Investigating Avalanche Risk Impact on Accommodation Facilities in the Municipalities of Abruzzo Region

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Abstract. The increase in outdoor recreational activities, particularly ski tourism and trekking, has led to a significant intensification of anthropic presence in mountain regions, with a consequent growth in demand for facilities and infrastructure. This trend, also observed in Abruzzo region, has caused the urban expansion, in and near avalanche-prone areas, increasing the risk to human settlements. Catastrophic events, such as the tragic disaster involving the Hotel Rigopiano in the municipality of Farindola (Abruzzo, Italy) on 18 January 2017, highlight the urgency of addressing avalanche risk. Avalanches, defined as a sudden instability of the snowpack and its subsequent sliding down on a slope, pose a serious threat to settlements, residential areas and infrastructure. Legislative measures, such as the Regional Law No. 47/92 and the Avalanche Hazard Location Map, aim to mitigate avalanche risk by regulating land use in vulnerable areas.

The methodology developed in this article focuses on the construction of static and dynamic risk scenarios using user-friendly data, contributing to a wider multi-risk analysis framework. Furthermore, the work presented is aligned with the goals of the SICURA project, which aims to build risk scenarios within a global framework of smart security technologies.

Keywords: Avalanche risk · Urban planning · SICURA project · Accommodation facilities

1 Introduction

The transition from traditional agricultural toward service- and leisure-orientated societies, especially outdoor activities, encouraged population and tourist influx and led to socioeconomic activities development in mountainous areas. This shift is reflected by an increasing use of those areas for settlement, industry, and recreational service [1, 2].

The development of winter mountain tourism has historically interfered with avalanche activity and impacts on the mountain environment. The diversification of tourist activities, with particular reference to ski tourism, trekking, etc., has caused a significant intensification of anthropic elements in mountainous regions, resulting in an

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increased demand for facilities and infrastructure. All this represents an implicit issue for human safety relating to avalanche risk [3, 4].

In cases of scarcity of suitable areas for urban transformation, urban expansion in avalanche-prone area has occurred [2, 5]. This directly effects the level of exposure of settlements and the need to find new solutions to ensure the liveability of these places from a risk perspective [6]. Some studies have focused on the temporal evolution of avalanche risk caused by changes in exposure, for example the variation in the number of buildings was investigated in Davos (Switzerland) and Galtur (Austria) [2, 5], the demographic trend was considerate in Sakhalin Island (Russia) [7], while the evolution of the number of places in each alpine hut and refuge was analysed in Făgăraș Mountains (Romania) [3].

The territory of the Abruzzo region is predominantly mountainous (65%) [8]. While this results in a very high probability of being affected by avalanche phenomena, it also represents a great attraction for mountain tourism. The increasing in exposure, as a consequence of this trend, involves an increase in risk estimated as a combination of hazard, exposure and vulnerability [9].

This variability of avalanche risk linked to local changes in socio-economic and environmental drivers is an important factor to consider [10]. In particular, it should be noted that the climate change, with variations in temperature and snowfall properties, can modify the activity of the avalanche dynamics by altering the existing frequency–magnitude relationships for hazard scenarios [11]. Extreme events are increasingly frequent, strongly affecting slope stability and can generate avalanche movements [12, 13]. The result of increased avalanche risk levels is the occurrence of catastrophic events just as happened on 18 January 2017 in the municipality of Farindola (in the province of Pescara) where, as a result of heavy snowfalls, an avalanche hit the Hotel Rigopiano causing the death of 29 people and the total destruction of the structure [14, 15].

According to the Italian Civil Protection Agency, avalanches are defined as critical events caused by the sudden loss of stability of snow on a slope, followed by the sliding downhill of the portion of snowpack affected by the fracture. More in general, the risk is represented by the possibility that a natural or human-induced phenomenon, may cause harmful effects on the population, residential and productive settlements, and infrastructure within a particular area over a specific period of time. Within the framework of avalanche risk, the Regional Law No. 47/92 [16] regulates avalanche risk prevention activities by defining the Avalanche Hazard Location Map ("Avalanche Map" from now on), developed and approved by Regional Government Decree No. 559/21. This information allows the planning of transformations, assessing, among other things, the need for defence measures or regulating the development of new infrastructure and urban settlements.

The approach proposed in this article was developed as part of the PhD project carried out in collaboration with the Regional Civil Protection Agency (Abruzzo region) and concerning the analysis of spatial dynamics and local planning in the context of avalanche risk. The methodology built in this first phase concerns the development of dynamic risk scenarios related to avalanche phenomena, based on simple and user-friendly data. It is configured as a step in a multi-risk analysis that fits into the methodological framework proposed by the project "caSa Intelligente delle teCnologie per la sicURezza (Intelligent

Home of Security Technology)" – SICURA with regard to the construction of risk scenarios [17, 18].

2 Study Area

The study area covers the municipalities of the "Gran Sasso e Monti della Laga National Park" (PNGSML – EUAP0007) included in the Abruzzo region. The Park was established by the Law No. 394/91 "Framework Law on Protected Areas" and covers a territory of 1,500 square kilometres (sq km) in three regions of central Italy (Fig. 1). The 84.4% of the Park's area is located in the Abruzzo region, 9.10% in the Lazio region, and 6.5% in the Marche region.

The area of the Gran Sasso e Monti della Laga National Park ("National Park" from now on), involves a total of 44 municipalities including 40 Abruzzo municipalities whose administrative boundaries are, in some cases, totally inside to the park, while in other cases are only partially included (Fig. 2).

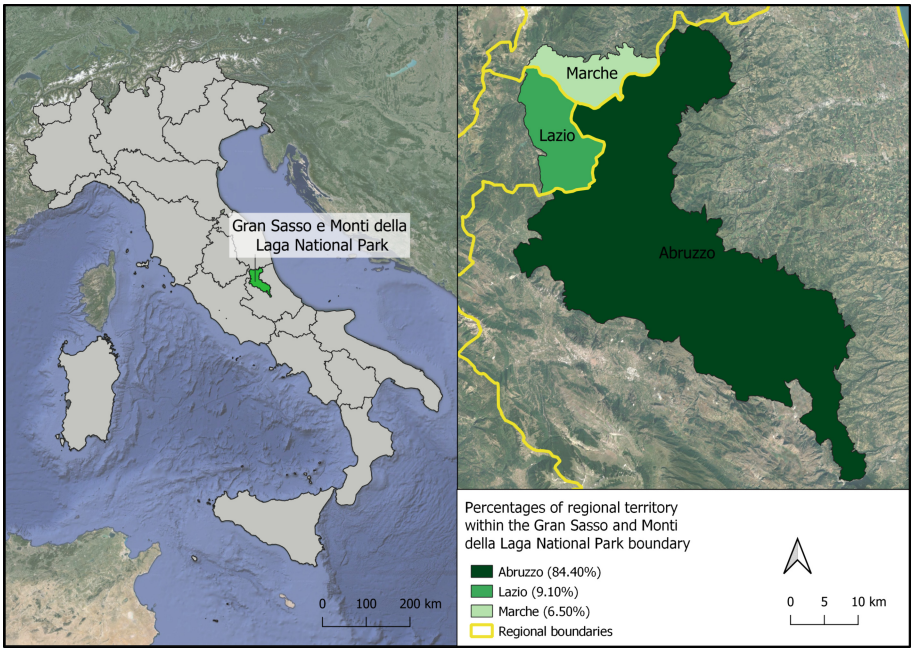

Fig. 1. Territorial framework. Italy and regional boundaries (on the left); Gran Sasso e Monti della Laga National Park with reference to regional boundaries.

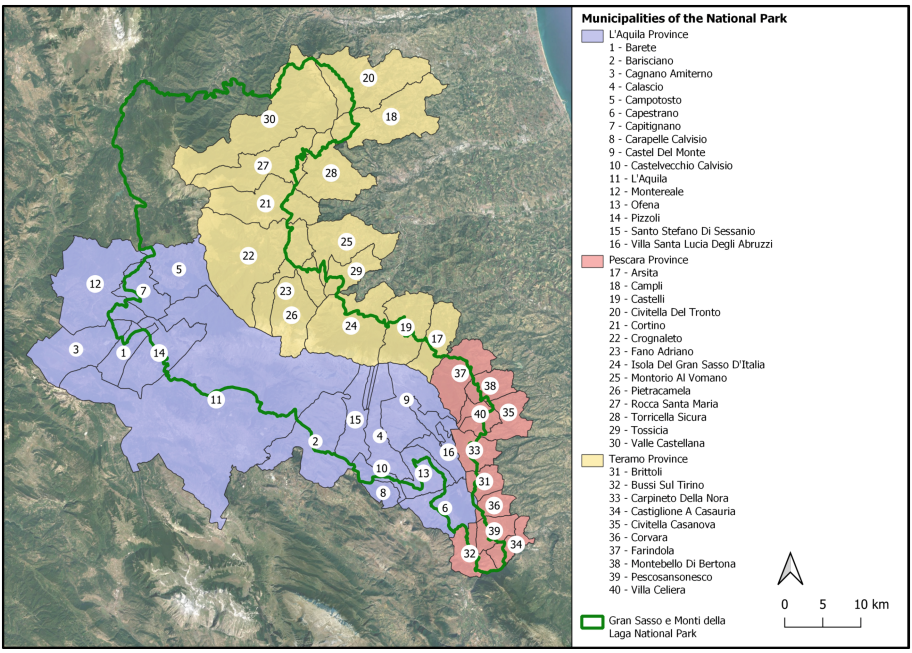

Fig. 2. Municipalities included in the National Park of Gran Sasso and Monti della Laga. The three provinces are represented with different colours. Among the 40 municipalities involved, some are totally internal to the park while others are included only in part.

The population density (inhabitants per square kilometer) is calculated from the data of resident population, updated to 1 January 2023, extracted from the database of the National Institute of Statistics (ISTAT [19]). The density population value ranges from a minimum of 3.1 inhabitants per square kilometer for the municipality of Calascio to a maximum of 616.3 inhabitants per square kilometer for the municipality of L'Aquila.

The territory of the National Park is mainly mountainous and most of urban settlements are developed in valleys and flat areas. The distribution of urbanized areas, therefore, reflects the topographical characteristics of this area. Considering the urbanizing area only as the buildings area extracted from the National Dataset of Structural Aggregates provided by the Regional Civil Protection Agency, it is possible to evaluate the urbanization density index for the portion of the territory of municipalities inside the park. It assumes the highest values for the municipality of L'Aquila, while the lowest one is recorded for the municipality of Barisciano.

3 Materials and Methods

One part of the SICURA project, focuses attention on integrating technological and methodological innovations into spatial planning tools to preserve the socio-economic framework of the territory under consideration.

Specifically, the project addresses urban and spatial resilience in response to climate change and risk conditions, with the aim of moving from static to dynamic spatial risk scenarios.

A static risk scenario concerns the vulnerability of populations or structures, based on their residence and geographic location, as documented [20]. In contrast, a dynamic risk scenario must consider population movement patterns to assess potential risks in particular areas at specific times of day [21].

In the building of these scenarios, we consider factors such as population flows and infrastructure exposure, using a framework that includes six main assets: urban, ecosystem, risk, urban planning, socioeconomic, and policies related to urban strategy [18].

The methodology of this article focuses on the analysis of avalanche risk related to the location of accommodation facilities in the territories of the municipalities within the National Park. A preliminary static risk scenario is evaluated by a density map related to the location of accommodation facilities. The dynamic preliminary risk scenario, on the other hand, is assessed by a density map related to the location of accommodation facilities weighted by the number of beds in each of them.

The overlay between the density map related to the dynamic scenario and the Avalanche Map allows the identification of the main analysis hotspots for the avalanche risk exposure factor.

3.1 Dataset

The data used for the analysis is about accommodation facilities and Avalanche Map.

The dataset of the accommodation facilities in the Abruzzo region for the year 2023 was provided by the Regional Civil Protection Agency. It contains information for each accommodation facilities about: i) the municipality of location; ii) type of structure (Hotels, Bed & Breakfasts, Campsites, Holiday homes, Country houses, Hostels, etc.); iii) star rating (1, 2, 3, 4 stars or undefined); iv) alphanumeric code associated with the structure; v) name; vi) address; vii) total number of bedrooms; viii) total number of beds; ix) total number of bathrooms.

The accommodation facilities were not directly associated with their geographic coordinates. For this reason, it was necessary to add geographic information in order to make the data comparable with other geographic layers useful for avalanche hazard exposure analyses. This was done automatically through GIS software with the use of the MMQGIS plugin [22] that allows to convert addresses to geographic coordinates. In this way the database was transformed into point shapefile data.

According to the Regional Government Decree No. 559/21, the Avalanche Map (Fig. 3), is not a risk map because it does not give indications about the frequency and intensity of phenomena or predictions of future events. It only reports the phenomena occurring up to the time of its drafting and represents avalanche sites and not individual

avalanches. There is currently no avalanche risk mapping for the Abruzzo region, but only the indication of the localization of avalanche-prone sites through the Avalanche Map is available. Information on the avalanche hazard level is provided daily by the MeteoMont Service [23] on a synoptic scale, taking into account the snowpack stability conditions at survey points and forecasted weather conditions.

Elaboration is divided into two successive phases, the interpretation of aerial photographs of the study area and subsequent direct investigation on the ground. Each avalanche, identified with a progressive numbering at the municipal scale, is associated with a technical report containing topographic information (slope and aspect of the avalanche site), vegetation details, frequency of the phenomenon, presence or absence of defence works, and any damages caused.

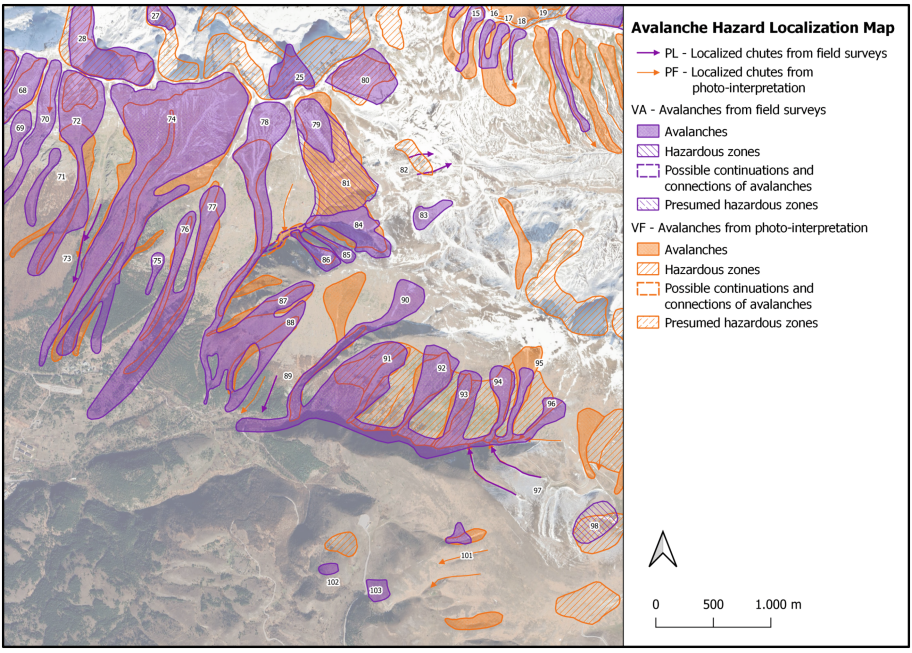

Fig. 3. General visualization of the Avalanche Map with its characteristic elements. Each avalanche is identified with a progressive numbering at municipal scale associated with a technical report.

In Fig. 3 the avalanches, hazardous zones and localized chutes are represented in purple if detected through field surveys, and in orange if detected through aerial photointerpretation. Each avalanche phenomenon observed on the ground is represented with reference to the maximum dimensions historically reached. In case the avalanche has expanded in the runout zone following different directions during different events, it is mapped the envelope of the maximum limits reached. The size of the avalanche site area is not modified based on the presence of defence works.

3.2 Validation and Density Map

The validation process is necessary to check and correct any errors in the geo-localization of accommodation facilities after their transformation into geographic data using the "MMQGIS" plugin.

A manual correction of the erroneous results generated by automatic geo-localization was carried out. The accurate location of the accommodation has been achieved through the support of geographic internet services (Google Maps [24]), digital travel assistance services (ViaMichelin [25]), tourism-dedicated websites (Abruzzo Turismo [26]), and other search engines (Microsoft Bing [27]). With the simultaneous use of these sources, it was possible to check and, if necessary, correct location of each individual accommodation facility and validate or make corrections to the database. Additionally, the database was integrated with information regarding any criticalities found (such as overlapping of different accommodation point features, facility status or name, incorrect or incomplete address from the original dataset, etc.).

The density maps were generated to perform a territorial analysis of the presence of accommodation facilities within the municipalities of the National Park. The heatmap plugin, available on QGIS, uses Kernel Density Estimation to create a density (heatmap) raster from an input point vector layer. Each pixel of the raster map corresponds to a different density value depending on the type of information analysed.

A preliminary risk scenario is evaluated by two density maps related to the location of accommodation facilities and the number of beds. The density maps were generated considering: (a) the locations of accommodation facilities; (b) the locations of accommodation facilities with weights based on the number of beds available for each of that.

The following characteristics were considered a pixel size of 50x50 meters and a Kernel bandwidth of 10,000 m radius. The radius specifies the distance around a point at which the influence of the point is felt.

The density map (a) could be considered a static preliminary risk scenario since it is based only on the presence of the accommodation facility without considering its possible capacity and thus the presence of users.

The density map (b) could be considered a dynamic preliminary risk scenario since it is based on the presence of users in accommodation facilities.

The density maps obtained were overlaid with the Avalanche Map. This operation allowed highlighting the presence of people and accommodation facilities in avalanche-prone areas, thus providing a basis for future exposure and risk analysis. The information regarding the number of beds, directly correlated to the type of facility, can be interpreted as the accommodation capacity of the structure itself. Using this data, it will be possible to generate various risk scenarios by adjusting the exposure level according to the assumed occupancy percentage for the facility (maximum, half, etc.).

4 Results

The density maps (Fig. 4) related to the location of accommodation facilities and to the location of accommodation facilities weighted by the number of beds allow to evaluate respectively the static and the dynamic preliminary risk scenarios.

The first heatmap (a) reveals the highest density value for the city of L'Aquila, while significant density values are observed in the municipalities of Santo Stefano di Sessanio and Castel del Monte. The second heatmap (b), shows a different density values distribution. High values are found in the municipalities of L'Aquila, Santo Stefano di Sessanio, Pietracamela and Rocca Santa Maria. The highest value is recorded, obviously, for the city of L'Aquila as a result of the high number of accommodation facilities.

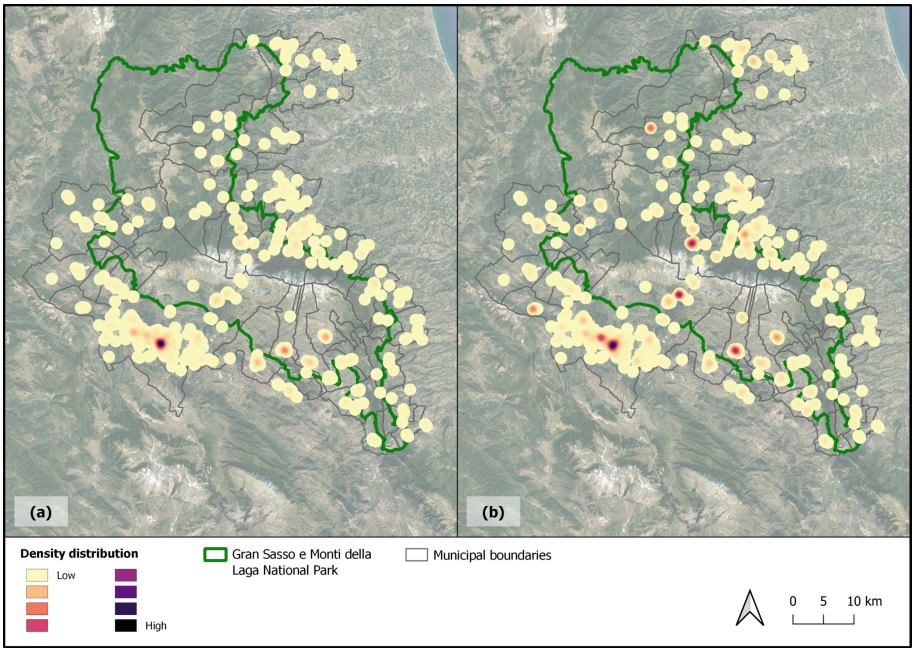

Fig. 4. Comparison between the density map based on the location of the accommodation facilities (a) and the density map based on the number of beds present in structures (b).

The dynamic scenario makes it possible to define an order of priority of the areas to consider as hotspots for the avalanche risk exposure factor and for which exposure and risk analyses are required.

Overlaying the density map (b) with the Avalanche Map, some criticalities are identified. In particular, the areas of Fonte Cerreto (L'Aquila) and Prati di Tivo (Pietracamela), located inside the National Park, are characterised by significant density values and certain avalanche phenomena (Fig. 5).

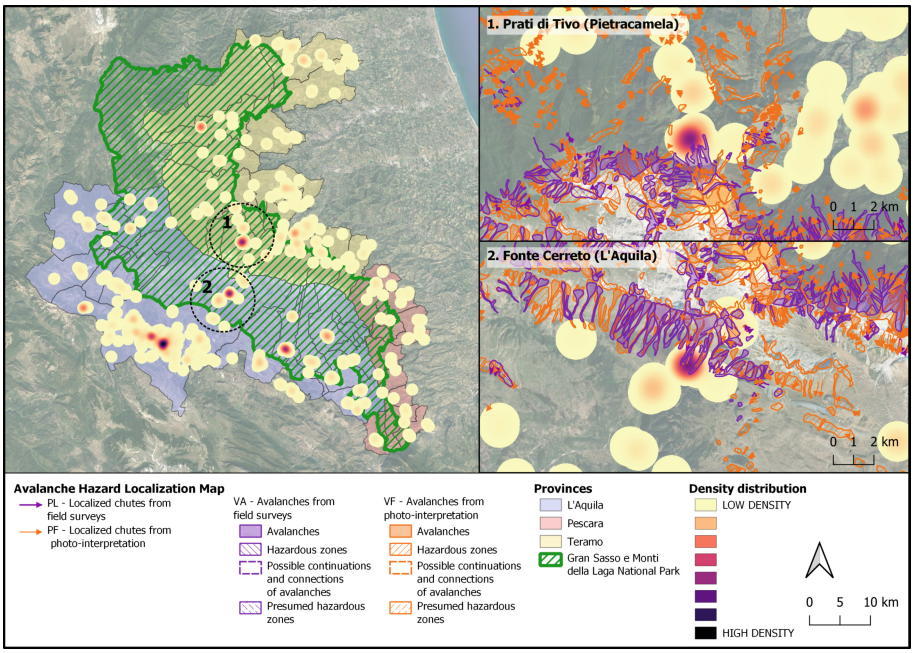

Fig. 5. Density map related to the location of accommodation facilities weighted by the number of beds and focus on critical avalanche prone areas of Prati di Tivo (Pietracamela) and Fonte Cerreto (L'Aquila).

5 Discussion and Conclusions

As part of this work, a preliminary analysis of the exposure of accommodation facilities in the municipalities of the Gran Sasso e Monti della Laga National Park was carried out, with particular reference to the avalanche hazard.

A static risk scenario, based on the location of the accommodation facilities in the territory, and a dynamic risk scenario, based on the accommodation capacity of the individual facilities, were built. The density maps obtained were overlayed with the Avalanche Hazard Location Map allowing the identification of critical areas with high levels of avalanche hazard and exposure, and the definition of an order of priority in the elaboration of future exposure and risk analyses for these hotspots.

In a risk analysis of a territory, it is essential to know the hazard, exposure and vulnerability factors that contribute to the risk definition and also their dynamic properties that are often not considered. In fact, the traditional approach to the risk is a static one [4] i.e. it does not consider the population flows that frequent places for reason different than residence. Variation in the intensity and frequency of natural hazards also as a consequence of climate change [11–13], together with changing in socio-economic conditions and settlement patterns induce variations in the level of risk to societies. Therefore, the spatio-temporal variability of risk factors is essential for a sustainable risk management [11].

This work covered the 40 municipalities in the Abruzzo region of the Gran Sasso and Monti della Laga National Park. The vulnerability of this territory is partly represented by the significant natural heritage of the Natural Park.

In fact, as other mountainous areas, it has been affected, over the years, by an intensification of the anthropic presence as a consequence of a society increasingly oriented towards the development of recreational and tourist services that affect the spatial planning of these areas. In response to the growing demand for facilities and infrastructure, urban development has often taken place within areas at risk, with a consequent increase in the exposure of the facilities themselves and of the people accommodated [2, 4, 5]. For winter tourism, the main natural hazard in mountain areas is snow avalanches, caused by the loss of stability of the snowpack on a slope.

The proposed methodology has been applied to the avalanche risk, however, for territories, such as the Abruzzo region, characterised by multiple hazards (hydrogeological, hydraulic and seismic hazard, landslides, etc.), a multi-risk analysis is needed. For this reason, the activity carried out with the SICURA project is fundamental to the collection of big data and the implementation of exposure and risk analyses through the development of 5G technology, focused on the security of infrastructures, environment, and cities. This is achieved through the use of solutions based on the Internet of Things (IoT) and artificial intelligence (AI), with a focus on cyber security [17, 18]. Through the collection of these data, it is possible to carry out multi-risk analyses and build different exposure scenarios in relation to the variation of tourist flows and the impact of climate change on the hazard of an area [28, 29]. Saving human lives is always the main objective for risk reduction and mitigation. In this context, the aim of this work is also directly related to the "Global Goals of the 2030 Agenda for Sustainable Development", and in particular to the following Goals: 3 – Good Health and Well-being, in relation to fighting mortality; 11 - Sustainable Cities and Communities, for the safety, sustainability and resilience of urban systems; 13 - Climate Action, for combating climate change; and 15 - Life on Land, for preventing deforestation and safeguarding ecosystems [30].

The preliminary elaborations, carried out in this study, provided results that can be used as input data in more in-depth analysis of the exposure in avalanche-prone areas. In the context of the goal of the PhD project, this methodology is useful as a first step to analyze the degree of interference between human settlements and avalanche sites and then develop a map of risk levels by combining information on land vulnerability and the avalanche hazard levels. The preliminary methodology presented is replicable since it uses simple available data. Moreover, it results in a decision support system for policy makers to act and plan transformation even in the most vulnerable areas such as natural parks and other protected areas.

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Authors Contributions. Conceptualization Lucia Saganeiti (LS) and Lorena Fiorini (LF); formal analysis Sara Pietrangeli (SP) and Donatella Guisa (DG); investigation SP; methodology LS, LF, SP; supervision LS; validation LF and LS; writing original draft LS, SP, LF.

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