium (SIGMA): public institution in charge of the environmental and public health management in	Data were obtained through a personal petition. A list was provided based on the flood risk management plan for the Garrotxa region (SIGMA, 2017).

	the Garrotxa region.	
Wildfires	Catalan Government's Wildfire Prevention Service: public institution which forms part of the Catalan Agriculture, Livestock, Fisheries and Food Department, and is in charge of wildfire prevention and risk management in Catalonia.	Data were directly retrieved from the online records (Dades Obertes Catalunya, 2023). Data ranged from 2011 to the present and excluded wildfires affecting croplands or urban areas.
	SIGMA	Data were obtained through a personal petition. Two datasets were provided: 1) Alta Garrotxa wildfire records: 1975 to present and 2) Garrotxa wildfire records: 1991 to present
Meteorological data	State Meteorological Agency (Aemet) and Catalan Meteorological Service (Meteocat): both are public institutions responsible for collecting meteorological data and producing weather forecasts in Spain and Catalonia, respectively.	Data were retrieved using their Application Programming Interface (API) (AEMET, n.d.; METEOCAT, n.d.).

Table 3: Summary of the different written sources and methodologies used to collect the natural hazard events occurred in the Garrotxa region (1900-2023).

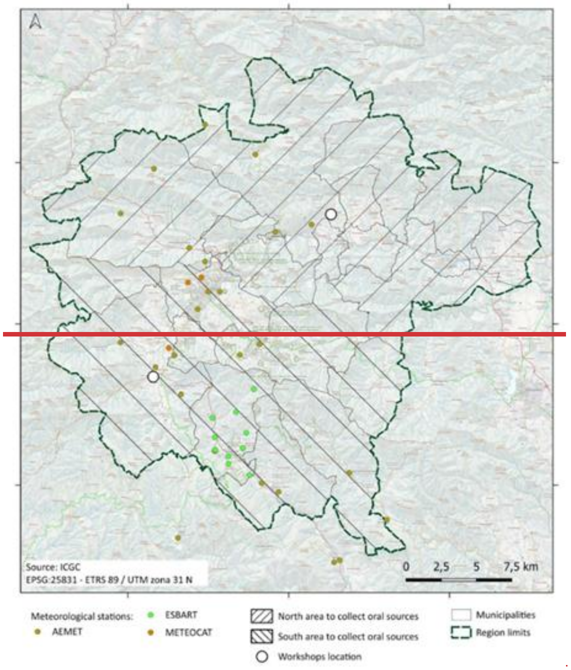
Written source category	**Natural hazard**	**Written source**	**Methods and Actions**
Press archives, through digitized newspaper collections	Landslides, Rockfalls, Floods, Wildfires, Ground subsidences	Municipal Archive of Girona: preserves historical documents essential for studying the history of Girona province, an administrative division to which Garrotxa belongs.	Press archives were retrieved and are free and publicly available online (Ajuntament de Girona, n.d.; ReGira, n.d.). Search strategies included using natural-hazard specific terms, the term *Garrotxa*, the name of specific municipalities, and using both Catalan and Spanish languages.
		Marià Vayreda Library: main library of the Garrotxa region, located in its capital, Olot.	
Scientific literature	Landslides and Rockfalls	Nierga et al., 2022; Vilar, 2022;	Data were consulted manually. The ground subsidences dataset of Fábregat (2020) was provided through a personal petition.
	Floods	Nierga et al., 2022	
	Wildfires	Maya and Bendinelli, 2005; Nierga et al., 2022	
	Ground subsidences	Gutiérrez et al., 2016; Fábregat et al., 2019; Fábregat, 2020	

Table 4: Summary of the citizen science workshops performed.

Details	**Date**	16 and 17 January 2024
	Place	Montagut townhall (municipality in northern Garrotxa) and civic center of La Vall d'en Bas (southern Garrotxa). See Fig. 2A and Fig. 3.
	Participants	Ten. Different backgrounds: community members, rural officers, politicians, geologists, and meteorologists.
Outreach activities and channels used	1) Poster distributed via WhatsApp, official municipal channels, and the social media and website of the Center for Territorial Sustainability; 2) Interviews in local television; 3) Direct invitations to local individuals with expertise in geology, meteorology and wildfire management.	
Methodology	Participants were encouraged to mark on a printed map the locations where they recalled natural hazard impacts occurring in the Garrotxa region during the period 1900–2023. Notes were also taken on site to collect additional relevant information.	
Type of data collected	1) Map of the Garrotxa region with natural hazard events marked (see Fig. 2B); 2) Personal memories, particularly regarding the 1940 flood and hazard interactions between rainfall, river swelling, blockages, flooding, and ground movements (Oix municipality, 1970s); 3) Recommendations of written sources for additional data retrieval, such as	

	Vilar (2022); 4) An observational record of landslides and rockfalls; 5) Precipitation data for Sant Feliu de Pallerols and Les Planes d'Hostoles (two municipalities in Garrotxa) provided by the local meteorological group named ESBART.

Figure 2: A) Participants in the workshop held in Montagut on 16 January 2024. B) Printed map of the Garrotxa region used during the citizen science workshops.



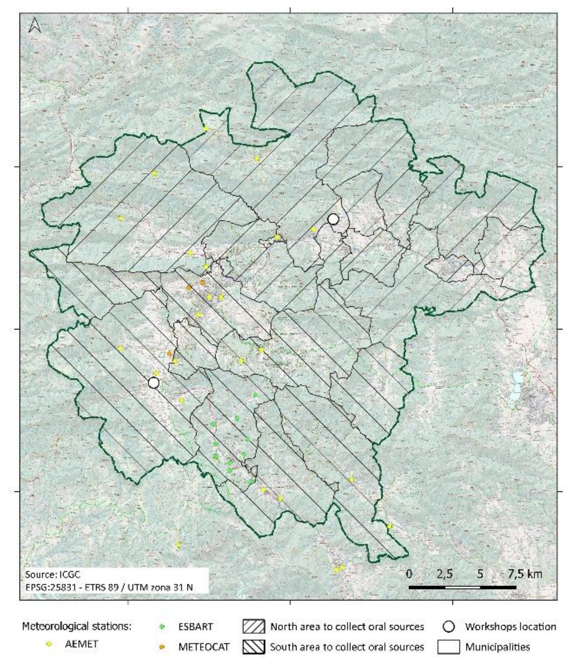


Figure 3: Map showing the meteorological stations from various sources (Aemet, Meteocat, and ESBART) used for data collection, along with the locations of the citizen science workshops held. Base map service of the Cartographic and Geological Institute of Catalonia (ICGC), under a CC BY 4.0 license.

All sources were georeferenced, standardized, and entered into a unified relational structure. Each record includes metadata on provenance and reliability.

3.34 Data processing and validation workflow

Raw data were processed in two stages: (1) Standardization and merging: Temporal data reformatted to DD-MM-YYYY, and spatial coordinates converted to UTM Zone 31 N (EPSG:25831); (2) Duplicate detection and cross-validation: Automated string and coordinate matching in Python identified potential duplicates (e.g., two reports of the same flood). All candidates were manually checked against source texts. Discrepancies between institutions (e.g., AEMET vs METEOCAT rainfall units) were resolved through conversion scripts. A more detailed description of the data processing procedures is provided in Supplementary Information S1.~~.~~

As for data cross-validation and quality assurance, ~~3.5 Cross-validation and quality assurance~~

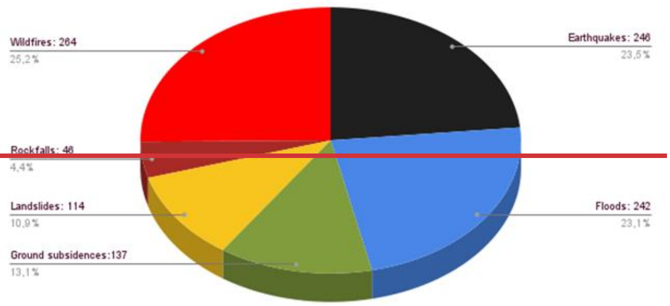
~~We applied~~ three methods ~~to conduct cross-validation and quality assurance~~were applied: (1) Spatial verification: events plotted in QGIS and visually checked against topographic basemaps; (2) Expert review: geologists from SIGMA and the Natural Risks Assessment and Management Service (NRAMS) verified 100 randomly selected entries for plausibility; and (3) Uncertainty documentation: the fields "*np_ini_date*" (non-precise initial date) and "*np_fin_date*" (non-precise final date) are used to record uncertainty arising from the absence of exact dates in the written and oral sources consulted. This multi-layer validation ensures that even heterogeneous, century-spanning information attains consistent standards for subsequent analysis.

4 Results

4.1 Dataset overview

The finalized Garrotxa natural hazard event dataset contains 1,049 records covering six hazard types: Wildfires (264), Earthquakes (246), Floods (242), Ground subsidences (137), Landslides (114), ~~Floods (242),~~and Rockfalls (46)~~, Wildfires (264), and Ground subsidences (137)~~ (Fig. 4). The final table has a total of 45 categorized variables spanning location, timing, physical descriptors, triggering factors, and metadata fields for quality control. About 73 % of events derive from inventoried sources and 27 % from non-inventoried written or oral materials (Fig. 5). Temporal coverage is uneven, with a clear increase in reporting after 1980, reflecting improved monitoring and media documentation. This bias does not necessarily indicate higher hazard frequency but improved detectability and institutional recording capacity.

The dataset is publicly available at https://digital.csic.es/handle/10261/394924 (Lagresa et al., 2025). Table S1~~2~~ provides information on the coordinate reference system used for geolocating the different natural hazard events, as well as the codes, descriptions, units (where applicable) or examples for each variable collected across the various natural hazards.



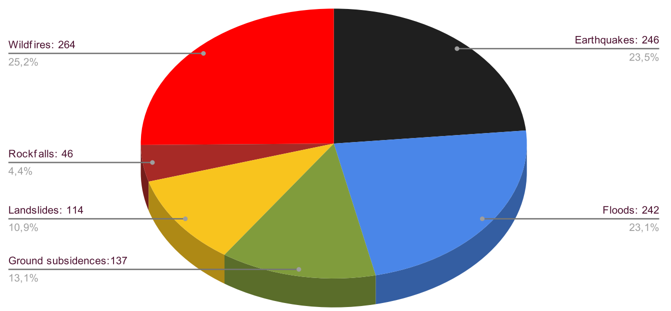
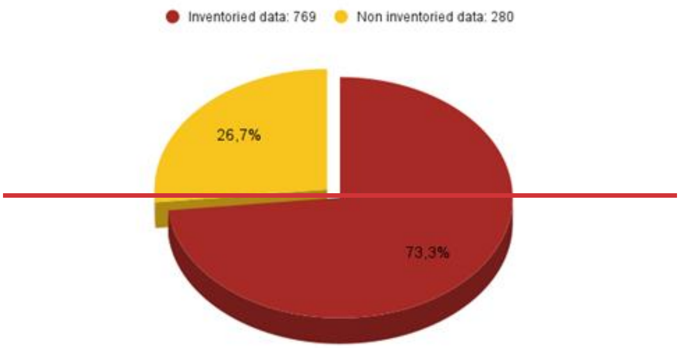


Figure 4: Total recorded events in the Garrotxa region (1900–2023), distributed by type of natural hazard (wildfires, rockfalls, landslides, ground subsidences, earthquakes and floods).



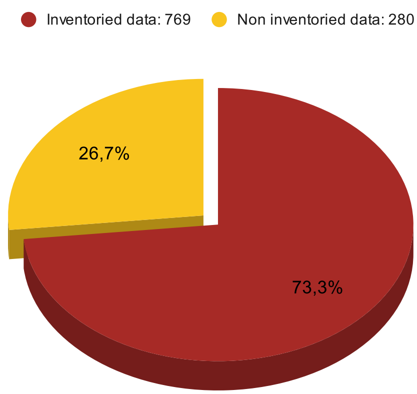


Figure 5: Percentage of recorded natural hazard events in the Garrotxa region (1900–2023) by data source (previously inventoried and non-inventoried).

4.2 Preliminary analysis of hazard interrelationships

Although the primary purpose of the dataset is descriptive, a simple exploratory analysis was performed to illustrate its potential for multi-hazard investigation. We examined temporal and spatial co-occurrence among hazard events using a simple~~ynthetic~~ yet realistic procedure, intended solely for demonstration purposes.

First, heuristic assumptions regarding potential temporal and spatial relationships between triggering hazards and subsequently triggered hazards were defined. These assumptions were informed by a preliminary inspection of the dataset~~, and by~~ prior geological knowledge of the study area, and by existing literature describing interactions between natural hazards (e.g., Gill and Malamud, 2014; UNDRR and ISC, 2025). ~~.~~

Based on these considerations, plausible temporal and spatial windows were defined to explore potential trigger–response relationships within the dataset. These thresholds do not represent definitive physical limits but were selected as heuristic values to illustrate how the dataset can be used to explore possible multi-hazard interactions. The assumed trigger–response relationships and the corresponding temporal and spatial windows are summarized in Table 5.~~The assumed trigger–response relationships, along with the corresponding temporal and spatial windows, are summarized in Table 5.~~ Wildfire and ground subsidences were not considered as triggering hazards for other events in this exploratory analysis. Ground subsidences~~s~~ were only evaluated as potentially triggered hazards. Wildfires were excluded from the interrelationship analysis due to their predominantly anthropogenic origin in La Garrotxa, which limits the interpretability of temporal and spatial associations within the adopted analytical framework. Therefore, a total of 912 events out of the total of 1049 were finally considered for this analysis.

Table 5. Assumed temporal and spatial windows for trigger–hazard co-occurrence used in the exploratory analysis. ~~**These temporal and spatial thresholds do not represent definitive physical limits but were selected to provide a plausible framework for illustrating how the dataset can be used to explore multi-hazard interactions.**~~

Trigger hazard	Potentially triggered hazards	Temporal window	Spatial window
Flood	Landslide, rockfall, ground subsidences	Within 7 days	Within 2 km
Earthquake	Landslide, rockfall, ground subsidences	Within 7 days	Within 25 km
Landslide	Flood, rockfall	Within 7 days	Within 1 km
Rockfall	Flood, landslide	Within 7 days	Within 1 km

Out of the 912 events considered, 79 (approximately 8.4%) participated in at least one potential interrelated occurrence. Table 6 presents a sample of the observed relative frequencies of these interrelations. Percentages are calculated with respect to the total number of events of each potentially triggered hazard type and indicate the proportion of those events that were temporally and spatially associated with a given trigger hazard, according to the adopted criteria. For example, 28.6 % of landslide events were temporally and spatially associated with flood occurrences within a 7-day window and a 2-km distance threshold.

Table 6. Relative frequencies (expressed as percentages) of potentially triggered hazard events (columns) that were temporally and spatially associated with a given trigger hazard (rows), according to the assumed criteria. "–" indicates that no interrelated occurrences were identified for the corresponding hazard combination under the adopted criteria.

Trigger hazard	Relative frequencies of potentially triggered hazards		
	Landslide events (%)	Rockfall events (%)	Ground subsidences events (%)
Flood	28.6 %	5 %	-
Earthquake	5.5 %	22.5 %	27.8 %

In addition to hazard–hazard interrelations, a complementary exploratory analysis was conducted to examine associations between selected natural hazards and meteorological conditions. For this purpose, a set of simple meteorological thresholds was defined, and hazard occurrences were evaluated with respect to whether they coincided with these conditions within the relevant temporal context.

Table 7 summarizes the most characteristic hazard–meteorological associations identified. Percentages represent the proportion of events of each hazard type that occurred under the specified meteorological conditions. These associations are intended to illustrate potential links between hazards and meteorological drivers, rather than to establish causal relationships.

Table 7. Relative frequencies (expressed as percentages) of hazard events occurring under selected meteorological conditions. Percentages are calculated relative to the total number of events of each hazard type. "–" indicates that no associations were identified under the adopted criteria.

Meteorological condition	Wildfire events (%)	Flood events (%)	Landslide events (%)
Maximum temperature ≥ 30 ºC	28.7 %	-	-
Wind ≥ 20 km/h	4.9 %	-	-
Precipitation < 50 mm in the previous 2 weeks	87.2 %	-	-
Rainfall ≥ 100 mm	-	96 %	71.1 %

Patterns observed in Tables 6 and 7 are broadly consistent with commonly reported multi-hazard sequences and hazard-meteorology in Mediterranean mountain regions (e.g., Guzzetti et al., 2007; Turco et al., 2018; Rodríguez-Peces et al., 2020). In particular, rainfall-driven processes appear to dominate, with intense precipitation episodes frequently associated with flood occurrences and slope instabilities (Table 7). Seismic activity is occasionally followed by localized rockfalls or minor ground subsidences, although associated magnitudes are generally low (ML < 4) (Table 6). In addition, wildfire occurrences tend to coincide with periods characterized by limited precipitation over several consecutive days and elevated temperatures, as reflected in the adopted meteorological thresholds (Table 7). These associations are consistent with the regional climatic setting but should be interpreted cautiously, as they do not imply direct causality.

The temporal distribution of identified interrelations reflects a recency bias, with approximately 66% of associations occurring after 2011. This pattern likely results from both an increased reporting of hazard events and a substantial improvement in detection and documentation capabilities in recent decades.

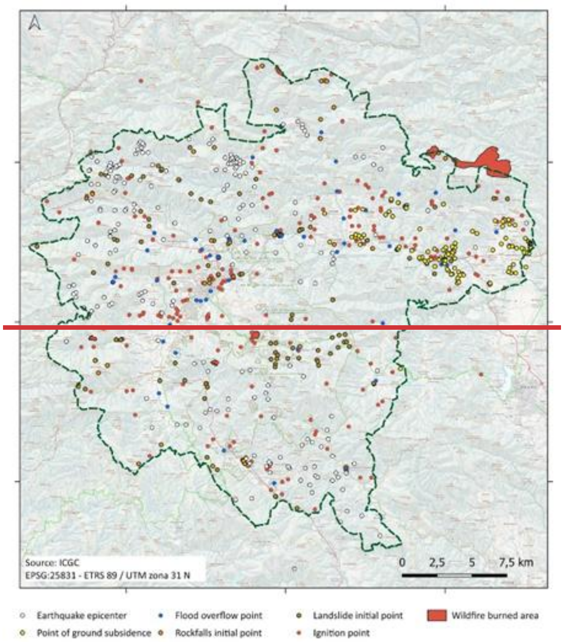
A key limitation of the present analysis remains the uneven quantity of available data across events. Interrelationships are more readily identified for well-documented episodes, such as major storms (e.g., the Gloria event in January 2020), where several hazards were widely reported and therefore recorded as separate entries in the dataset. As a result, potential interactions become easier to detect in such cases, highlighting the importance of data completeness for robust multi-hazard analysis.~~highlighting the importance of data completeness for robust multi-hazard analysis.~~

Although preliminary and based on synthetic aggregation, these findings demonstrate the capacity of the dataset to support exploratory multi-hazard association and causal-chain analyses once more complete and probabilistic information becomes available.

4.3 Spatial and temporal distribution

V~~Spatial v~~isualization in QGIS (Fig. 6) reveals several~~-~~ areas where different hazards spatially overlap~~multi-hazard clusters~~, including: (1) the Fluvià River valley, where flood and landslide ~~events overlap~~are both present; (2) the Bas and Santa Pau valleys, combining volcanic substrates and steep slopes conducive to slope instability; and (3) the Alta Garrotxa range, showing numerous wildfire and rockfall events. Such clustering supports the identification of priority areas for integrated risk mitigation rather than single-hazard interventions.

Concerning temporal distribution, Fig. 7 shows an apparent rise in hazard occurrence after 2000. While partly due to improved reporting, this trend coincides with observed regional increases in extreme rainfall frequency and summer heatwave duration, aligning with findings from the Catalan Meteorological Service (Meteocat, 2024). The dataset therefore also offers an empirical basis for studying climate-hazard linkages at the regional scale.



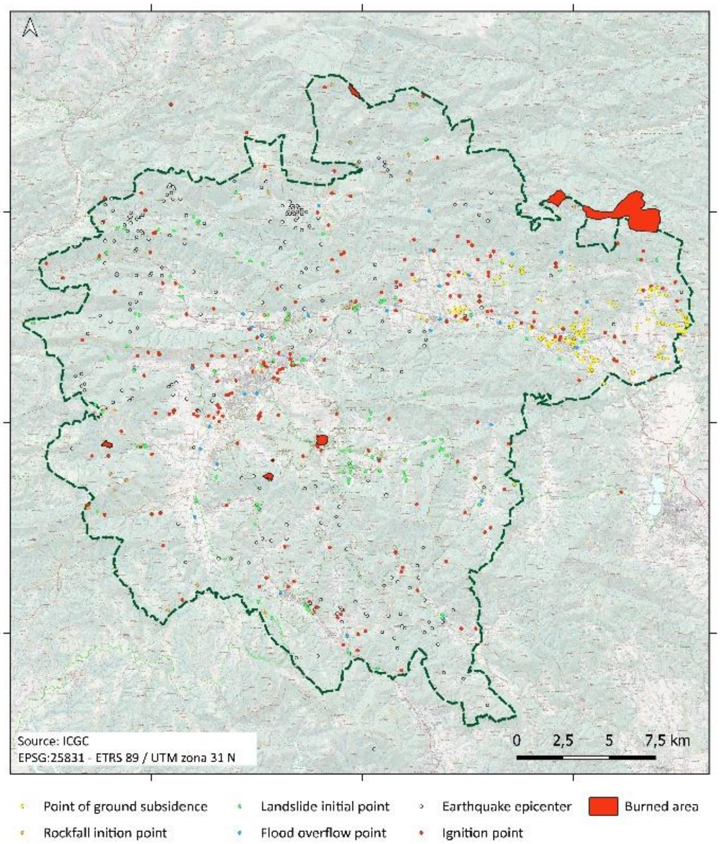
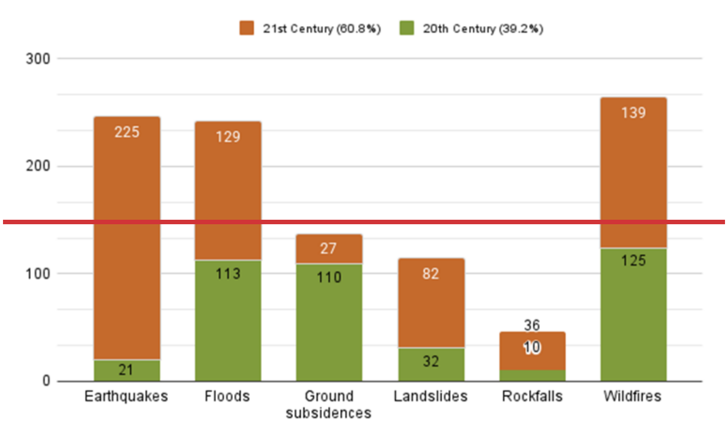


Figure 6: Geographical distribution of the total recorded natural hazard events occurred in the Garrotxa (1900–2023). Base map service of the Cartographic and Geological Institute of Catalonia (ICGC), under a CC BY 4.0 license.



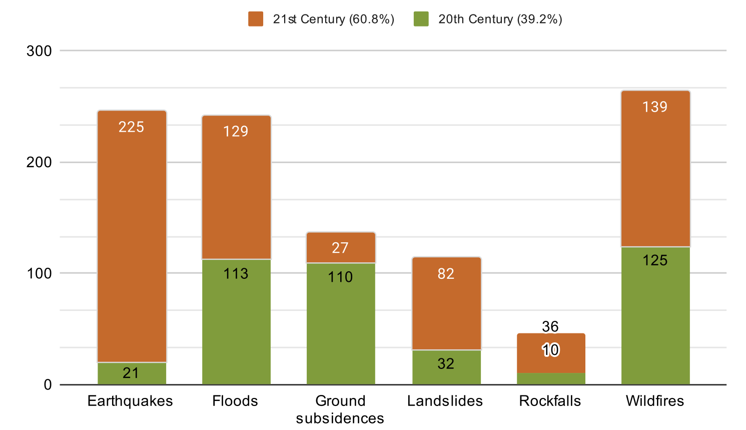


Figure 7: Total recorded events for each natural hazard in the Garrotxa region (1900–2023), distributed by century (20th and 21st).

5 Discussion

5.1 Dataset value and comparison with existing repositories

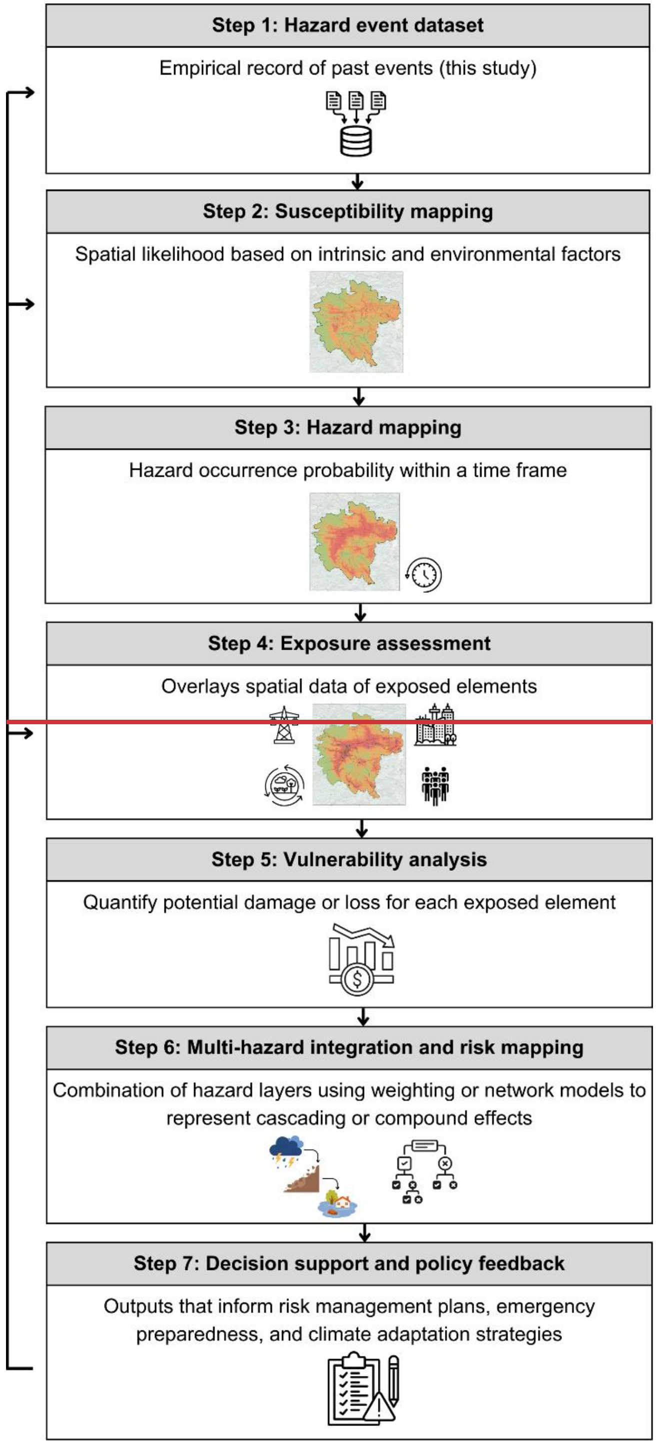
The Garrotxa natural hazard event dataset fills a unique spatial and thematic gap between global/national repositories (e.g., EM-DAT, SHELDUS, Risk Data Hub) and local administrative records. Compared with EM-DAT, which lists only disasters causing major economic losses or fatalities, our dataset captures all scales of events, including minor but frequent slope movements and small wildfires that shape local vulnerability. In contrast to SHELDUS (county-level U.S. data) or the Copernicus Emergency Management Service (European-scale), the Garrotxa dataset reaches municipality-level geospatial resolution (< 250 m). Moreover, it integrates non-institutional information such as historical newspapers and citizen-science memories, rarely present in official inventories.

From a scientific perspective, these differences translate into three clear contributions: (1) Enhanced resolution and completeness, supporting validation of susceptibility models that require fine-scale inputs; (2) Inclusion of cultural memory, linking physical events with community perception, crucial for risk-communication studies; and (3) Interoperable structure, as variables follow common vocabularies (e.g., INSPIRE, UNDRR Hazard Glossary), facilitating cross-dataset integration at European scale. Thus, the dataset moves beyond a purely archival purpose and becomes an enabling infrastructure for multi-hazard data-driven research.

5.2 Workflow toward multi-hazard risk assessment

The dataset forms the first step in a chain leading to a comprehensive multi-hazard risk analysis. Figure 8 (described below) outlines the sequential steps and data requirements in this process. Step 1, Hazard Event Dataset (Observed Data), uses an empirical record of past events, as detailed in this study. Step 2, Susceptibility Mapping, identifies the relative likelihood (low to high classes) of a hazard occurring at a specific location, based on intrinsic and environmental factors such as slope, lithology, and rainfall. Step 3, Hazard Mapping, integrates susceptibility data with the probability of an event occurring within a given time frame, such as flood inundation probability for 50- or 100-year return periods. Step 4, Exposure Assessment, overlays spatial data to identify exposed elements like people, buildings, infrastructure, and ecosystems. Step 5, Vulnerability Analysis, quantifies potential damage or loss for each exposed element. Step 6, Multi-Hazard Integration and Risk Mapping, combines hazard layers using weighting or network models to represent cascading or compound effects. Finally, Step 7, Decision Support and Policy Feedback, produces outputs that inform risk management plans, emergency preparedness, and climate adaptation strategies.

A susceptibility map expresses the relative predisposition of a location to event initiation, while a hazard map quantifies the probability of a given event magnitude occurring within a specified period. Not all hazard types have both products routinely: landslides, for example, often have susceptibility maps but rarely fully probabilistic hazard maps.


Step 1: Hazard event dataset
Empirical record of past events (this study)
Step 2: Susceptibility mapping
Spatial likelihood based on intrinsic and environmental factors
Step 3: Hazard mapping
Hazard occurrence probability within a time frame
Step 4: Exposure assessment
Overlays spatial data of exposed elements
Step 5: Vulnerability analysis
Quantify potential damage or loss for each exposed element
Step 6: Multi-hazard integration and risk mapping
Combination of hazard layers using weighting or network models to represent cascading or compound effects
Step 7: Decision support and policy feedback
Outputs that inform risk management plans, emergency preparedness, and climate adaptation strategies

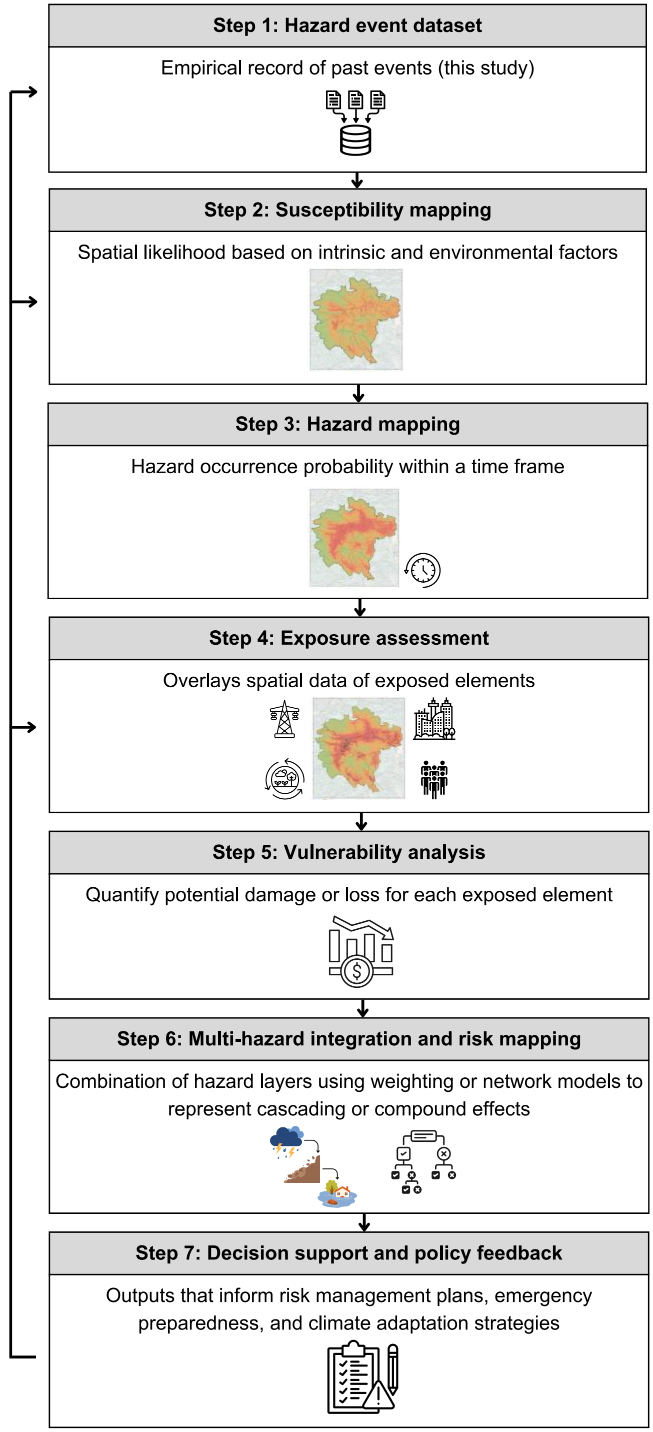


Figure 8: General workflow for an integrated multi-hazard risk assessment. Each step is represented by rectangular boxes linked by arrows. Icons in the chart symbolize datasets, GIS analyses, and feedback loops to policy actors.

5.3 Implications for regional risk management

For the Regional County Council and SIGMA, the dataset provides the first integrated evidence base of ~~all~~ recorded natural-hazard events in Garrotxa. Previously, disparate archives hindered coordinated action. Now, cross-hazard visualization reveals which municipalities face overlapping threats. For example, the overlap of flood and landslide records along the Fluvià River underscores the need for joint hydraulic–geotechnical planning, while patterns linking wildfire records to periods of limited precipitation and elevated temperatures inform vegetation-management priorities..

To maximize long-term utility, the dataset should be synchronized with existing real-time monitoring networks (meteorological and seismic) so that new events feed automatically into the dataset~~base~~. Developing an open-data API would further enable public transparency and early-warning integration.

Beyond Garrotxa, this initiative demonstrates a replicable governance model: a partnership between research institutions and local administrations that aligns with the National Plan for Adaptation to Climate Change (2021–2030) in Spain.

5.4 Challenges of data collection and processing

One of the main challenges encountered during dataset compilation was the scarcity of pre-inventoried data from official records, particularly for geological hazards such as landslides, rockfalls, and ground subsidences. Consequently, alternative sources, including historical newspapers and input from local experts, had to be consulted. Earthquakes were the only hazard type for which all relevant information could be retrieved from existing inventories, due to the presence of an established seismic monitoring network in the region.

Gathering information beyond official inventories proved time-consuming, but enabled the identification of additional events and improved data completeness. The integration of data from different institutional sources also required methodological adjustments, as similar datasets were often stored using different formats that had to be standardized before inclusion in the dataset.

Another challenge arose from the varying nature of the consulted sources. While inventoried datasets generally provided structured and precise parameters, written or oral sources often contained incomplete or subjective information, requiring additional verification through aerial imagery or expert consultation.

Human influence also had to be considered for certain hazards, including wildfires, floods, rockfalls, and landslides. This highlights the importance of accounting for human–environment interactions in hazard datasets. Finally, the largely manual nature of the data collection process underscores the need for future automation, for example through tools capable of extracting structured information from digitized archives or other semi-structured sources.

In terms of scalability, we believe that the approach presented here could be adapted to regions with characteristics similar to Garrotxa, as well as to other geographical contexts. Because hazards are recorded individually, the dataset structure can be readily extended to additional hazard types or adapted to different regional settings. However, the transferability of this approach may be constrained by data availability and by the heterogeneity of existing data sources and formats.

5.5 Main and limitations of this study

The scope of this paper is primarily limited to the presentation of the natural hazard dataset, which represents a foundational step toward broader multi-hazard risk assessment. In addition, a simple exploratory analysis is provided to illustrate how the dataset may be applied in multi-hazard investigations; however, this example is intended for demonstration purposes only and does not constitute a comprehensive framework for analyzing hazard interrelationships.

The dataset currently includes events related to six types of natural hazards. Although these hazards were selected based on their relevance to the study area and the availability of reliable information, the exclusion of other hazards may limit the scope of future multi-hazard analyses.

The time span covered by the dataset (1900–2023) also introduces limitations. Some significant events, or even entire hazard types with longer recurrence intervals, such as volcanic activity, may not be represented. Consequently, the available record may not fully capture long-term hazard dynamics, particularly for rare but high-impact events.

Finally, no formal quantification of uncertainty has yet been conducted to assess the quality of the resulting dataset, particularly with respect to reliability, validity, and provenance (Koedel et al., 2022).Despite its contributions, several limitations remain. Data heterogeneity exists, as different institutions record events with varying precision, with early-century entries relying on qualitative descriptions. Temporal bias is present, as record density increases after 1980, reflecting monitoring improvements rather than actual hazard escalation. Uncertainty quantification is lacking, as statistical confidence measures for location and magnitude are not yet formalized (e.g., Koedel et al., 2022), though a forthcoming phase will apply Bayesian updating to estimate data reliability. The scope is limited to six hazard types, and expanding to include windstorms or snow hazards will require additional data sources. Additionally, the dataset is currently single-layer, with inter-hazard relationships explored preliminarily but not explicitly modeled probabilistically. Future research should focus on (1) implementing automated web scraping of new events from press feeds, (2) developing multi-hazard network models using this dataset as training input, and (3) standardizing data formats across other regions for national integration.

6 Conclusions

This study provides the first integrated dataset compiling documented occurrences of earthquakes, landslides, wildfires, rockfalls, floods, and ground subsidences affecting the Garrotxa region between 1900 and 2023. By integrating inventoried datasets, historical written sources, and citizen-science contributions, the study consolidates previously scattered information into a coherent and quality-controlled dataset. In total, 1,049 events were documented, offering the most comprehensive reconstruction to date of natural-hazard occurrence in the region.

The exploratory analysis illustrates how the dataset can support the investigation of spatial and temporal relationships between hazards. By analysing event co-occurrence, the dataset highlights plausible interactions such as flood-induced slope failures, earthquake-related instabilities, and meteorological conditions associated with floods or wildfires. Although these observations are exploratory, they demonstrate the potential of the dataset to investigate cascading and compound hazard processes.

Comparison with national and international repositories shows that the Garrotxa dataset fills an important spatial and thematic gap between global disaster databases and local records. While large-scale repositories primarily document major disasters at national or continental scales, this dataset captures events across all magnitudes and provides municipality-level spatial resolution, incorporating locally validated information often absent from broader inventories.

Overall, the dataset constitutes both a regional data resource and a methodological reference for compiling and validating heterogeneous hazard information. The proposed workflow illustrates how diverse historical, institutional, and citizen-science data can be systematically integrated, representing a first step toward data-driven multi-hazard risk assessment and offering a methodological basis that can inform similar efforts in other regions.

This work presents the first integrated natural hazard event dataset for the Garrotxa region (Catalonia, Spain), documenting 1049 events from 1900 to 2023. By merging official inventories, historical sources, and citizen-science inputs, it transforms scattered information into a coherent, quality-controlled resource.

Beyond data compilation, the study illustrates how such a dataset can support the identification of preliminary hazard interrelationships as well as hazard-meteorological associations, and outlines a workflow toward comprehensive multi-hazard risk assessment. Comparative analysis shows that it complements and enhances broader databases by adding fine-scale, locally validated records.

In practical terms, the dataset equips regional authorities with a foundation for evidence-based risk planning and establishes a replicable model for other territories. Future extensions should quantify uncertainties and integrate probabilistic modeling, enabling transition from descriptive catalogues to predictive, data-driven multi-hazard risk maps.

Data availability

The historical record of natural hazard events occurred in the Garrotxa region (Catalonia, Spain) from 1900 until 2023 is publicly available at: https://digital.csic.es/handle/10261/394924 (Lagresa et al., 2025).

Author contribution

AL: Formal analysis, Investigation, Methodology, Visualization, Writing–original draft, Writing–review&editing. **MLS:** Conceptualization, Investigation, Methodology, Supervision, Writing–original draft, Writing–review&editing. **ISP:** Project administration, Writing–original draft, Writing–review&editing. **MMS:** Data curation, Formal analysis, Investigation, Methodology, Software, Writing–original draft. **JME:** Data curation, Formal analysis, Investigation, Methodology, Software. **MJL:** Funding acquisition, Project administration, Supervision. **AO:** Resources, Supervision. **LP:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Writing–original draft. ~~**ISP:** Project administration, Writing–original draft, Writing–review&editing.~~ **JM:** Conceptualization, Resources, Supervision, Writing–review&editing.

Competing interests

The authors declare that they have no conflict of interest.

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Supplementary Information S1

This section explains how data from the different sources were incorporated into the final dataset for each natural hazard. To remove duplicate values, a script was run on all collected data.

Regarding earthquakes, both datasets obtained from the ICGC were merged into a single Excel table. The date was standardized into a DD/MM/YYYY format and geographical coordinates were converted to UTM. Duplicate records were identified and removed when necessary. Finally, the earthquakes were sorted by date and incorporated into the final dataset.

In the case of landslides and rockfalls, two additional fields were created (*Non-precise initial date* and *Non-precise final date*) when lacking exact dates in the written and oral sources consulted. Also, due to lack of data, a volume classification in cubic meters (m^3) was established: Small (0–10), Medium (10–100), Large (100–1,000), and Very large (>1,000). Aerial photographs or descriptions provided in the news articles were consulted in order to infer the information. The field was left blank if not enough reference could be gathered. In some cases, local experts helped identify the exact geographical coordinates of the rockfall or landslide occurrence. Seismic amplification and lithology values were added to each recorded event. The seismic amplification map was developed separately, and each value was then assigned to the corresponding events using QGIS. Landslide and rockfall events triggered by tunnel construction or mining operations were excluded. Landslides occurring on roadside slopes were retained due to their relevance in the Garrotxa region as active hazards.

As for wildfires, the Alta Garrotxa dataset provided by SIGMA included wildfire events that had originated outside the study area. A buffer analysis was performed to decide which should be included in the final dataset. The following criteria was used: 1) Wildfires originating more than 5 km beyond the regional boundary were excluded. 2) Wildfires within the 5 km buffer were analyzed individually. Those affecting less than 10 hectares were disregarded. 3) A second buffer (1 km) was applied to further refine the dataset. Wildfires affecting more than 0.5 hectares within this zone were included. For wildfires known to have burned less than 1 hectare but without exact data available, the value *-1* was used in the *Magnitude* variable. Local experts assisted in identifying specific locations of the ignition points when data was missing. When coordinates could not be established, the event was included in the dataset with only the affected municipality specified. Maximum air temperature and maximum recorded wind speed were added to each wildfire record. These values were obtained for the specific day of each event and from the nearest available meteorological station. A script was developed to standardize and harmonize all meterological data as they were provided in different formats by Aemet and Meteocat. Regarding anthropogenic influence on wildfire occurrence in the region, the majority of wildfires are human-induced. Nevertheless, all events affecting forested areas were included, as their environmental impact was considered significant. In the case of the information gathered during the oral citizen science workshop, the recorded events were collected separately in an Excel table, validated using ortophotos and included if not duplicated.

In relation to ground subsidences, the *Non-precise initial date* and *Non-precise final date* fields were also applied when specific event dates were unavailable. These temporal ranges were determined by consulting aerial images of the area. For collapses identified on the earliest available imagery (1945 and 1956), the initial date of occurrence was left blank. Each sinkhole location was individually reviewed by local geologists to ensure that the assigned coordinates were as accurate as possible.

Concerning floods, in the dataset obtained from Llasat et al. (2022), each flood record included all the municipalities affected by that event in a single field. A script was executed to split each flood record into individual entries by municipality. A unique flood identifier (*flood_id field*) was assigned to each event to ensure that these entries were not counted as separate flood events. Finally, the dataset was filtered to retain only records referring to municipalities within Garrotxa. If georeferenced information lacked, insights from the citizen science workshop and close collaboration with regional experts were used to identify probable flood locations within each municipality. A QGIS point layer was created to represent the most probable overflow locations. For each flood event, rainfall on the day of the flood from the nearest meteorological station was added. In cases where heavy rainfall was continuous throughout the month, the variable *Duration* was marked as *Monthly*. All flood events potentially exacerbated by human negligence or land-use changes were fully included in the dataset.

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Table S1~~2~~: Summary of the coordinate reference system used to build the natural hazard dataset as well as the variables considered for each natural hazard, providing a description and its units, where necessary.

Metadata		
Coordinates Reference System: ETRS89 Code: EPSG:25831		
Common variables		
Code	**Description**	**Units (if applicable)/ Examples**
code	Identification event code	e.g. L01 (for landslides)
ini_date	Initial date	DD/MM/YYYY
fin_date	Final date	DD/MM/YYYY
np_ini_date	Non-precise initial date: Earliest possible date when the event is known to have occurred.	DD/MM/YYYY
np_fin_date	Non-precise final date: Latest possible date when the event is known to have occurred.	DD/MM/YYYY
duration	Event duration	Number of days
latitude	Geographic coordinate in terms of latitude for the event occurrence	Meters (m) in projected coordinate system UTM 31N

longitude	Geographic coordinate in terms of longitude for the event occurrence	Meters (m) in projected coordinate system UTM 31N
Earthquakes		
depth	Epicenter depth	Kilometers (km)
local_magnitude	Earthquake local magnitude	e.g. 0,7
intensity	Earthquake intensity as measured by the European Macroseismic Scale (1998 version)	e.g. IV
Floods		
flood_id	Identification code for the same rainfall episode	e.g. 1
affected_municipality	Municipality affected by the flood	e.g. Sant Feliu de Pallerols
total_rain	Daily rainfall of the area closest to the flood	Tenths of a millimeter
Ground subsidences		
date_formation	Year of formation/identification of the ground subsidence	Year (YYYY)
perimeter	Perimeter of the ground subsidence	Meters (m)
area	Area of the ground subsidence	Square meters (m^2)
depth	Depth of the ground subsidence	Meters (m)
average_depth	Average depth of the ground subsidence	Meters (m)
volume	Volume of the ground subsidence	Cubic meters (m^3)
nearest_distance_collapse	Distance from the nearest collapse	Meters (m)
evaporite_unit	Geological formation of the type of evaporite rock where the sinkhole occurred	e.g. Serrat Formation
geomorphic_unit	Geomorphical unit where the collapse occurred	e.g. Bedrock
activity	Indicates whether the sinkhole is active (showing signs of movement) or inactive (no current movement)	Active/Inactive
Landslides and Rockfalls		
volume	Volume of the event	Cubic meters (m^3)
volume_classification	If the volume is not precise, the following classification is used: small (0-10), medium (10-100), large (100-1.000) and very large (more than 1.000)	Cubic meters (m^3)
lithology	Lithological classification of the rock where the gravitational process is located. Source: ICGC	e.g. Limestones and dolomites

stratigraphic_sequence	Stratigraphic sequence extracted from the ICGC layer description (Geological map 1:50.000)	e.g. Lower section of the Vallfogona Formation
age	Lithology age extracted from the ICGC layer description (Geological map 1:50.000)	e.g. Holocene
topography	Terrain slope where the gravitational process was produced	Degrees (º)
clas_amplitsismica	Six different classifications according to the seismic amplification values attributed to each type of terrain	e.g. 1
vs30	Average shear-wave velocity in the top 30 meters of the terrain	m s-1
vmed	Mean shear-wave velocity	m s-1
fa	Site amplification factor for short periods	e.g. 0,86
fv	Site amplification factor for long periods	e.g. 0,76
Wildfires		
affected_municipality	Municipality affected by the wildfire	e.g. Sant Aniol de Finestres
hatree	Tree forest area burned	hectares
hanotree	Scrub, herbal or pasture forest area burned	hectares
hanoforest	Non forested (urban and agricultural) burned area	hectares
haforest	Forested area burned	hectares
hapasture	Pastures area burned	hectares
area	Total area burned	hectares
temp_ext	Daily temperature of the area closest to the wildfire	ºC
wind_velocity	Wind velocity of the closest area to the wildfire	$km\ h^{-1}$