



Natural hazard insurance: dissemination strategies using geological knowledge

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Abstract

During the last decades, natural hazards, such as earthquakes, volcanic eruptions, landslides, floods, storms, droughts, and cyclones, have increased in frequency and severity, influenced by climate change and population growth. These natural hazards can become sudden-onset disasters, causing human losses and property damages that affect economic stability and growth. Although there is a pressing need for risk decrease and adaptation strategies to these unexpected events, targeted natural hazard insurance would be a valuable tool to counteract governmental and individual consequences. This paper summarizes an overview of risk assessment and mitigation strategies based on geological, geomorphological, and meteorological factors. The study includes an examination of monitoring systems for movement and gas emissions, risk and emergency maps, and highlighting the vulnerability of different areas at national and regional levels. Furthermore, the paper addresses the importance of promoting comprehensive geological and geotechnical knowledge among citizens of every socio-economical group and proposing the tools to effectively deliver the message, aiming at increasing the willingness for natural hazard insurance at both individual and governmental scales for human and property protection.

Keywords Natural hazards · Geology · Risk management · Insurance

1 Introduction

Since the first half of the twentieth century, researchers are focussing on the description and analysis of natural hazards (Macdonald et al. 2012; Monte et al. 2021). Different classifications of hazards exist, mainly based on their

cause (natural, technological, social), origin (geophysical, hydrological, climatological, meteorological, extraterrestrial, or biological events) and/or intensity (common natural, extremely natural, biological agents or chronic catastrophes on a global scale) (IRDR 2021; Monte et al. 2021). Sometimes, there is not a strict differentiation between the types of hazards as influences among them may exist. A hazard is strongly connected with phenomena that may cause harm to the well-being of individuals with a measured probability.

The combination of a hazard with vulnerable issues was defined as the risk derived from a hazard. Based on “risk” definitions (IRDR 2021), it constitutes the key component for describing the need to prepare an individual, community, or system to be protected (Fig. 1). The scale of danger is not considered equal to the risk. Measures to improve risk assessment are developed to understand and prevent the risk and improve preparedness and thus, adaptation to potential changes driven by external sources or socioeconomic factors is critical. Adaptation strategies vary depending on location and the system’s needs. Ways of management of risks aiming to mitigate the potential effects are defined as mitigation strategies. Usually, interactions between adaptation and

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Fig. 1 Parameters for risk amount measurement

mitigation strategies exist. However, sometimes adaptation strategies might not be conducive to mitigation strategies, while other times, their interactions are overlooked (Rosenzweig and Tubiello 2007). Such strategies have a high impact if they are combined with communication strategies that distribute information or use other procedures that increase knowledge availability (Southwell et al. 2005).

1.1 Risk and financial vulnerability related to natural hazard insurance

Except for the physical and social resilience that can be increased by the aforementioned strategies (adaptation, mitigation, and communication strategies), there is a need to increase financial resilience. This can be achieved by implementing sustainable and cost-effective financial protection operations and/or policies. Such methods can be used at national, subnational, or even regional levels involving the governments, businesses, farmers, householders, and individuals in general (Vivo et al. 2021). Insurance or other forms of financial protection can reduce financial vulnerability and the impact of natural hazards. Moreover, insurance can strengthen adaptive positions and support economic recovery on both governmental and individual scales (Mushonga and Mishi 2022; OECD 2021a).

The protection of urbanized areas from natural hazards, such as hurricanes, landslides, cyclones, floods, droughts, earthquakes, and tsunamis, due to the influence of climate change in combination with population rise, is one of the key points of the strategic actions of the Agenda 2030 (Nations 2015), which in the framework of sustainable development set 17 Sustainable Development Goals (SDGs). These

highlighted the need for the government's efforts to better regulate land use, mainly in cities to decrease the harmful effects of the climate change and ensure prolonged sustainability (Commission 2016). However, as hazards have increased both in frequency and level of risk, many of them ended up disastrously (Schwarze et al. 2011). Geological, geomorphological, and meteorological factors are some of the key components for turning natural hazards into disasters. Knowing those factors at a regional and national level is critical for developing strategies that could effectively mitigate the natural hazards risks to avoid a disaster. While several risk adaptation and mitigation strategies, such as monitoring systems (Auflič et al. 2023), early warning system, and maps (Anelli et al. 2022), have been developed over time, there is a problem related to their implementation in regional, subnational, or even national level. While the technical and methodological knowledge of such techniques are available in the scientific community and researchers are focussing on investigations that aim in the simplicity of the techniques and in the decrease of cost, the individuals or even the communities are not aware of both the factors that turn a hazard into a disaster and the strategies or tools that scientific community developed in order to warn and protect the individuals and communities from such uncomfords. Communication strategies can be developed to solve the lack of knowledge by transferring the scientific knowledge to be comprehensible for the individuals' knowledge.

Based on the report "The Human Cost of Disasters 2000–2019", 7348 serious catastrophic events (Fig. 2) were exposed, offending 1.23 million victims and affecting the economic situation of 4.2 billion people with global economic losses of around US\$2.97 trillion. Compared with 1980–1999, 4212 events were recorded, affecting 3.25 billion people and resulting in economic losses of approximately US\$1.63 trillion (OECD 2021b; UNDRR 2020). As there is almost a 60% increase in catastrophic events that nearly doubled the economic losses, well-designed management from physical, social as well as economic sides of view is mandatory. Insurance markets can work as critical components for protecting households, businesses, and governments from the financial impacts of natural hazards. It must be highlighted that countries covered with high levels of insurance could recover within 12 months after exposure to a catastrophic event, while those with limited insurance could need 4 years for complete recovery (Carpenter et al. 2020). In 2010, the European Council tried to develop a report related to the facilitation and support of appropriate disaster risk insurance, financial risk transfer markets, and regional insurance pooling aiming at the transfer and cooperation knowledge as well as the seed of financing under the framework of the European Union (EU). Despite the development of the "Green Paper" report as the first step for the development

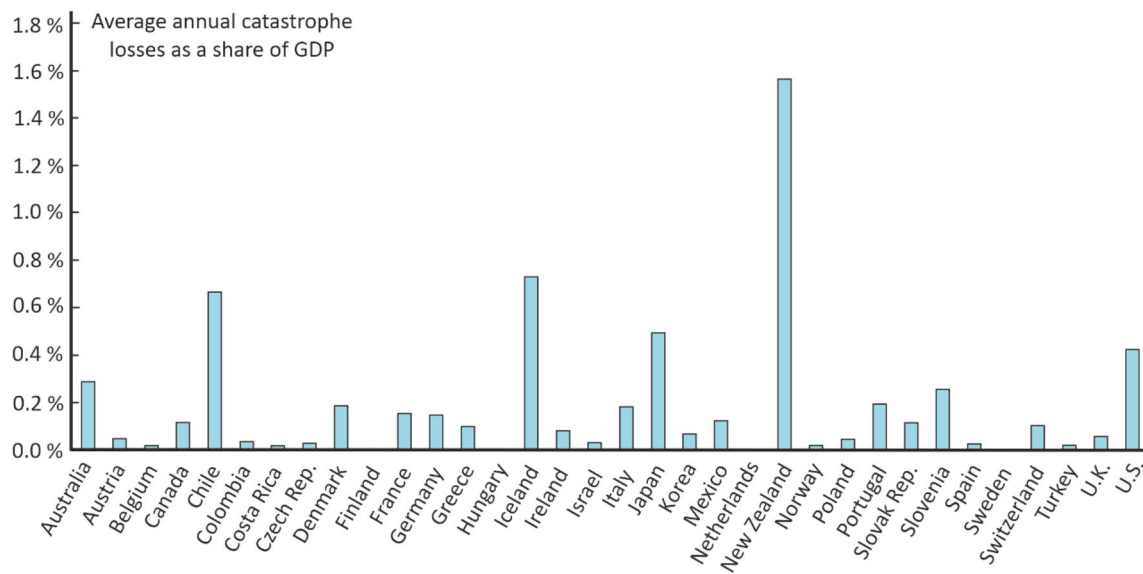


Fig. 2 OECD calculations based on natural catastrophes data provided by Swiss Re and PCS. Data on OECD country GDP is from OECD (2021a, b)

of a relative EU directive, no further steps were achieved (Commission 2013). Besides the low insurance protection in European countries, many countries of the Organization for Economic Cooperation and Development (OECD) also have low insurance protection (OECD 2021b). Natural hazard insurance could redistribute and reduce the potential financial risk related to adverse events by sharing costs among individuals or during different periods of time (Commission 2013).

The concept of insurance is based on transferring individual risks to an insurer's pool. The “collection” of risks can lead to natural hazard cost reduction in any specific time period (Commission 2013). Insurance supervisors and regulators can press the insurance companies for broader coverage of all relevant natural hazards aiming for a broader use of insurance packages (OECD 2021b). Nevertheless, individuals or even communities must ensure they have the knowledge to evaluate the necessity of specific natural hazard insurance in their area. A characteristic example is earthquake insurance. It may be considered a prerequisite in areas of high seismic risk, however, owners of houses built under the framework of earthquake-proof specifications may opt for low-cost insurance.

As a community comprises several social groups, it is mandatory to adapt well-designed communication strategies to meet each group's needs and expectations. Usually, countries with developing economies suffer more from natural hazards (Kahn 2005) due to the lack of effective resilience measures. Thus, straightforward communication tools that individuals or the public sector could utilize are the priority for compliance with the principle of leaving no one behind.

New technologies in the insurance field could provide opportunities for reducing insurance underwriting costs, claims settlement and distribution, and the design of advanced products such as parametric insurance. The natural hazard risk insurance programs may offer a possible solution for an affordable way to cover complex risks or for high-risk policyholders, leading to reduced public financial exposure (OECD 2021b). Such knowledge can be widespread through specific communication strategies that inform individuals with different backgrounds.

1.2 Objectives

Several geological factors are strongly influencing the appearance of natural hazards, the increase of risk, and thus the appearance of a natural disaster. When natural disasters occur in an area, the individuals are personally and financially affected. To limit or even to eliminate such effects of a natural hazard, several adaptation and mitigation strategies had been developed. The present study aims to cover basic aspects of adaptation and mitigation strategies based on an area's geological, geomorphological, and meteorological factors. It is acknowledged that the lack of knowledge of risk resilience techniques is the main problem for the risk prevention of individuals and communities. A deep understanding of the basic geological principles related to natural hazards and the available strategies for risk resilience is mandatory for the protection of individuals and their properties. For the complete protection of a community, the information of all the social groups is mandatory. Thus, communication strategies which can be addressed to different audiences are

critical for the protection of a community under the possible occurrence of a natural hazard. Such information and communication strategies are further described below.

Progress in resilience against natural hazards involves the systematic assimilation of pre-existing hazard-specific communication tools and methodologies into a comprehensive methodological framework designed to enhance community resilience in the face of natural hazards. Moreover, this integrated approach incorporates the beneficial use of insurance mechanisms as a vital component of the strategy. By amalgamating a diverse array of hazard-specific communication tools within a cohesive framework, the primary aim is to create a robust system that effectively disseminates critical information, raises community awareness, and fosters preparedness to confront various natural hazards.

In addition to the communication aspect, the incorporation of insurance against natural hazards serves as a significant element in fortifying community resilience. By leveraging insurance coverage, communities can significantly reduce the financial burden and the adverse impact of natural disasters on their livelihoods. Insurance policies tailored to specific hazard risks can offer a safety net, facilitating post-disaster recovery and promoting a swift return to normalcy. This symbiotic integration of hazard-specific communication tools and insurance strategies will collectively empower communities to not only respond effectively to natural disasters but also build greater adaptive capacity to mitigate potential losses and ensure a more sustainable path to recovery and resilience. The ultimate goal is to forge a harmonious and all-encompassing approach that bolsters community resilience, reducing vulnerability, and fostering a proactive stance in confronting the challenges posed by natural hazards.

When all the groups that constitute a community are informed for the risks of their area and the strategies that could be implemented for the minimization of the effects, they are in a position to claim personal or community coverage by the use of physical or financial insurance. Thus, the present review study has three main objectives: (1) The increase of individuals' geological knowledge for risk management, (2) The highlight of the obstacles in individual's willingness against natural hazards insurance, and (3) The information and communication strategies for the widespread of geological knowledge aiming in the overcome of individual's willingness against natural hazards insurance.

The main goal of the present review study is to propose different tools, methods, and procedures for the information of all the groups that constitute a community aiming at their protection from a physical and financial perspective. Based on an anthropocentric approach, the protection of human resources is a priority. When their protection is guaranteed, the assurance of their properties referred to the generic buildings and individual properties as well as the assurance

of critical infrastructures, such as the electricity sector, the transportation, the water sector, and the sewage system must be ensured. Such infrastructures are the key components for the individuals' well-being while they are also significant for the warming and the activation of a community in case of risk. The need of the protection of these sectors is higher in the case of combined natural hazards. A characteristic example is the exposure to a wildfire under an epidemic period. In this case, the transport of individuals must be ensured maintaining all hygiene measures to avoid the transmission of the epidemic. The investment in proper natural hazard insurance, with respect to the geological factors of an area, could protect the individuals, communities, or systems to avoid any financial losses. Proper communication strategies can lead to the achievement of ideal investment.

2 Geological knowledge for risk management

Developing risk adaptation and mitigation strategies is mandatory to protect individuals and communities against natural hazards. Strategies of high interest related to geological, geomorphological, and meteorological factors that influence the occurrence of a natural hazard are presented in this section and divided into two main categories: the monitoring systems frequently used as early warning systems and the mapping (Fig. 3). This categorization relies on the scope of the study. It does not mean that such tools cannot be combined.

2.1 Mapping

Mapping is one of the most widespread and traditional methods used to monitor a wide variety of natural hazards (Hearn 2019). Geological, geomorphological, and engineering geological field mapping is mandatory for the natural hazards study. A group of techniques employed to systematically record the ground morphology, landforms, processes, materials, lithologies, surface conditions, groundwater sources or levels, and tectonic conditions that affect the surface or the subsurface of the Earth are combined for effective mapping. Adding digital data, images of different scales, multimedia, and combining different map layers can lead to the specification of high-risk areas. Based on the designed maps, hazard identification can be achieved and a risk management plan can be organized. The accuracy of maps depends on the covered area and the technological development, as accurate satellite images, aerial photographs, geographic information systems (GIS), and high-tech geological equipment can be combined for a high-quality result (Auflič et al. 2023). The combination of geological maps with socioeconomic maps containing a spatial distribution of the vulnerable groups of

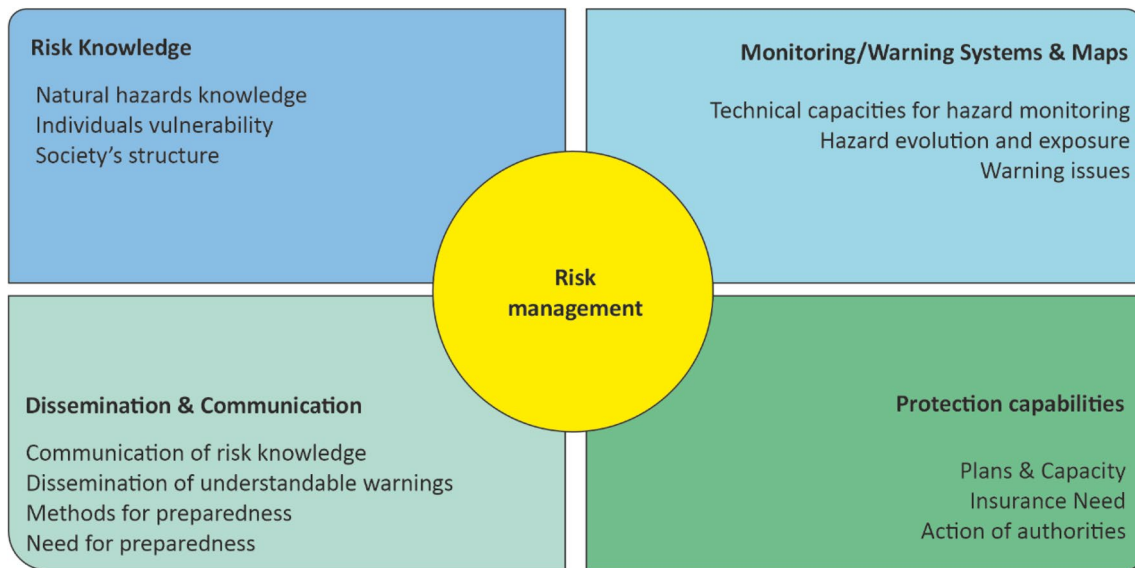


Fig. 3 Aspects of risk management

a community can reflect the high-risk areas. The mapping of protective infrastructures is also crucial for the final protection of individuals.

When combined with existing maps, monitoring techniques could provide results that can work as warning systems. However, data from sensors or numerical data cannot provide semantic meaning if they are not given in a spatial–temporal framework. The semantic Earth observation data cubes are an advanced procedure that could provide a solution for combining big-data with latitude, longitude, and time. These data expert systems work with semantic queries that individuals can understand to insert new information automatically in a machine-based way (Augustin et al. 2019).

2.2 Monitoring/early warning systems

Remote sensing is one of the tools used for recognizing and monitoring landslides, floods, and earthquakes and has been widely applied after the launch of the Landsat satellite in 1972 (Notti et al. 2020). Remote sensing detects and monitors the physical features presented in an area by measuring reflected and emitted radiation from a specific distance, such as from a satellite or aircraft. The image analysis of measurements taken at different times could lead to high resolution and dimensionality of spatial as well as spectral data. Remote sensing imaging instruments are mainly divided into active and passive sensors, separated into optical, radar, multispectral/hyperspectral, or Light Detection and Ranging (LiDAR). The passive ones measure solar energy that is reflected or emitted from features existing on Earth's surface. In contrast, the active ones generate their signal,

measured after its reflection back from the Earth's surface. Depending on the sensors installation platforms, they are divided into satellite-based, aircraft-based, unmanned aerial vehicle (UAV)-based as well as ground-based. Images from remote sensing may differ from spatial, radiometric, spectral, and temporal aspects. Passive sensors installed on satellites, such as Landsat, IKONOS, QuickBird, SPOT, WorldView, and Sentinel, are integrated on multispectral or even better on hyperspectral systems operating over a variety of spatial resolutions (Casagli et al. 2017; Chen et al. 2019; Philipp et al. 2021; Ye et al. 2019). Images are taken in VIS–NIR–SWIR, and far infrared, and the microwave portion of EM is provided and can be further analysed by a range of methods. Active sensors history began with the airborne satellite Synthetic Aperture Radar (SAR) in 1991, when ERS-1 was launched. Since then, Radarsat, ALOS, Cosmo-SkyMed, TerraSAR-X, and Sentinel are some of the space-borne platforms that have the ability to monitor motions in the microwave part of the spectrum (Bianchini et al. 2013; Philipp et al. 2021; Rott and Nagler 2006).

After one decade, a novel technique for near real-time monitoring was introduced by the ground-based SAR system (e.g. InSAR, LiDAR, DInSAR). Ground height could be measured by Light Detection and Ranging (LiDAR), which is categorized as airborne LiDAR (ALS) and terrain LiDAR (TLS) (Auflīč et al. 2023). Such a technique could be advantageous for landslide detection and monitoring. Differential Interferometric Synthetic Aperture Radar (DInSAR) prevails for surface displacement analysis with high precision. However, it is limited in the scenes' correlation due to the change in surface properties when soil moisture, vegetation, or snow exists (Philipp et al. 2021).

Interferometric Synthetic Aperture Radar (InSAR) is regularly used to investigate surface displacement measures providing information for the underlying processes. It is a well-designed technique for ground deformation measurements caused by seismic events, volcanic eruptions, landslides, and other geophysical phenomena that can cause such deformations (Bignami et al. 2021). UAVs are also known, especially for high-risk situations, as they ensure the lack of human life danger. Moreover, they are beneficial for inaccessible areas at low altitudes and with flights implemented close to the tested objects where manned systems are insufficient (Casagli et al. 2017). The temporal resolution gives information for the temporal distance of the acquisitions of two images that cover the same area. When the sensor is on a satellite, the temporal resolution may vary from hours to days depending on the geostationary nature of the platform orbit (Auflič et al. 2023). The remote sensors with temporal resolution in the scale of hours with high spatial accuracy can work as efficient warning systems for slow-onset natural hazards.

Geotechnical monitoring is a helpful technique for identifying displacement and surface depth that provides feedback for prediction modelling and stability analysis (Chae et al. 2017). Sensors that are frequently used for this technique are inclinometers, tiltmeters, extensometers, and geophones. Such sensors are usually installed in boreholes or/and on the surface of possible landslides and can give periodic, continuous, near real-time, or even real-time measurements (Auflič et al. 2023). With the real-time record of measurements in an online system, there is the opportunity to provide a danger signal to inform the communities or individuals for immediate action. GNSS/LPS-based Online Control and Alarm System (GOCA) is another technique that can be applied as an early warning system, especially for real-time deformation monitoring due to natural hazards such as landslides and volcanoes. It consists of a set of GPS sensors and communication units placed in the monitoring area connected to two GOCA software: sensor communication and deformation analysis. The packages are running in a central computational system and the object point positions are given to reference points. The online deformation analysis is based on the Kalman filter or a flexible user-defined displacement estimation. When a critical state is reached, proved by statistical testing, the setting of an alarm is enabled (Jäger and González 2006). Distributed fibre optic monitoring technology is also used for the geotechnical monitoring of pipelines. These pipelines are usually installed in areas with significant seismic activity or permafrost areas where visual inspection is difficult or impossible. Optical fibres use distributed strain and temperature measurements correlated to the Brillouin scattering sensitivity, giving details for the mechanical and thermal stresses. The scattering analysis is combined with the time domain technique resulting in strain and temperature measurement profiles. The temperature measurements control soil erosion or dune migration (Ravet et al.

2017). Geotechnical monitoring is sometimes combined with ground-based geodetic methods. These provide monitoring and observation of points' absolute displacements concerning stable reference points in an area of interest (Haberler-Weber 2005). One of the most widely used geodetic methods is the tachymetric measurements, where geodetic reflecting prisms are located in stable areas to establish reference points.

In contrast, another set of prisms is placed in the tested area. To fulfil the geodetic network, a measurement instrument is included. The reference points must be carefully selected to ensure their long-term stability and the high accuracy of the method (Haberler-Weber 2005; Peternel et al. 2017). While this method provides real-time monitoring by an automatic procedure, it is restricted to a limited area where the ground points are placed.

Geo-hydrological monitoring is mandatory for a wide range of natural hazards, such as landslides, debris flows, and floods that are usual in mountain environments or shallow landslides and debris flows as results of sediment transport and soil erosion (Gariano and Guzzetti 2016). Such natural hazards can have as a source, over a long time, rainfall triggering events that could vary in duration and intensity (Abbate et al. 2021). Measuring water-related parameters for areas with high-risk sensitivity is crucial for predicting flood initiation, landslide initiation, and movement (Bezák et al. 2021). The water has the ability to reduce the shear strength of geological materials by becoming saturated. Increasing pore water pressure decreases the resistance to shear stress and causes instability. Parameters such as precipitation, pore water pressure, groundwater level, soil moisture, snow cover thickness, and water discharge can be measured periodically or continuously with near real-time data collection. If an automatic way designs the monitoring, immediate notification for potential risks can be spread to inform and protect the public (Auflič et al. 2023). Except for monitoring processes, modelling tools are used to describe geo-hydrological processes. The open-source model PCR-GLOWB-2 (Sutanudjaja et al. 2018) and the model CRHyME (Abbate et al. 2023), both written in Python, are some of the models that aim to reproduce water balance over terrain and simulate processes related to hydrogeological hazards, including solid transport, erosion, shallow landslide, and debris flow. The models can address and quantify several processes that could occur simultaneously, are physically connected, and cannot be described separately (Abbate et al. 2023).

3 Obstacles in individual's willingness against natural hazards insurance

The main obstacles to an individual's willingness to be insured for natural hazards are mainly social and financial parameters. The lack of concerns related to them can work

as obstacles for individuals to understand the necessity of their protection against natural hazards (Brondi et al. 2021).

The social parameters are mainly divided into the following components (Amirsadat et al. 2023): (i) awareness, (ii) knowledge and skills, (iii) attitude, (iv) social capital, and (v) social position.

The awareness of individuals is crucial for their protection against natural hazards (Ivčević et al. 2020). The awareness of individuals could be enhanced by the knowledge of ways to reduce natural hazards, plans for preparation and implementation of crisis management at least at the neighbourhood level, necessary measures to prepare against hazards, as well as practical ways for the training and the information communication against the hazard (Engdahl and Lidskog 2014). At a neighbourhood level, three main aspects must be covered for the increase individuals awareness and the ensure of community's well-being: the knowledge of places that are in severe danger or they are sensitive to the reoccurrence of a hazard, the existence of relief groups that could deal with natural hazards, and the specification of groups with high-sensitivity against the risk.

In some cases, there is an unjustified overconfidence in the integrity of a structure to withstand shocks from natural hazards that leads to the adoption of low-risk safety measures (Luís et al. 2016). A typical example is the building of houses in technically filled rivers with the belief that there is a limited possibility of river flooding under extreme meteorological events (Amirsadat et al. 2023).

The knowledge could cover aspects such as the necessary education about preparation against natural hazards derived by access to specific sources, such as radio, television, and the Internet. The lack of access has a double impact on risk protection willingness and understanding of the hazards' significance. First, the knowledge of vulnerable individuals, such as physically disabled, elderly, deaf or blind people in a community, is crucial for their proper protection (Amirsadat et al. 2023). Actions from the authorities and potential coverage of their insurance are helpful for the community and increase the safety feeling of such individuals (Wachinger et al. 2013). Correlated to this, the people's knowledge of organizations or institutions responsible for reducing the risk in the face of a natural hazard is mandatory (Green 2008). In case of social readiness to set up temporary shelters or find safe places to pass the natural hazard danger, the necessity of insurance, at least for individuals' life, could be avoided. Despite that, the lack of such infrastructures is another parameter for enhancing the willingness for complete insurance. The experiential knowledge of individuals against the face of a hazard, especially under the lack of insurance, and the observation of indigenous feedback under these events are also crucial for buying insurance (Gruev-Vintila and Rouquette 2007). Thus, people's attitude that they can deal

with natural hazards due to their skills decreases their willingness to insure (Amirsadat et al. 2023).

Social capital deals with an individual's participation in social groups or networks that could increase trust and solidarity (Sarrica et al. 2018). In this case, the citizens believe in collective action and cooperation that could increase the effectiveness against a natural hazard. This may be a fact; however, when the intensity of a hazard is high proper management cannot be ensured. Correlated to social capital, social position is also critical for the willingness to insurance. The belief that a person belongs to a group with common behaviour, economic status or education level can lead to the acceptance or rejection of insurance.

The financial parameters are mainly divided into (Amirsadat et al. 2023) (i) employment, (ii) income and expenses, (iii) access to economic resources, (iv) diversity of livelihoods, (v) capital and assets, and (vi) stability and distribution of income.

It is evident in countries with high unemployment rates that asking for individuals' coverage is redundant. Moreover, the amount of income correlated with the expenses necessary for individuals' livelihood is critical for the measurement of the available money that could be spent for extra activities that could ensure their safety. Another variable related to income and expenses is the number of people who base their livelihood on that salary. A typical example is a large family usually supported by two individuals who have to cover the basic needs of all the family members. Thus, the stability and distribution of income are crucial for the individuals' livelihood and welfare (Amirsadat et al. 2023).

Recovery of the community covering aspects such as the limited time of finding a job after losing one, having a second job, use of technologies in business development, support to new businesses and institutions, financial independence, and properties values are only some of the aspects that influence the cost of insurance for both individuals and communities. The law of demand also plays a significant role in insurance companies.

The approach that insurance companies follow is also crucial for the insurance market. Thus, companies have to deal with the psychology of decision-making (Mushonga and Mishi 2022). Two main decision-making approaches have the economic agents to consider when dealing with natural hazard uncertainty: the normative and the descriptive approach. The normative approach includes mathematical and analytical tools in which individuals make rational decisions (Pasquini et al. 2019). The descriptive approach focusses on the perspective of the actual decision-making process, considering the prospect theory and understanding the human mind's flaws. Research proved that economic agents use heuristic decisions for insurance purchasing (Pasquini et al. 2019; Sum and Nordin 2018). In this process, agents use shortcuts in decisions making due to limited

cognitive capacities and with the purpose of saving time and cognitive resources (Sum and Nordin 2018). The derived problems from this procedure can be solved by involving experts related to natural hazards (e.g. geologists or environmentalists) in the insurance companies, aiming to increase individuals' trust and willingness for insurance.

4 Information and communication strategies

The development of advanced communication strategies taking advantage of technological evolution can lead to effective informing of society. Several strategies that have been already used for the widespread of knowledge in relative or other sectors are given below. Some of them are still under development, while others refer to tools that could be potentially useful and need further investigation. As the background of individuals even in the same community may differ, the combination of more than one information and communication strategies could be mandatory for the spread of knowledge to all the social groups aiming in the principle of “leave nobody behind”. Information and communication strategies that could be used in the communities aiming to increase the geological knowledge among the individuals with an ulterior motive the increase of natural hazard insurance willingness are the databases development, the collection of relative images and videos, the development of related educational material, the gamification, and the engagement of stakeholders in citizen science.

4.1 Databases development

Long-term databases containing the measures derived from the monitoring systems, described in Sect. 2.2, can be utilized to establish the record of the occurrences of a natural hazard event (Dunbar 2007). The databases are available to the public to educate and inform about hot spots and natural hazards trends. Web technologies, such as retrieval capabilities and interactive search, can be used to access databases more easily. National databases are of high importance due to their extended coverage. Among them, the National Geophysical Data Center (NGDC) Worldwide Significant Earthquake Database, the NGDC Significant Volcano Database, the NGDC Worldwide Tsunami Database, and the Volcanic ash advisory database of the National Oceanic and Atmospheric Administration (NOAA) that covering the related times, casualties, damages, as well as the physical characteristics of the natural hazards (e.g. the maximum water height for tsunami or the volcanic ash location in the atmosphere), are included in the databases (Dunbar 2007).

Due to the potential interactions between the different natural hazards, developing a relational database management

system (RDBMS) is mandatory, at least for the hazards with strong correlations. The available data can be exported as tables, reports, interactive maps or custom CD-ROMs. The maps are connected to a geographic information system (GIS) or to additional auxiliary geospatial data. The different GIS layers can be included given extra information such as an area's topography, political boundaries, or population density. In addition, hyperlinks and hazard pictures can be included to provide further details of a natural hazard (Dunbar 2007).

4.2 Natural hazards images and videos

Capturing the consequences of natural hazards effects via images or videos is critical for permanently storing the derived information. In addition, these media could serve as reminders for both the public and the scientific community and can work as tools for their preparation to handle similar future consequences (Dunbar 2007). The images and videos can be uploaded to online platforms or connected to Google Earth or similar software that allows a virtual tour in the affected areas.

Moreover, the development of informative posters or videos can be achieved by graphical designers or other experts in the field. The posters may be put up in the local area, such as in offices, shops, waiting areas, bus stops, schools or public noticeboards, presented in relative or non-relative exhibitions, or uploaded on social media aiming at public awareness. The videos can be widespread as advertising tools on both the Internet and TV media, while they can be created as educational material in schools, universities, or conferences. Moreover, videos targeted at specific groups can also be developed aiming at a deep understanding of the audience. A typical example of the coverage of targeted needs is the development of videos related to site-specific natural hazards provided to tourists who want to visit such areas aiming at their awareness and protection in case of need. This is mandatory for areas containing volcanoes or areas sensitive to tsunamis. Such videos can be played on airplanes, ships, or other transportation media.

4.3 Educational material

The implementation of courses on natural hazards in all the grades of educational systems is crucial for knowledge communication across all ages. The courses can cover sources of natural hazards, ways to limit their impacts or even their exposure, tools to manage and mitigate risks, and ways of protection during risk events. Moreover, organizing conferences and workshops involving authorities, the public and experts in the field can provide deep communication involving individuals of higher ages.

4.4 Gamification

Teenagers between 12 and 17 years old frequently use the Internet and 94% of US teens supported its use as a medium for helping them with homework or learning new content (Lenhart et al. 2005). Online games play an essential role for communication purposes not only in teenagers but also in individuals of older age as they could be used for both entertainment and educational purposes. Quiz, simulation, sandbox, real-time strategy, action-adventure, survival, and platformer games could be used to develop games focussed on natural hazards concepts. UN Office for Disaster Risk Reduction (UNDRR), in cooperation with other organizations, governments and academic communities, developed, among other tools, an online game. This game aims to teach children how to develop communities' infrastructures with high safety and how early warning systems, education, and evacuation plans can protect human lives and properties (UNDRR 2018). All the related aspects, such as population, budget, natural hazard probability, physical parameters, and consequences, are included in the game, as given in Fig. 4 (UNDRR 2018).

Board or virtual reality games with scenarios related to natural hazards can be developed to fulfil the above tasks.

4.5 Engaging stakeholders in citizen science

The field of citizen science has expanded rapidly with the development of smartphones in the last few years, allowing more information to be shared through digital media (Sarica et al. 2018). By using phones with built-in GPS receivers, volunteers can readily provide geo-location information about events in real time, supporting the popularization of science around the new concept of citizens' observatories. The term "citizens' observatories" was first used in 2014 in the EU FP7 Topic ENV.2012.6.5-1: 'Developing community-based environmental monitoring and information systems using innovative and novel Earth observation applications' applied to a framework that combined participatory community monitoring with monitoring by policymakers, scientists, and other stakeholders.

In practice, citizens' observatories typically share a similar model (Liu et al. 2017) that includes engaging the participation of citizens in data collection, data interpretation, and information delivery. The model normally combines

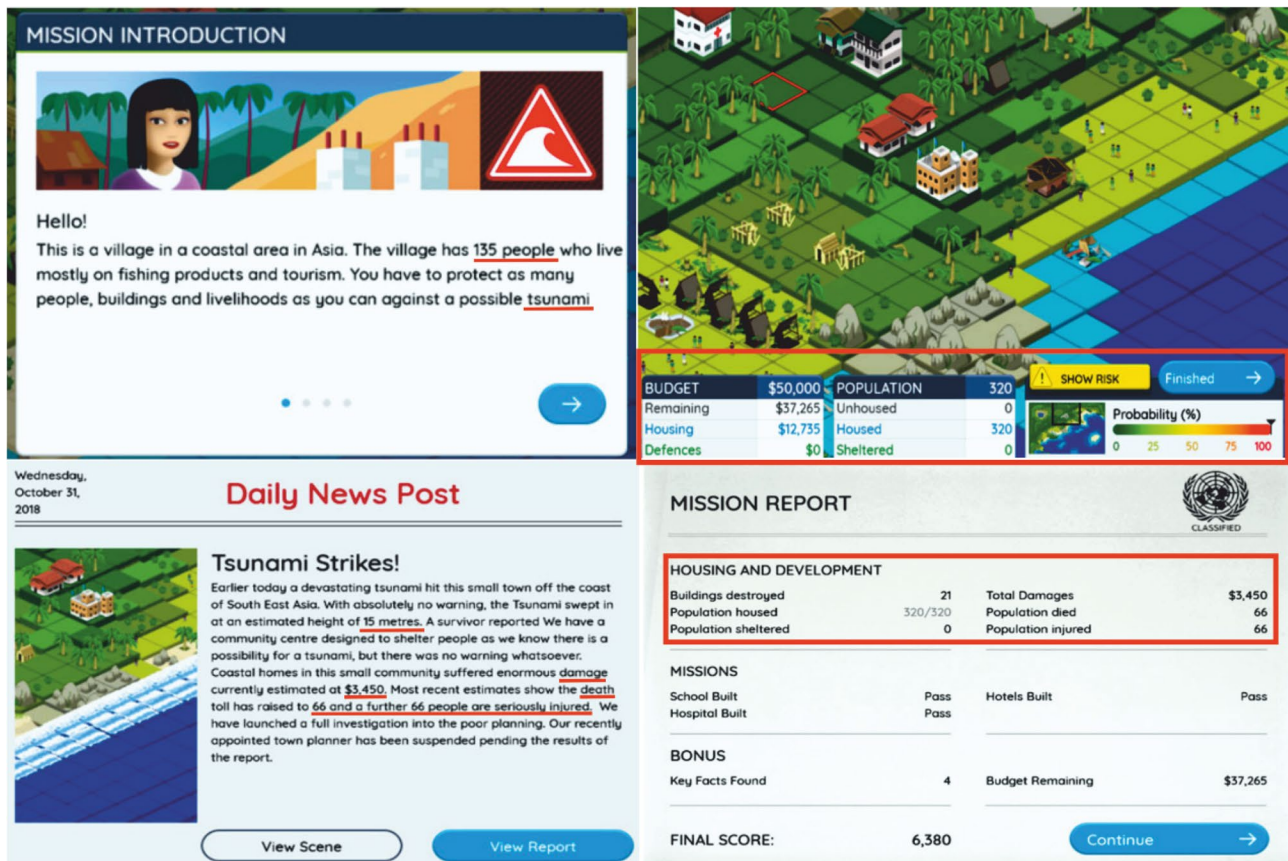


Fig. 4 Natural hazard parameters as aspects of game development (UNDRR 2018)

(i) sequential aspects, (ii) interaction with citizens and other stakeholders, (iii) data collection tools, and (iv) an ICT infrastructure that underlies the citizens' observatories framework and supports effective citizen participation.

The ICT infrastructure (represented in the oval at the top of Fig. 5) is an essential part of the citizens' observatories model, and it normally encompasses boundary services with sensors and apps, data management, and data storage support (Liu et al. 2017). A practical example in the AGEO platform and its ICT infrastructure including the AGEO mobile app that enables two-way communication between citizens and other stakeholders, fostering co-design and collaborative management processes. With this ICT infrastructure, new citizens' observatories focussed on geohazards across the European Atlantic region were set up. Citizens Observatories promote the participation of diverse groups of stakeholders in different activities and, from the AGEO experience, they may also work even in situations of crisis as the COVID pandemic. A clear benefit of citizen observatories and the existence of an open information flow is the transferability and replication potential.

For example, the methodological approach in the AGEO project started with the identification of existing networks (on the area of influence of each pilot site), then pilot leaders

and local partners used referrals to get in touch with existing community networks and relied on word of mouth to spread information, facilitated by the access to digital sources describing AGEO (e.g. website and social media).

The approach was typically initiated with a face-to-face or online meeting with managers/responsible from the relevant stakeholders' groups (e.g. recreational, non-profit groups, landowners' associations, fire squad/police stations and local/regional schools), where the goals of AGEO were explained, and digital/printed materials provided. The follow-up on the initial contacts typically included a request to respond to a survey (in the local language) addressing natural hazards and generic community concerns. These surveys included questions such as "What are your concerns relating to natural hazards?", "How would you like the Citizens Observatory to be?", "Would you like to be involved?", and created favourable conditions for further engagement. In the second stage, social events within each group of stakeholders were organized to boost people's participation. These were linked to the observatory topic, conveyed scientific-based information, and used formats tailored to the audiences. Examples of such events include guided tours, open discussion/workshop sessions, and visits to and from schools.

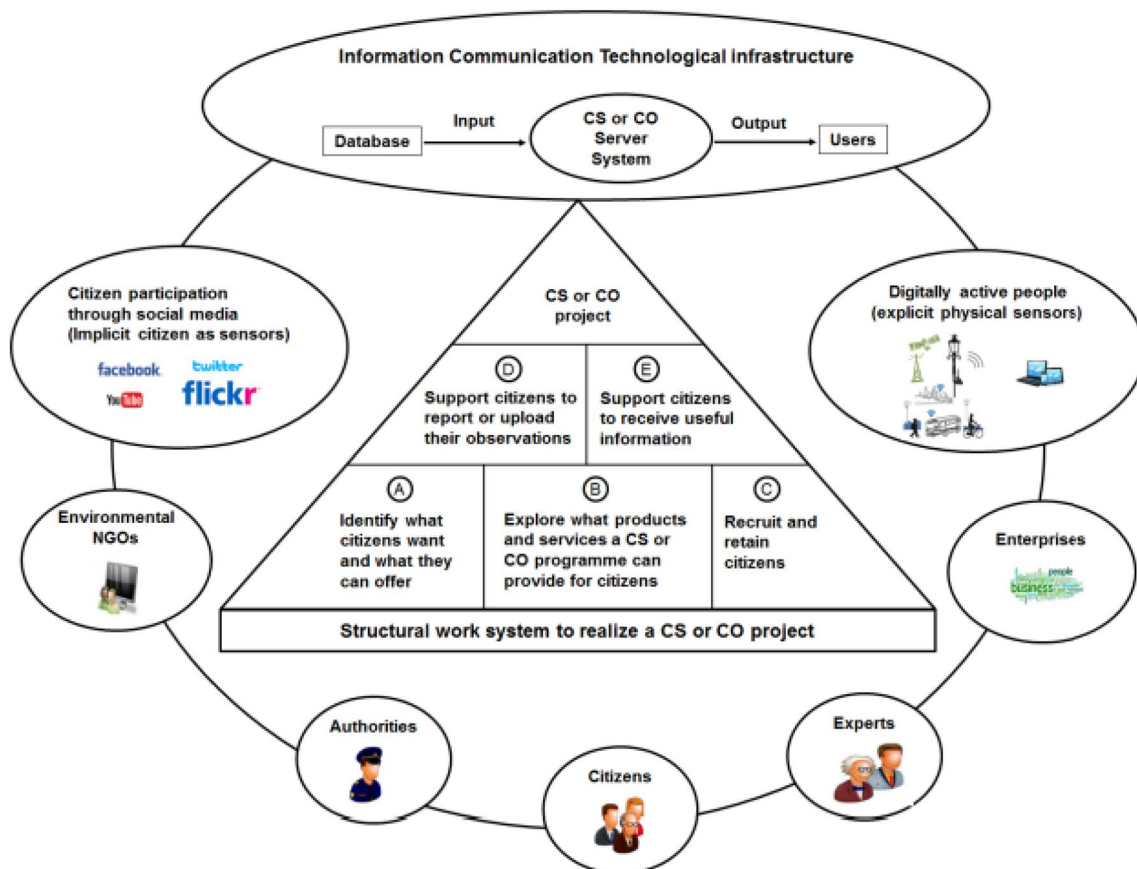


Fig. 5 A common model for citizens' observatories programs in practice. *Source:* Liu et al. (2017)

The experience with AGEO has confirmed that the five crucial factors that drive stakeholder engagement are as follows:

1. **Relevance:** citizens are more likely to engage in a citizen science project if they feel that the project is relevant to their interests and concerns. Relevance can be enhanced by involving stakeholders in the design and implementation of the project and by clearly communicating the goals and benefits of the project.
2. **Accessibility:** citizen science projects must be designed to be accessible to all stakeholders, regardless of their scientific expertise or technology skills. This may involve training and support, developing user-friendly interfaces, and ensuring the project is culturally and linguistically appropriate.
3. **Trust:** trust is critical in stakeholder engagement, particularly for underrepresented communities. Building trust requires transparent communication, the use of reliable and trustworthy sources of information, and ensuring that the data collected are secure and protected.
4. **Recognition and incentives:** these play an important role in motivating citizens to participate in a citizen science project. This may involve providing opportunities for hands-on involvement, recognizing contributions and achievements, and offering tangible benefits such as access to training and resources.
5. **Sustainability:** Maintaining stakeholder engagement over time can be challenging, especially if the process is time-consuming or if the results are not immediately apparent. Ensuring the sustainability of the project requires continuous engagement and communication and providing ongoing opportunities for participation

5 Future perspectives and conclusions

With natural hazard incidence continuously increasing over time, optimum risk management is critical for the well-being of society. In this article, it is argued for the benefit of the prospective reader that several aspects can be developed to enhance risk management, including risk knowledge, monitoring and warning service development, dissemination and communication strategies, and protection capabilities. The present review study focussing in three main objectives: (1) the increase of individuals' geological knowledge for risk management, (2) the highlight of the obstacles in individual's willingness against natural hazards insurance, and (3) the information and communication strategies for the widespread of geological knowledge aiming in the overcome of individual's willingness against natural hazards insurance.

Geological knowledge can be implemented as a tool for individuals to understand the natural hazard risk sources as

well as to develop monitoring, warning, and response strategies based on area-specific geomorphological, geological, hydrogeological, geotechnical, and meteorological factors. A deep understanding of risk knowledge can increase the individual or community's awareness and thus increase their willingness to involve ways of protection in their daily life. Buying relative insurance protects their economic stability and properties against the effects of natural hazards. The highlight of high-risk areas, especially in the urban areas, based on gained experience by previous events correlated with the present circumstances and the geological knowledge for the specific areas derived from monitoring and early warning systems and maps, could lead to a prioritization of insurance needs. Dissemination and communication strategies for spreading knowledge across the spectrum of groups that comprise a society are critical for the high protection of the society as well as the increase of insurance willingness buying in case this is mandatory. Databases development, educational tools, audiovisual material, and gamification are the only communication tools that could provide insurance involvement in human life.

With the advent of new and advanced communication and Earth Observation technologies, the potential for proactive citizen involvement in disaster preparedness, mitigation, and warning has increased, particularly in the context of the ongoing effects of climate change. The citizen science approach can significantly contribute by providing a large volume of data that can enhance our understanding of natural hazards and the associated risks. This information can inform decision-making processes related to disaster preparedness and response, ultimately reducing the risk of harm to communities and ecosystems. Furthermore, citizen science can increase awareness and encourage community engagement in disaster risk reduction efforts, promoting a more active role in protecting both themselves and their communities.

In this vision, technological advances and capacity-building actions would enable integrating risk authorities and citizen communities' viewpoints, combining theoretical and empirical perspectives with real-world, on-the-ground applications, thus creating resilient societies with a shared understanding of risks, roles, and responsibilities between risk agencies and risk publics. This change would probably be gradual, starting with information-sharing mechanisms (such as the already adopted emergency warnings sent to mobile phones within one region) and moving on to collaborative environments where experts and citizens serve to work together to tackle complex compound-risk scenarios and multi-agent threats jointly.

As the need for individual's protection is getting higher due to the population increase and the climatic change effects, the need for insurance in a wide area of sectors appears. Until 2070, households and critical infrastructure should all be covered by insurance. Based on an

anthropocentric approach, the protection of human resources is coming first, followed by the protection of individuals' properties, mainly focussed on their houses, followed by the protection of critical infrastructures such as roads, water supplies, and electricity supplies that ensure the well-being of individuals. The willingness of individuals for insurances can be increased by the development of a common threshold/indicator at which the individuals are willing to insure their assets against natural hazards. Such an indicator should be the result of a multidisciplinary research where at least social and geological sciences are involved. The financial contribution of public authorities for insurance could decrease the excessive necessary expenses in a case of a natural disaster while could decrease the cost of insurance corresponding to each citizen. Such a decrease in the price of insurance could lead to price competitiveness by aiming to price reduction and price threshold establishment. Thus, the insurance price will be accessibly for everyone and insurance will be considered a matter of course, not a luxury.

Author contributions E.G. and P.T. conceived the presented idea, collected the available data, and prepared the figures. E.G., P.T., N.C., V.C., and S.B. wrote the manuscript. All authors reviewed the manuscript, provided critical feedback, and helped shape the manuscript.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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References

- Abbate A, Papini M, Longoni L (2021) Analysis of meteorological parameters triggering rainfall-induced landslide: a review of 70 years in Valtellina. *Nat Hazards Earth Syst Sci* 21:2041–2058. <https://doi.org/10.5194/nhess-21-2041-2021>
- Abbate A, Mancusi L, Frigerio A, Papini M, Longoni L (2023) CRHyME (climatic rainfall hydrogeological model experiment): a new model for geo-hydrological hazard assessment at the basin scale. *Nat Hazards Earth Syst Sci Discuss* 2023:1–51. <https://doi.org/10.5194/nhess-2023-15>
- Amirsadat M, Omidipour K, Bastaminia A, Meshkinghalam M (2023) Resilience capacities to reduce the impacts of natural disasters (flood). *Nat Hazards*. <https://doi.org/10.21203/rs.3.rs-2388363/v1>
- Anelli D, Tajani F, Ranieri R (2022) Urban resilience against natural disasters: mapping the risk with an innovative indicators-based assessment approach. *J Clean Prod* 371:133496. <https://doi.org/10.1016/j.jclepro.2022.133496>
- Aufl  ch MJ, Herrera G, Mateos RM, Poyiadji E, Quental L, Severine B, Peternel T, Podolszki L, Calcaterra S, Kociu A, Warmuz B, Jel  nek J, Hadjicharalambous K, Becher GP, Dashwood C, Ondrus P, Minkevi  cius V, Todorovi   S, M  ller JJ, Marturia J (2023) Landslide monitoring techniques in the Geological Surveys of Europe. *Landslides*. <https://doi.org/10.1007/s10346-022-02007-1>
- Augustin H, Sudmanns M, Tiede D, Lang S, Baraldi A (2019) Semantic earth observation data cubes. *Data* 4:102
- Bezak N, Jo  t S, Ma  ek M, Jur  ek T, Je   J, Peternel T, Matja   M (2021) Investigation of potential debris flows above the Koro  ska Bela settlement, NW Slovenia, from hydro-technical and conceptual design perspectives. *Landslides*. <https://doi.org/10.1007/s10346-021-01774-7>
- Bianchini S, Herrera G, Mateos RM, Notti D, Garcia I, Mora O, Moretti S (2013) Landslide activity maps generation by means of persistent scatterer interferometry. *Remote Sens* 5:6198–6222
- Bignami C, Antonioli A, Atzori S, Kiratzi A, Polcari M, Sviggas N, Tolomei C, Laboratory G (2021) Mapping InSAR deformation of low and moderate earthquakes. *Proc Comput Sci* 181:214–219. <https://doi.org/10.1016/j.procs.2021.01.139>
- Brondi S, Benedetti L, Tanga RC, Bertoldo R (2021) Between oblivion and drastic evidence: how local communities cope with seismic risk by forgetting and remembering. *Int J Disaster Risk Reduct* 56:102132. <https://doi.org/10.1016/j.ijdr.2021.102132>
- Carpenter O, Platt S, Evan T, Mahdavian F, Coburn A (2020) Optimising disaster recovery: the role of insurance capital in improving economic resilience. Cambridge Centre for Risk Studies and AXA XL
- Casagli N, Frodella W, Morelli S, Tofani V, Ciampalini A, Intrieri E, Raspini F, Rossi G, Tanteri L, Lu P (2017) Spaceborne, UAV and ground-based remote sensing techniques for landslide mapping, monitoring and early warning. *Geoenviron Disasters* 4:9. <https://doi.org/10.1186/s40677-017-0073-1>
- Chae B-G, Park H-J, Catani F, Simoni A, Berti M (2017) Landslide prediction, monitoring and early warning: a concise review of state-of-the-art. *Geosci J* 21:1033–1070. <https://doi.org/10.1007/s12303-017-0034-4>
- Chen T-HK, Prishchepov AV, Fensholt R, Sabel CE (2019) Detecting and monitoring long-term landslides in urbanized areas with nighttime light data and multi-seasonal Landsat imagery across Taiwan from 1998 to 2017. *Remote Sens Environ* 225:317–327. <https://doi.org/10.1016/j.rse.2019.03.013>
- Commission E (2013) GREEN PAPER on the insurance of natural and man-made disasters. Strasbourg
- Commission E (2016) Futuro Sostenibile dell'Europa: Prossime Tappe. L'azione europea a favore della sostenibilit  . Strasbourg
- Dunbar PK (2007) Increasing public awareness of natural hazards via the Internet. *Nat Hazards* 42:529–536. <https://doi.org/10.1007/s11069-006-9072-3>
- Engdahl E, Lidskog R (2014) Risk, communication and trust: towards an emotional understanding of trust. *Public Underst Sci* 23:703–717. <https://doi.org/10.1177/0963662512460953>
- Gariano SL, Guzzetti F (2016) Landslides in a changing climate. *Earth Sci Rev* 162:227–252. <https://doi.org/10.1016/j.earscirev.2016.08.011>

- Green RA (2008) Unauthorised development and seismic hazard vulnerability: a study of squatters and engineers in Istanbul, Turkey. *Disasters* 32:358–376. <https://doi.org/10.1111/j.1467-7717.2008.01044.x>
- Grucev-Vintila A, Rouquette ML (2007) Social thinking about collective risk: How do risk-related practice and personal involvement impact its social representations? *J Risk Res* 10:555–581. <https://doi.org/10.1080/13669870701338064>
- Haberler-Weber M (2005) Analysis and interpretation of geodetic landslide monitoring data based on fuzzy systems. *Nat Hazards Earth Syst Sci* 5:755–760. <https://doi.org/10.5194/nhess-5-755-2005>
- Hearn GJ (2019) Geomorphology in engineering geological mapping and modelling. *Bull Eng Geol Env* 78:723–742. <https://doi.org/10.1007/s10064-017-1166-5>
- IRDR (2021) IRDR compilation: a ten-year science quest for disaster risk reduction, p 315
- Ivčević A, Bertoldo R, Mazurek H, Siame L, Guignard S, Ben Moussa A, Bellier O (2020) Local risk awareness and precautionary behaviour in a multi-hazard region of North Morocco. *Int J Disaster Risk Reduct* 50:101724. <https://doi.org/10.1016/j.ijdr.2020.101724>
- Jäger R, González F (2006) GNSS/LPS based online control and alarm system (GOCA)—mathematical models and technical realization of a system for natural and geotechnical deformation monitoring and hazard prevention. In: Sansò F, Gil AJ (eds) *Geodetic deformation monitoring: from geophysical to engineering roles*. Springer, Berlin, pp 293–303
- Kahn ME (2005) The death toll from natural disasters: the role of income, geography, and institutions. *Rev Econ Stat* 87:271–284. <https://doi.org/10.1162/0034653053970339>
- Lenhart A, Madden M, Hitlin P (2005) Teens and technology, youth are leading the transition to a fully wired and mobile nation. *Pew Internet and American Life Project*, Washington, DC, p 48
- Liu H-Y, Grossberndt S, Koburnus M (2017) Citizen science and citizens' observatories: trends, roles, challenges and development needs for science and environmental governance. In: Foody G, See L, Fritz S, Mooney P, Olteanu-Raimond A-M, Fonte CC, Antoniou V (eds) *Mapping and the citizen sensor*. Ubiquity Press, London
- Luís S, Pinho L, Lima ML, Roseta-Palma C, Martins FC, Betâmio de Almeida A (2016) Is it all about awareness? The normalization of coastal risk. *J Risk Res* 19:810–826. <https://doi.org/10.1080/13669877.2015.1042507>
- Macdonald N, Chester D, Sangster H, Todd B, Hooke J (2012) The significance of Gilbert F. White's 1945 paper 'Human adjustment to floods' in the development of risk and hazard management. *Progr Phys Geogr Earth Environ* 36:125–133. <https://doi.org/10.1177/0309133311414607>
- Monte BEO, Goldenfum JA, Michel GP, Cavalcanti JRDA (2021) Terminology of natural hazards and disasters: a review and the case of Brazil. *Int J Disaster Risk Reduct* 52:101970. <https://doi.org/10.1016/j.ijdr.2020.101970>
- Mushonga FB, Mishi S (2022) Natural hazard insurance demand: a systematic review. *Jamba* 14:1223. <https://doi.org/10.4102/jamba.v14i1.1223>
- Nations U (2015) Transforming our world: the 2030 agenda for sustainable development
- Notti D, Cina A, Manzino A, Colombo A, Bendea IH, Mollo P, Giordan D (2020) Low-cost GNSS solution for continuous monitoring of slope instabilities applied to Madonna Del Sasso Sanctuary (NW Italy). *Sensors* 20:289
- OECD (2021a) Enhancing financial protection against catastrophe risks: the role of catastrophe risk insurance programmes
- OECD (2021b) Financial management of catastrophe risks: approaches to building financial resilience
- Pasquini L, Steynor A, Waagsaether K (2019) The psychology of decision making under uncertainty. United States Agency International Development - USAID. www.climate-links.org/sites/default/files/asset/document/2019_USAID_ATLAS_The%20Psychology%20of%20Decision-Making_Literature%20Review.pdf
- Peternel T, Kumelj Š, Oštir K, Komac M (2017) Monitoring the Potoška planina landslide (NW Slovenia) using UAV photogrammetry and tachymetric measurements. *Landslides* 14:395–406. <https://doi.org/10.1007/s10346-016-0759-6>
- Philipp M, Dietz A, Buchelt S, Kuenzer C (2021) Trends in satellite earth observation for permafrost related analyses—a review. *Remote Sens* 13:1217
- Ravet F, Niklès M, Rochat E (2017) A decade of pipeline geotechnical monitoring using distributed fiber optic monitoring technology. ASME 2017 international pipeline geotechnical conference
- Rosenzweig C, Tubiello FN (2007) Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. *Mitig Adapt Strat Glob Change* 12:855–873. <https://doi.org/10.1007/s11027-007-9103-8>
- Rott H, Nagler T (2006) The contribution of radar interferometry to the assessment of landslide hazards. *Adv Space Res* 37:710–719. <https://doi.org/10.1016/j.asr.2005.06.059>
- Sarrica M, Farinosi M, Comunello F, Brondi S, Parisi L, Fortunati L (2018) Shaken and stirred: social representations, social media and community empowerment in emergency contexts. *Semiotica* 2018:321–346. <https://doi.org/10.1515/sem-2016-0208>
- Schwarze R, Schwindt M, Weck-Hannemann H, Raschky P, Zahn F, Wagner GG (2011) Natural hazard insurance in Europe: tailored responses to climate change are needed. *Environ Policy Gov* 21:14–30. <https://doi.org/10.1002/eet.554>
- Southwell D, Gannaway D, Orrell J, Chalmers D, Abraham C (2005) Strategies for effective dissemination of project outcomes: a report for the Carrick Institute for Learning and Teaching in Higher Education. The University of Queensland and Flinders University. https://ltr.edu.au/resources/dissemination_uqandflinders_strategieffectivedissemination_2005.pdf
- Sum RM, Nordin N (2018) Decision-making biases in insurance purchasing. *J Adv Res Social Behav Sci* 10(2):165–179
- Sutanudjaja EH, van Beek R, Wanders N, Wada Y, Bosmans JHC, Drost N, van der Ent RJ, de Graaf IEM, Hoch JM, de Jong K, Karssenberg D, López López P, Peßenteiner S, Schmitz O, Straatsma MW, Vannamettee E, Wisser D, Bierkens MFP (2018) PCR-GLOBWB 2: a 5 arcmin global hydrological and water resources model. *Geosci Model Dev* 11:2429–2453. <https://doi.org/10.5194/gmd-11-2429-2018>
- UNDRR (2018) Play and learn to stop disasters! <https://www.stopdisastersgame.org/#1540393337878-fb4ab577-b2c2>
- UNDRR (2020) The human cost of disasters. An overview of the last 20 years (2000–2019), p 30
- UNDRR (2023) Sendai framework terminology on disaster risk reduction. <https://www.undrr.org/terminology>. Accessed 18/3/2023
- Vivo G, Cook S, Pele D, Markhvida M, Stefan C, Fraser S (2021) Financial risk and opportunities to build resilience in Europe: funding gaps and disaster risk financing instruments. *Economic Analysis of Prevention and Preparedness in European Union Member States and Countries under EU Civil Protection Mechanism*
- Wachinger G, Renn O, Begg C, Kuhlicke C (2013) The risk perception paradox—implications for governance and communication of natural hazards. *Risk Anal* 33:1049–1065. <https://doi.org/10.1111/j.1539-6924.2012.01942.x>
- Ye C, Li Y, Cui P, Liang L, Pirasteh S, Marcato J, Gonçalves WN, Li J (2019) Landslide detection of hyperspectral remote sensing data based on deep learning with constraints. *IEEE J Sel Top Appl Earth Observ Remote Sens* 12:5047–5060. <https://doi.org/10.1109/JSTARS.2019.2951725>