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Disaster Management on a Regional Scale: Knowledge Platform toward Overall Hotspot Identification

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A B S T R A C T

As climate change intensifies, natural events are following suit, potentially disrupting the functioning of cities. It is therefore crucial to identify the interrelationships between different natural events when building more resilient cities, as these events present potential catastrophes upon impact. This study is aimed at building a knowledge platform for the identification of overall risk hotspot areas in the Abruzzo region in Italy. The Abruzzo region is one of the many regions in Italy that is vulnerable to multiple disaster risks. To build this knowledge platform, we used the multi-risk assessment concept to identify the risk hotspot areas of interacting disaster indicators. Our methodology was based on the risk matrix method to assess the interaction between the hazard and the exposure indicators. We overlayed both indicators in a geographic information system environment to estimate these hotspots using graphical analysis. The study results clearly show that risk hotspots are concentrated in urban areas with high population density. Nearly half of the population lives in these areas. It is important to note that risk hotspots are not isolated in urban areas. They often co-occur with multiple risks, which is useful for determining strategic intervention measures to implement for disaster risk reduction. The multi-risk hotspot map developed from this research is invaluable for planning risk reduction measures. It is essential for supporting decision-making and emergency response planning in the event of impact from hazards that could cause cascading disasters.

Keywords: hazard, multi-risk, hotspot, risk reduction, multi-hazard

1. Introduction

Disaster management, a multifaceted scientific concept that deals with the application of knowledge and practices to mitigate the severe impacts of disasters on people and societies is the focus point for responding to the ever-devasting effect of disasters. Most disasters are known to occur in rapid succession (cascading or escalating) leaving societies with difficulties in responding to multiple situations as seen in central Italy, particularly the Abruzzo region, which in recent years faced impacts from multi-disasters (earthquakes, landslides, wildfires, and avalanches) in 2017, while it was yet to recover from the devastating earthquakes of 2009 (Di Ludovico & Di Lodovico, 2020). Although natural disasters are non-preventable phenomena that present tough challenges to survival, their complexities can be managed by planning and implementing frameworks to handle them. Disaster management primarily revolves around preparing and preventing the impacts of hazards, responding to the impacts, and recovering from these impacts, especially by "building back better" (Ismail-Zadeh & Cutter 2015; United Nations Office for Disaster Risk Reduction, 2017; Tsai & Chan, 2023). Intricately disaster management constitutes themes such as Disaster Risk Management (DRM), which is the systematic and comprehensive process of identifying potential risks by analyzing the elements of risk (hazard, vulnerability, and exposure) to lessen the harmful impact of natural and man-made disasters. It primarily entails the coordinated efforts of multi-sectors such as government agencies, private sectors, communities, and individuals to manage and significantly reduce disaster risk effectively (Ismail-Zadeh & Cutter 2015; Marin et al., 2019; Y. J. Chen et al., 2023). Regional and national disaster management has in recent years gained considerable interest from researchers (Di Ludovico & Di Lodovico, 2020), with emphasis on integrating approaches that recognizethe interconnectivity of prevention, preparedness, response, and recovery phases, ensuring that post-disaster activities are incorporated into prevention and preparedness (Ostadtaghizadeh et al., 2015; Aitsi-Selmi et al., 2016). DRM studies focus on risk assessment, risk management, risk communication, and response to one or at most two potential hazards with the likelihood of resulting in a disaster upon interaction with vulnerable infrastructures (Lavell &Maskrey, 2014; Wang et al., 2020; Hsu & Sharma, 2023), however, a more robust approach that integrates multiple hazards of potential risks is vital (Cruz-Bello & Alfie-Cohen, 2022), such is an indication of a decisive role in disaster prevention/mitigation, landscape recovery, and especially in demonstrating the management capability of a region. Integrating multiple risks into a single knowledge platform/framework can potentially ensure improved regional protection and spatial planning, especially in the context of multi-risk scenarios.

Disaster Risk Reduction (DRR), which is a fragment DRM seldom focuses on the interaction of multiple hazards impacting a system (Marin et al., 2019), with most studies done on single or at most two risk scenarios, that may be managed through an existing plan or framework that addresses the disruption, leaving the challenges of inefficiency in handling multiple risk scenarios (UNISDR, 2017; Terzi et al., 2022). Multi-risk mapping is instrumental in improving the knowledge and understanding of the complexities of several risks impacting a region as seen in the case of the Abruzzo region in Italy (Di Ludovico & Di Lodovico, 2020). An all-hazard-at-a-place assessment is an approach that improves the handling of multi-risk situations and guides in developing a knowledge platform to identify overall hotspots on a regional scale, especially in the context of infrastructural and environmental protection. This research attempts to bridge the gap between risk assessment, management, and response to single risk scenarios of hazard, vulnerabilities, and exposure to develop a knowledge platform of the overall hotspot of these combined elements. Although multi-risk assessment may present challenges encountered when assessing multiple hazards in a single framework, estimating or harmonizing multi-risk scenarios, which is a similar challenge faced in this research, nevertheless, we adopted the strategy of treating all hazards on a global scale (Chen et al., 2016) i.e., no distinct characteristics of hazard were considered, to develop the knowledge platform that combined these risks into a single overall hotspot map. Henceforth, to achieve our goal three research questions were defined;

1) What are the risks present in the Abruzzo region?

2) How can we identify the hotspot and overall risk hotspot areas (based on a multi-risk assessment approach)?

3). How can this tool be useful in regional disaster risk reduction strategies/measures?

These questions were attempted by identifying the characteristics of the hazards, vulnerabilities, and exposure, identifying the hotspot areas where each topic is present, and assessing all risk hotspots at the same time. These multi-risk assessment studies of the hazards and exposition present in Abruzzo enable the determination of the areas for intervention measures based on all risk hotspot identification, to guide disaster response strategy for the civil protection services and to support decision-makers (Di Ludovico & Di Lodovico, 2020).

1.1 Literature review

Recently published scientific literature on DRR delves into exploring the strategies and development of tools that address multi-hazard situations (as seen by Terzi et al., 2022), especially in the face of rising catastrophic events that are severely affecting societies, providing challenges to existing risk/disaster management tools/frameworks which do not sufficiently address the impact of multiple hazards at a time (De Angeli et al., 2022). The recommendations for national risk assessment for disaster risk management by the European Commission (European Commission. Joint Research Centre., 2021) emphasize the need to conduct a multi-hazard and multi-sectoral risk assessment that indicates the most relevant risks, considering assets according to their vulnerability and importance through different disasters. Research publications such as Joshi et al., (2024) provide an assessment of the multi-hazard risk of rail infrastructure to local vulnerabilities of landslides, floods, and earthquakes, towards establishing adaptive pathways for disaster-resilient infrastructure planning amidst multiple scenarios of hazard in India. Risk scenarios are often more intricate within a regional scale, featuring numerous dimensions, including natural calamities, economic aspects, and socio-political ones. For this reason, it is critical to understand the multi-dimensionality of risk and areas (hotspots) that are at greater vulnerability of being impacted by these risks, to enable proper decision-making during prevention projects. The specifics of the risks based on the peculiarities of the risk landscape in specific regions make determining risks more effective. This specificity allows organizations and emergency managers to form a more complete picture of the risks, facilitating the development of risk management plans and prevention projects (Di Ludovico & Di Lodovico, 2020; Lee et al., 2021). In the concept of integrating several hazard and risk phenomena that create a knowledge system of potential multi-risk hotspot zones, Izumi et al., (2019) stress the significance of enhancing interfaces among science, technology, and policy-making to develop and implement DRR innovations effectively. Izumi et al. (2019) outlines the importance of investing in innovative approaches and tools based on science and technology to address gaps in disaster risk management. Ismail-Zadeh & Cutter, (2015) and Izumi et al., (2019) emphasize the importance of applying foundational coproduction theory to understand and explain the conditions under which community-led coproduction can be more effective than government or citizen, to allow “combined participatory” action of both government and citizens during risk (multi-risk) reduction planning, however, a study by SakicTrogrlic et al., (2024) show that the impact of multi-hazards is poorly understood, which stems from the absence of knowledge on the interrelationship of multiple hazards (for example, landslides triggered by an earthquake) and their spatiotemporal behaviors. On a different note, Poljnasek et al., (2017) point out that bridging the gap between “current disaster risk management status” and “ future challenges” is crucial in the integration of science and innovation into DRR. Such a proposition entails primarily focusing on understanding, communicating, and managing multi-hazard risks to address future multiple disaster risks. This important concept of risk management has resulted in the development of a tool that is utilized to not only recognize possible risks but also calculate them to enable measures that either completely annul the risk or reduce its impact as stated in ISO 31000:2018 (Lavell &Maskrey, 2014; EC 2019; Marin et al., 2019). The ISO 31000:2018 provides a basic approach for identifying, analyzing, and evaluating the risk of any type, however, it does not guide in complex situations such as multi-risks acting on a system/region at the same time. The

assessment process according to ISO 31000:2018, focuses on exploring a single risk to treat it to reduce its potential harm. Other risk reduction research presents a dynamic approach to integrating science and technology into DRR studies. For example, Lu et al., (2020) proposed a framework for simulating multi-hazard scenarios covering both individual buildings and urban areas. This proposition suggests an improvement of further development based on the “HAZUS” model developed by the United States Federal Emergency Management Agency (FEMA). Simulation models can inform and enhance the knowledge of decision-makers particularly in the context of regional multi-hazard or multi-risk management planning (Komendantova et al., 2013 Lu et al., 2020). More recently, it has been demonstrated that DRM is mainly centered on risk assessment, risk management, and risk reduction, risk communication (Lin, 2018; Wang et al., 2020; Chen et al., 2023; Gao et al., 2023). Consequently, there is some evidence of specific topics on multiple risk assessment (Chen et al., 2016; Pourghasemi et al., 2019; Terzi et al., 2019; Marin et al., 2019; Karatzetzou et al., 2022; Tsai & Chan, 2023). Although some attempts have been made to address multi-risk management, there is very little research on identifying the overall risk hotspot areas of these combined hazards acting on a system at the same time.

A recent study by Di Ludovico & Di Lodovico (2020) in the region, explicitly answers the question of identifying and mapping hotspots of multi-risk scenarios, however, their work is centered on categorizing high-priority intervention areas (HIPA) which is a little dissimilar to this study since our approach is based on risk matrix application for overall hotspot areas identification, moreover, there is still a great deal of work to be done in this area to update the knowledge of hotspot risk areas, since these natural phenomena (landslides, floods, fires, seismic) are constantly evolving. Hence, this research is focused on identifying and estimating hazards, and their interaction with the population density of the region.

Although this research focuses on multi-risk analysis and estimation, scientific studies are particularly focused on multi-hazard topics (Bathrellos et al., 2017; De Angeli et al., 2022), indicating evidence of limited literature in multi-risk studies and a gap that needs to be filled. SakicTrogrlic et al., (2024) strongly suggest a shift in disaster management perspective from merely managing individual hazards to a broader approach to managing risks, underscoring the importance of multi-hazard and multi-risk assessment and management. A review by Tilloy et al., (2019) identifies the interrelationship between different natural hazards, with a major focus on fourteen distinct hazards and how the same-time impact of these hazards is modeled, with an indication of the implication in disaster management for multi-hazards. A similar study by Gill & Malamud (2017) reveals the impact of anthropogenic activities on the causes of multi-hazard scenarios. These natural phenomena and hazards from human activities are potentially harmful events when not adequately identified and mapped to establish the extent of the risk and the response measures for future disasters. Gill & Malamud (2017) demonstrate this by integrating individual hazards into multi-hazard frameworks that better assess hazard potential (anthropogenic and natural) to improve disaster risk reduction strategies. From the above studies, there are insufficient scientific investigations connecting the multi-hazard (M-H), multi-vulnerability (M-V), and multi-exposition (M-E) to derive the Multi H-V-E risk. This study aims to close these gaps using a quantitative approach (Simmons et al., 2017) to address the topic of multi-risk hotspot estimation. It does this by combining multi-hazard maps and the exposition map and characterizing the high and medium components of each map based on a risk matrix of the interaction between hazard and population density of the region. The aim is to create a knowledge platform for overall risk hotspot areas and estimation of the risk present in the region.

In the concept of multi-risk assessment, frequent occurrence of different hazards threatening the same region requires a combined analysis of the most relevant risk scenarios to allow an adequate understanding of their impacts and to allow civil protection services to plan and prepare effective mitigation measures (Polese et al., 2024). Zchau (as cited in Simmons et al., 2017) took the first step to perform a full multi-risk assessment that consists of comparing more than one hazard affecting a region without explicit regard for their likely interactions but conforming and standardizing procedures of assessment amidst the different hazards. In essence, individual analysis of each hazard can be performed, however, common applicable conditions must be established to guarantee their comparability—an approach termed multi-layer single risk assessment. Polese et al. (2024), stress that to ensure a complete Multi-Risk Assessment (MRA), the several risks derived from these harmful events potentially impacting the same region "*should be compared and ranked, possible risk interactions due to simultaneous or cumulative occurrence of hazardous events over time should be considered as well*". The challenge in modeling the interaction of hazards and their possible related impact weakens the effectiveness of the MRA concept and its complete acceptance. Therefore, risk evaluation from different hazards is commonly performed through analysis of individual events (Poljansek et al., 2017). Risk interaction in the concept of MRA is focused on the interaction of both hazard and vulnerability (Di Ludovico & Di Lodovico, 2020) in our case exposition. Precisely the topic of multi-hazard may connote that different hazardous events may continuously threaten the same exposed elements or a single hazardous event may result in the cascade of others. The multi-vulnerability concept refers to the exposure of various elements (in this case population of inhabitants) with different degrees of possible impact on the vulnerability of these elements to each hazard (Polese et al., 2024).

The potentiality of underestimating the overall risk that may arise as a result of ignoring the interaction of the hazards, to provide an understanding of the comparative importance of several risks in an area is vital to enable decision-making in the field of DRR. Tools such as risk matrices, risk indices, and risk curves (Simmons et al., 2017) are often proposed for standardization of risk assessment in the aspect of multi-risk analysis; with major preference given to risk matrices due to their simplicity and communication of qualitative or semi-quantitative risk analysis approach (Polese et al., 2024). Although considerable efforts are underway to transition from single-risk to full multi-risk assessment, risks due to natural hazards are still considered single entities, sideling the decision-making and management process (Hochrainer-Stigler et al., 2023). A similar practice is seen in the context of multi-hazards, where most risk assessments focus principally on addressing multi-hazard scenarios by overlying multiple single hazards ignoring the interrelation between the hazards (Clarke & Obrien, 2016; Chen et al., 2016; Pourghasemi et al., 2019; Karatzetzou et al., 2022). The assessment of multiple hazards and risks is still complicated with difficulties as seen in the publications (Simmons et al., 2017; Terzi et al., 2019; Wang et al., 2020; De Angeli et al., 2022).

Observations from this study in the assessment of scientific literature divide the multi-risk approaches into three categories *(1) qualitative (2) semi-qualitative, and (3) quantitative* approaches. This research is focused on the application of qualitative risk assessment to define the risk hotspot areas in the study region, by simply using the matrix technique. The general deduction from previous literature is that studies on multi-risk assessment may appear complex due to the variabilities in characteristics of individual hazards acting on a system (Terzi et al., 2019; Curt, 2021; De Angeli et al., 2022; Tsai & Chan, 2023; Safaeian et al., 2024) but an overlook of these variations and consideration of all hazards under a global perspective (assuming that all hazards possess the same characteristics), allows a multi-risk assessment of the risk scenarios present in the Abruzzo region to produce an estimate of the risk hotspot areas based on the risk matrix technique. It is paramount to note that there is no unified agreement on multi-hazard interrelationships and that the definitions or descriptions are rather based on individual discretion. Furthermore, it is important to point out that interrelations are present between risk indicators and risk levels i.e. hazard, exposure, and vulnerability (Hochrainer-Stigler et al., 2023), this plays a key role in the multi-risk assessment of this study.

1.2 Study area description

The Abruzzo region is situated in the eastern part of the Central Apennine in the Italian peninsula, mainly characterized by an undulating and irregular landscape, and complex geological framework due to the historical extensional tectonic events in the area. These extensional activities resulted in forming

three categories of morphological features: the Apennine chain area, the Piedmont area, and the Coastal area (D'Alessandro et al., 2003). The study area has been referred to as "Europe's greenest region" owing to its vast land coverage by green vegetation, a primary contributor to wildfire incidents. Its irregular morphology and vegetation expose it to several natural and anthropogenic risks such as risks resulting from earthquakes, landslides, wildfires, avalanches, and floods which have constantly threatened the inhabitants of the region (Di Ludovico & Di Lodovico, 2020). The mountain chains are seen to have elevation peaks above mean sea level (a.m.s.l) of 2,912 m (Corno Grande), 2,794 m (Mount Amaro), and 2,486 m (Mount Velino) and extensive intramountain basins L'Aquila and Peligna which are the result of Italy's second largest lake draining in the late 70's.

The Abruzzo region is divided into three administrative provinces: L'Aquila, Chieti, Pescara, and Teramo (Fig.1), constituting a population density of 1,27 million (2021 census) over a land area of 10,832km2 with half the population living near the coast. The effect of migration as a result of climate change has seen a notable increase in the population density of the region, with rapid urbanization observed in the provinces of Pescara due to its accessibility (Cavuta et al., 2018). Owing to the historical natural events and their probabilistic future occurrence, the continued growth of risk as a result of population growth and urbanization needs to be accounted for. Such a claim is evident by the catastrophic events that hit the study areas in recent years (earthquakes in 2009, 2016, and 2017, floods in 2013 and 2015, landslides in 2017, wildfires in 2007 and 2017, and avalanches in 2017). These catastrophes have continued to cause loss of lives and disruption of the local economy (Di Ludovico & Di Lodovico, 2020; Carabella et al., 2022).

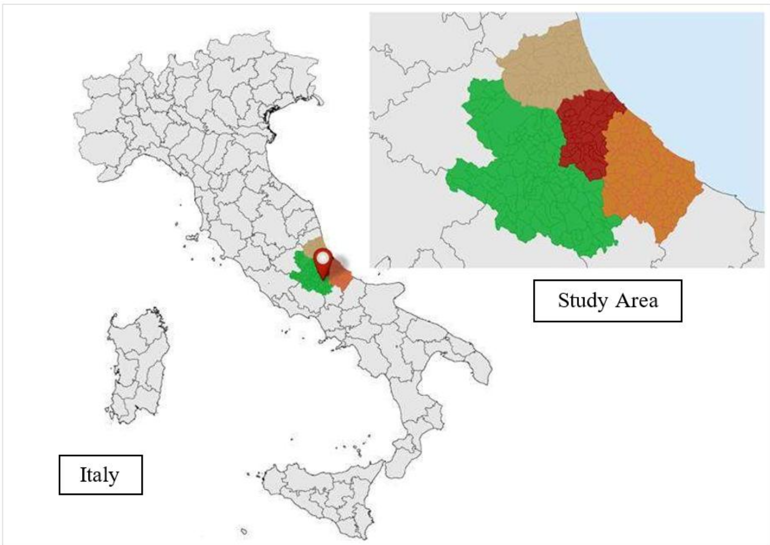

Fig. 1: Location of the study area (Abruzzo region) in Italy

2. Methodology

The concept for the knowledge of the platform is based primarily on the common definition of Risk (R) which is a function of the combination of the indicators: Hazard (H), Vulnerability (V), and Exposure (E), however, the vulnerability (V) indicators were not included on the study as a result of lack of access to data.

$$R = f(H,V,E) \quad (1)$$

Literature has often documented numerous risk formulations for estimating the impact of an event, and most of the studies (Yonson et al., 2018; Lantada et al., 2020)) argue that the multiplication of the indicators equates to the risk probability of a system.

$$R = H*V*E \quad (2)$$

However, some literature (Mamuji&Etkin, 2019) has streamlined the formulation to be a function of hazard (H) and Exposure (E) by considering vulnerability (V) as a similar element since a component cannot be vulnerable if it is not exposed (Di Ludovico & Di Lodovico, 2020). Therefore the formulation applied for this study is a simple combination of hazard (H) and exposure (E)

$R = H + E$ (3)

Since our research is based on a quantitative method, we decided to apply the risk formulation by Mamuji&Etkin, 2019, which presents the sum of the interaction between the Hazard and Exposure. In this case, vulnerability and exposure are considered as a single component.

The formulation allows the identification of the overall risk areas in the study region that are influenced by the indicators (hazard and exposition). Theformulation was realized by designing a risk matrix that enabled us to apply the formulation to the priority hazard level and the exposition data. Fig.2 presents a simple schematic strategy for generating the overall hotspot map. This was a useful guide for developing the flowchart diagram (Fig.3.) to achieve the desired result, and it allows an easy understanding of the study strategy in case of replication of a similar approach in other research/studies.

2.1 Research design & data collection

The methodology defined for the research is based on the simple steps: historical hazard inventory data collection from the Abruzzo Regional Civil Protection Services (RCPS) and dedicated Regional databases, hazard assessment, manual mapping of chemical industries at risk of major accidents via Google Street View, exposure, and multi-risk assessment. The different metadata, originally in vector format, were useful in generating the hazard components for the risk scenario, estimating the exposure of risk element (population density), and consequently assessing and establishing the risk scenarios present in the Abruzzo region, before building the final knowledge platform for all the hotspot risk.

The construction of the knowledge platform for the overall hotspot risk identification followed the structure of Risk Mapping[1], Assessment[2], and Estimation[3] based on geographic coverage of the indicators at play in the region (Fig.2&3).

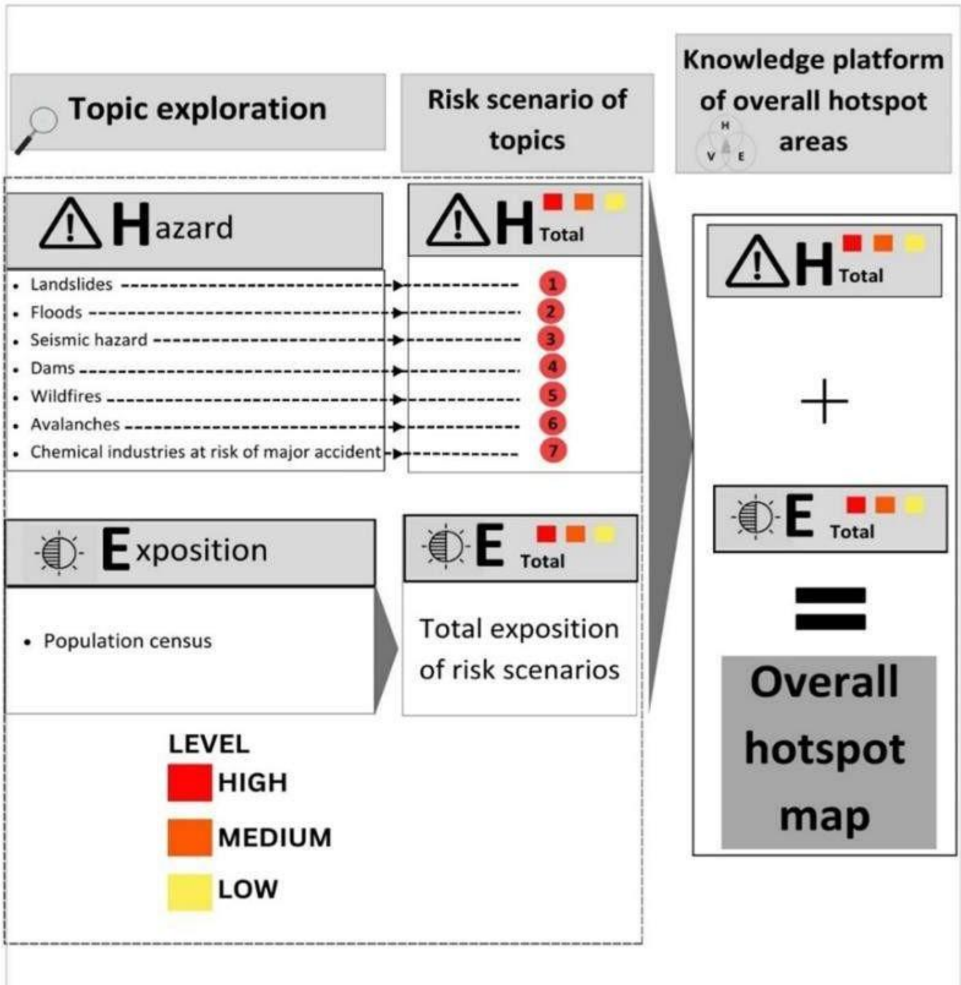

Fig.2 Strategy for constructing the knowledge platform of overall risk hotspot

An important note is that the vulnerability indicators of the region (building ages and naturalistic areas) were not included in the study due to a lack of access to these data as a result of privacy and data protection. Hence, only hazard and population census data were used for the study as shown in Fig.2. These data were used as the input data into the tool and other displayed data are a result of the manipulation of hazard and population data.

2.2 Hazard Knowledge System

Historical geographic hazard coverage data were collected and assembled as a first step for modelling the events affecting the region, the hazard topics in this research included the main phenomenon affecting the Abruzzo Region (i.e. landslides, seismic, floods, wildfires, avalanches). The landslides, wildfires, and flood (river) hazards were originally classified based on land surface area (in Km^2) at risk on a probability spectrum between very-high to low by the Italian Higher Institute for Environmental Protection and Research (ISPRA), however, the seismic data were reported in Peak Ground Acceleration (PGA) with ranges from 0.05 g to 0.25 g in each municipality.

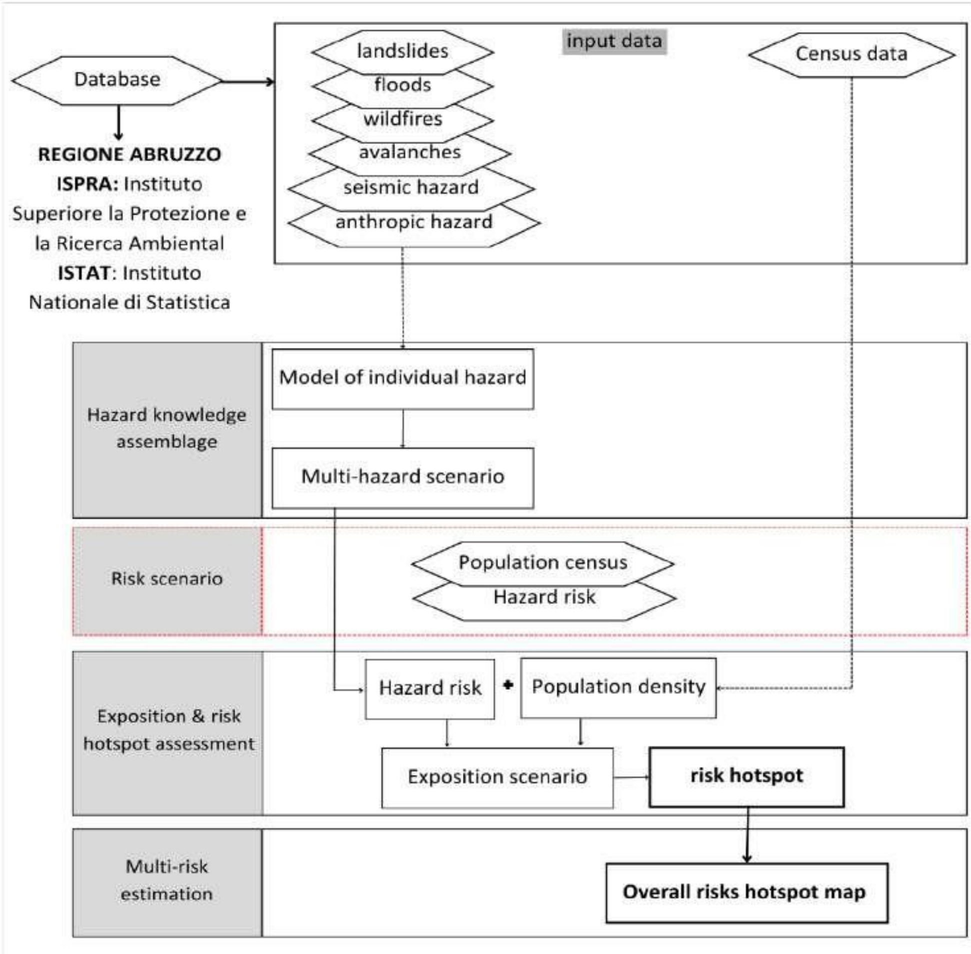

Fig.3 Flow chart of the methodology for identifying the hotspot areas

The probability spectrums of each hazard were reclassification into three distinctive levels i.e., from 1 to 3, where 1 represents low-hazard probability and 3 represents high-hazard probability. This recategorization of hazard probability levels enabled the assessment by correlating the hazard probability with population density to establish the risk levels of each scenario. Consequently, chemical industries considered to be at risk of major accidents (anthropogenic hazards) as listed by the Italian National Agency for Environmental Protection (https://www.artaabruzzo.it/) were evaluated and mapped using Google Street View in QGIS 3.34, to assess the probability of their impact on the exposed population. Other anthropic hazards included in the study are the dam locations and their floodable areas (however, only two data were available for dam flood areas). The avalanche data were historical records of avalanches, which were recorded mostly in the hilly areas of the region. The Individual hazard inventory data was carefully examined and then digitized to generate maps of the hazard components (Fig.3.1). Each of these maps was digitized on a scale of 1:1000000.

2.3 Exposure assessment

Exposure and vulnerability have often been considered as strictly related terms, in the concept of disaster risk reduction (Gallina et al., 2016; Terzi et al., 2019;). Due to the temporal and spatial variability of vulnerability and exposure, changes to any of these indicators may alter the risk of hazards affecting a region positively or negatively (Ismail-Zadeh & Cutter, 2015). Exposure is an important factor for measuring the losses that occur when a disaster impacts a region. In urban regions, the more elements at risk (exposure) that are present, the more likely the region will face the devasting effect of hazard impact. Consequently, the driving forces of exposure are rather complex and exhibit small to wide levels of social, economic, and political factors that influence urbanization, migration, and population growth, as seen in Fig.3.2. In this study, the exposition of elements at risk was evaluated in real-time through the population density map based on the census section (2021) available on the ISTAT platform. The population density distribution indicates the influence urbanization and availability of goods and services have on the growth of provinces in the region, as more people tend to migrate from municipalities that have no or scarce services to those with most of these services (in this case, Pescara and Teramo). To establish the total exposition, the area coverage was used to divide the total population of each area coverage to establish in decimal numbers the density, but these densities were grouped into 1, 2, & 3 to represent low, medium, and high densities to match the similar categorization of the hazard maps.

These were eventually used to calculate the total exposition risk by overlaying the maps of the individual risk maps based on the graphical analysis approach in QGIS 3.34.

The red and blue dotted areas represent the medium-high density areas, which is typical of the region. This density distribution is influenced by the cities since the majority of the population lives in cities where basic amenities are available. The low-density areas are mostly deserted with at most 2 or 4 inhabitants in their census zones, this comes as a result of the 2009 earthquake that resulted in the migration of people to more resilient cities.

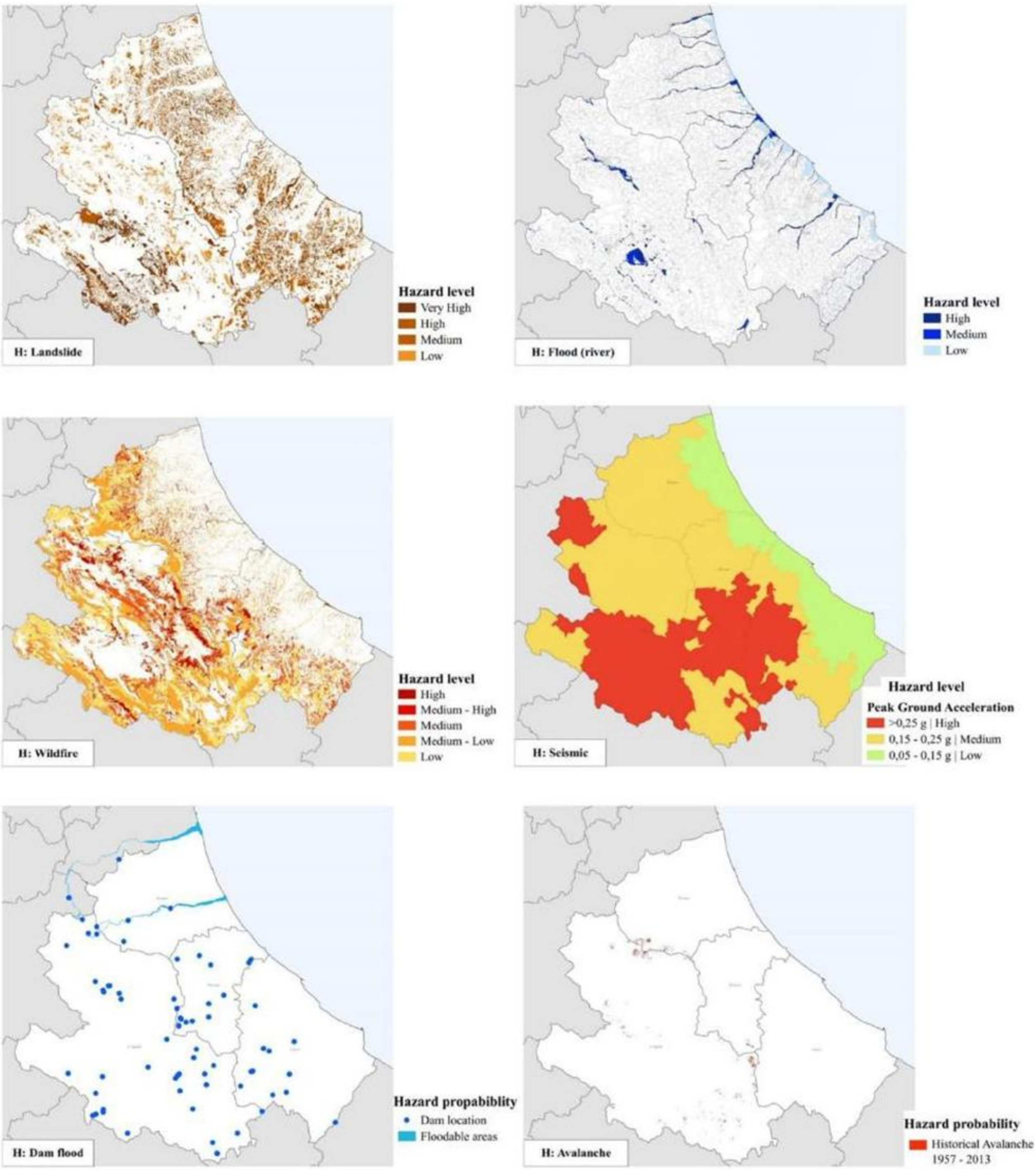

Fig.3.1 Hazard knowledge system for determining the risk scenarios

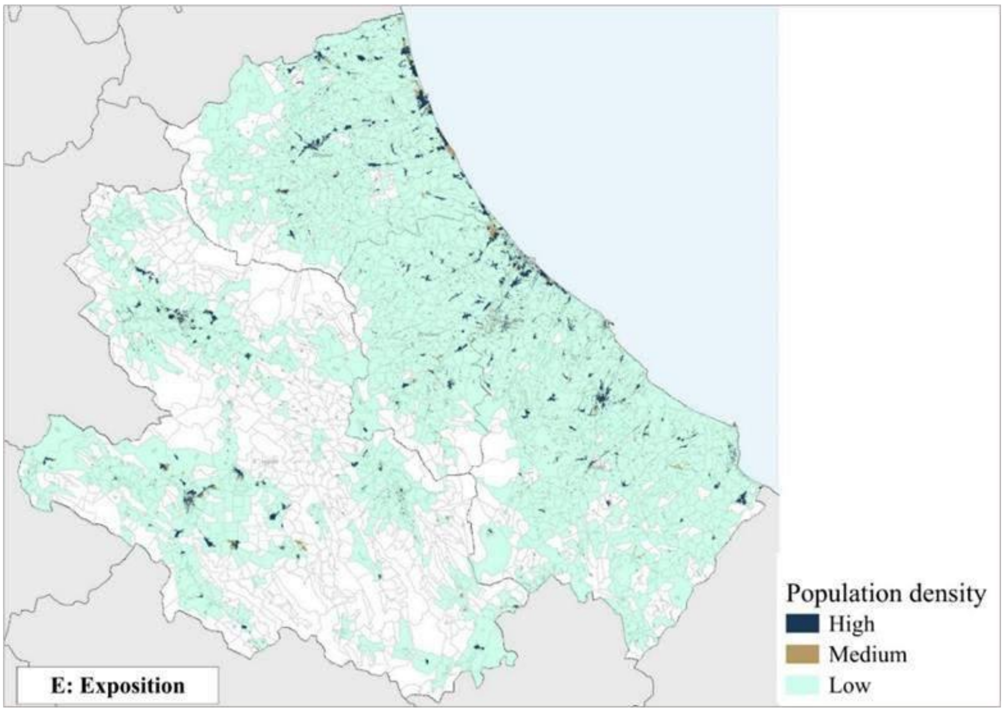

Fig.3.2 Population density showing degree of exposure

2.4 Risk Scenario Analysis

Different researchers have widely utilized the concept of vulnerability to define specific variables or elements that are at risk of being impacted by potential hazards (Papathoma-Köhle et al., 2019; Wood et al., 2021; Ziga-Abortta& Kruse, 2023; Choo & Yoon, 2024), these disparate vulnerability definitions have seen the terminology transform from simple to complex. Despite the diverse definitions, it is generally accepted to refer to the multi-faceted condition of susceptibility of an individual, community, or system to natural or man-made hazards and a lack of coping capacity (Choo & Yoon, 2024). An interesting definition of vulnerability by Qin et al., (2023) correlates with the vulnerability element (population) considered in this study, as it defines the element at risk of harmful impact of hazards in the Abruzzo region. Qin et al., (2023) define vulnerability in the context of urbanization, since rapid urbanization may to a greater extent connote high vulnerability. In their definition, they categorized urban vulnerability into three; referring to one of the categories as urban disaster vulnerability. In this study, to define what is at risk, a risk analysis was conducted by assessing the degree of interaction between the inhabitants- through the population census data (zones) and the individual hazard topics. Similarly, as in the hazard and population census data, a common level classification was done for the hazard scenarios when joined with the population census data, the spectrum of classification assigned was, low risk, medium risk, and high risk, the aim was to use these risk scenarios to generate the different degree of hotspots for each risk, but this was not possible due to the challenge encountered from the population census data -the overlay of the hazard on the population census data characterizes areas that are not at risk. To achieve the risk assessment of each hazard, a common approach of the graphical overlay method was applied (Fig.3.3) to determine the hotspot of each risk.

The risk scenario trend of all hazards exhibited a common pattern that gives an idea of areas under dangerous scenarios. When merged with the hazard scenario, the population concentration areas showed the intensity of the probabilistic risk, which defines the risk levels. These risk scenarios establish an understanding of the "vulnerabilities" the region faces and how it is distributed concerning the population census.

2.5 Identification of individual risk hotspot areas

Different methods are used to develop models of multi-risk analysis based on the specific need and context of the assessment (Komendantova et al., 2014; Gu et al., 2024; Portillo Juan & Negro Valdecantos, 2024). The approach for identifying risk hotspots for each hazard followed the matrix risk analysis method based on a qualitative approach. The model presents the multi-risk scenario existing in the study area. To define risk hotspots based on interaction with the element at risk (exposition), the areas where the high and medium hazards intersect with the high and medium degrees of population density were selected based on a 3x3 matrix method. Application of this risk matrix method enabled us to identify each risk hotspot as opposed to the initially planned approach. Hotspot areas were identified for each risk excluding the anthropic (chemical industries at risk), and avalanche since a categorization of the hazard could not be made. The hazard component maps used to assess risk hotspot areas based on the 3x3 matrix analysis are presented below (Fig.3.4) This approach of assessment is based on the simplified graphical analysis of overlying the hazard map on the population density map.

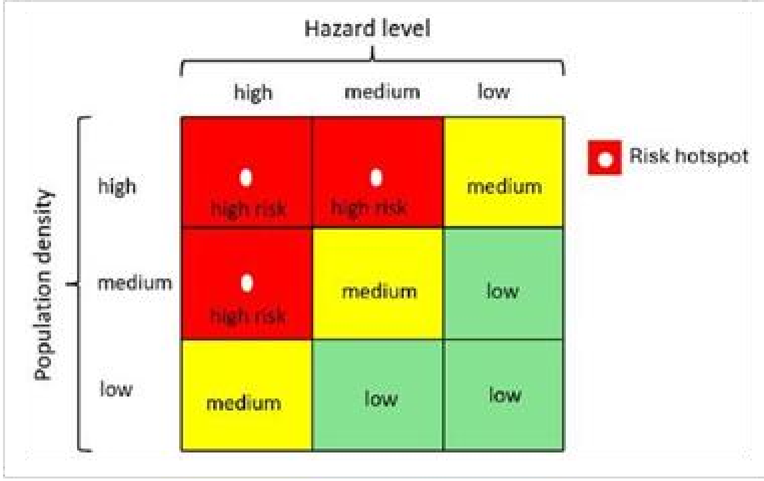

Fig.3.3. Risk matrix for identifying hotspot area

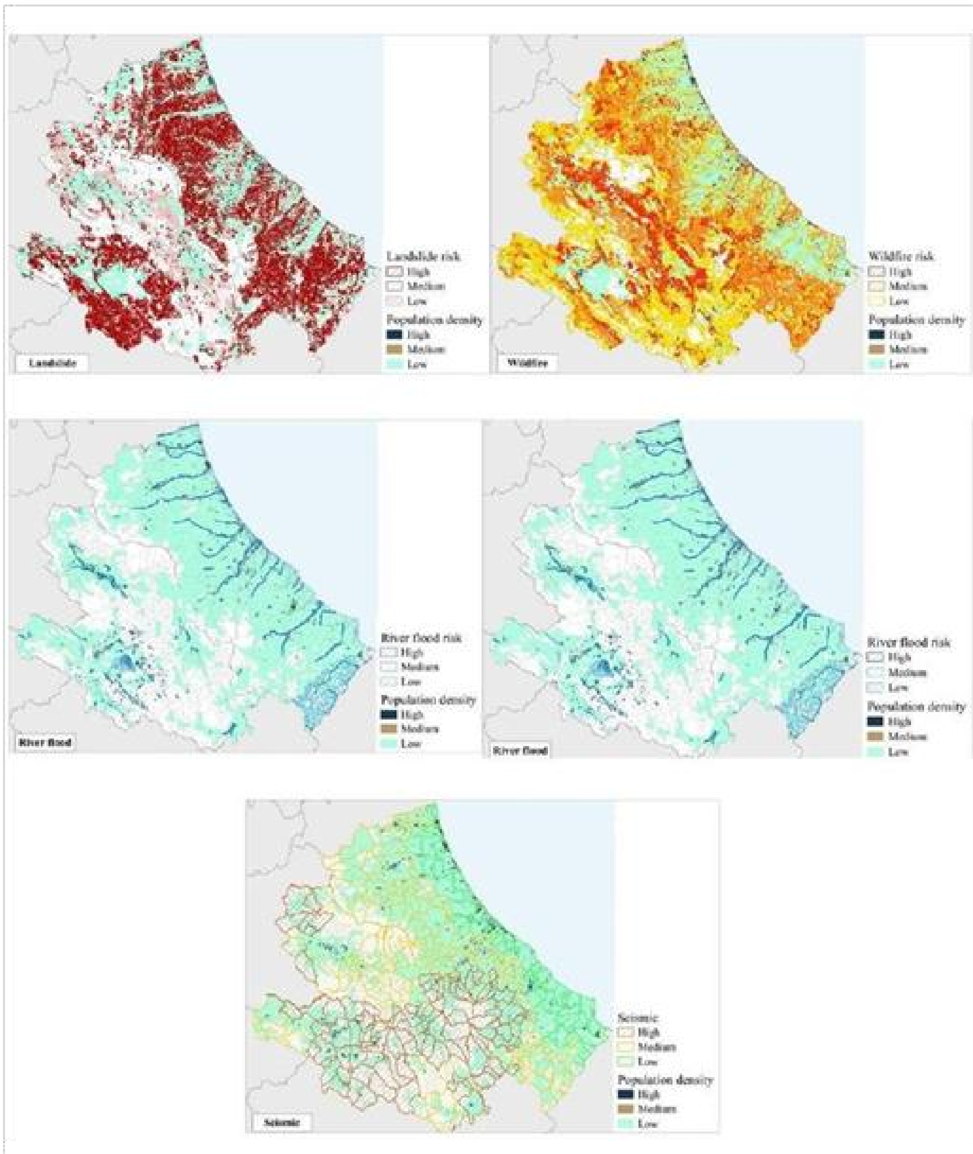

Fig.3.4. Hotspot area assessment maps for individual risks

The population density directly covered by the high and medium hazards was extracted for constructing the overall hotspot maps. This strategy was applied to all hazards (except the avalanche anthropic hazard that had no interaction with the exposition map).

Fig3.4 describes the area coverages of each risk scenario for all population densities. The landslide risk intensity is high in the coastal areas of the region, which is a typicality of the natural phenomenon, as loosed materials fall under the influence of gravity to low elevated areas. The landside risk is primarily influenced by the geomorphological structures of the landscape. Similarly, the flood risk is higher in the coastal area basically as a result of the recharge coming from the ocean. This presents a potentially dangerous situation, especially in the face of a continual sea level rise. The inland areas, which are mostly characterized by valleys and mountainous landscapes were more susceptible to wildfires and seismic risk. After observing the pattern of risk distribution, the decision of the approach to use for defining the hotspot areas was based on the population density map (Fig.3.2), since it depicts the areas with high concentration of inhabitants. Since we were defining the risk hotspot area, we only included the high-hazard high-population density, high- hazard medium-population density, and medium-hazard high-population density interaction areas, and then excluded the rest of the area.

The colored hatches in each risk scenario map show the population density covered by the high, medium, and low hazard, the population density is represented on each map with different colors to provide a good contrast between the two indicators (hazard and population density) to enable the efficient assessment of hotspot areas.

3. Result & Discussions

This research aimed to build a knowledge platform to identify overall hotspot areas of multi-risk scenarios present at the same. The study followed a simplified strategy consisting of risk identification, assessment, and estimation to build the knowledge platform. The innovation of the result of this research is the construction of an assessment-oriented H-E knowledge platform (Di Ludovico & Di Lodovico, 2020). The result obtained is a summary of all risk hotspots depicted in the individual risk hotspot identification maps (Fig.4.), indicating the risk hotspot areas in the Abruzzo region. The distinction in this study is the attempt to assess the interrelationship of these multiple risk scenarios, a challenge that has been expressed in several studies (De Angeli et al., 2022; SakicTrogrlic et al., 2024; Polese et al., 2024). The overall hotspot map (Fig.4.1) indicates areas at risk of catastrophe when all risks (multi- risk) are present. Table 1. shows the areas and quantities of exposition to these risks.

Table 1: Hotspot area coverage & population exposition in the Abruzzo region

Risk hotspot	Landslides	River flood	Dam flood	Seismic	Wildfires	Total
Hotspot areas coverage (km^2)	89.179	83.554	27.425	869.014	18.265	1087.437
%	8.20	7.68	2.52	79.91	1.68	10.039%
Population (n)	147779	113613	11328	259852	98679	631251
%	23.41	17.99	1.79	41.64	15.63	49.50%

Table 1. shows that, in the Abruzzo region, there is a substantial number of the population living in hotspot areas: 49.50% of the inhabitants (631251 inhabitants), most of the inhabitants are affected by the seismic and landslide risk (41.64% and 23.41% respectively). This high percentage of exposure is a result of the dominance of these risks in the region. The region has a total land area of 10,832 km2 with risk hotspots covering about 1087.437 km2 (10.039%) in urban areas. The population at flood risk amounts to 17.99%, while the wildfire risk makes up 15.63%, and the inhabitants susceptible to floods from dam failure are only at 1.79% risk. Calculations from the estimated surface coverage indicated that the seismic risk hotspot areas 869.014 km2 (i.e., 79.91%) are predominant. This signifies the deadlines of seismic risk (Zhang et al., 2022) in the Abruzzo region, as seen in past historical events. The Landslide and river flood risk hotspots constitute 89.179 km2 (8.20%), and 83.554 km2 (7.68%) respectively, indicating the need for several intervention measures in the region. The percentage area coverage of wildfire risk 18.265 km2 (1.68%) is considerably less, meaning that exposure is mostly confined to inhabitants living close to naturalistic/protected green areas (see Di Ludovico & Di Lodovico, 2020). Although the hotspot area coverage estimation was made for each risk situation, they do not occur discretely as there are areas where two or more risks are present, which is the bedrock of this study (multi-risk assessment). No data was recorded for avalanche and anthropic risk, hence the exclusion of data from these indicators. Most of these hotspots are located in urban areas, indicating a probable catastrophe when these hazards interact with the exposed population. Di Ludovico & Di Lodovico (2020), provide an estimate of the financial cost required to treat these risks based on their characteristics, however, their estimation focused more on reducing the risk of building. In the context of risk reduction, different intervention measures are required for the risk hotspot, and interventions are mostly centered in urban/capital cities areas, where the concentration of people is high (Koks et al., 2015). As much as intervention measures are needed to reduce disaster risk, it is important to identify the type of intervention each urban area needs to prioritize the actions and optimize the financial cost of such interventions. Disaster risk interventions can either be structural (e.g., constructing barriers for flood risk) or non-structural (e.g., evacuating exposed populations), and implementation of appropriate measures depends largely on the characteristics of risk present in the area, since they all may have different challenges and shortcomings of the type of resilience intervention to deploy (Rözer et al., 2023). The hotspot intervention areas (which can be estimated from the overall risk hotspot map; Fig4.1) represent those hotspots (Jaedicke et al., 2013; Marin et al., 2019) identified individual hazards with high-risk levels. In particular, these hotspot intervention areas, are areas where high population concentrations coincide with a dangerous degree of hazard impact. It is advisable to distinctively separate the hotspots to determine the type of intervention needed for separate risk hotspots. In this way, priorities for preventive and mitigation measures will be given to areas that face the most threat of disasters (Komendantova et al., 2014)

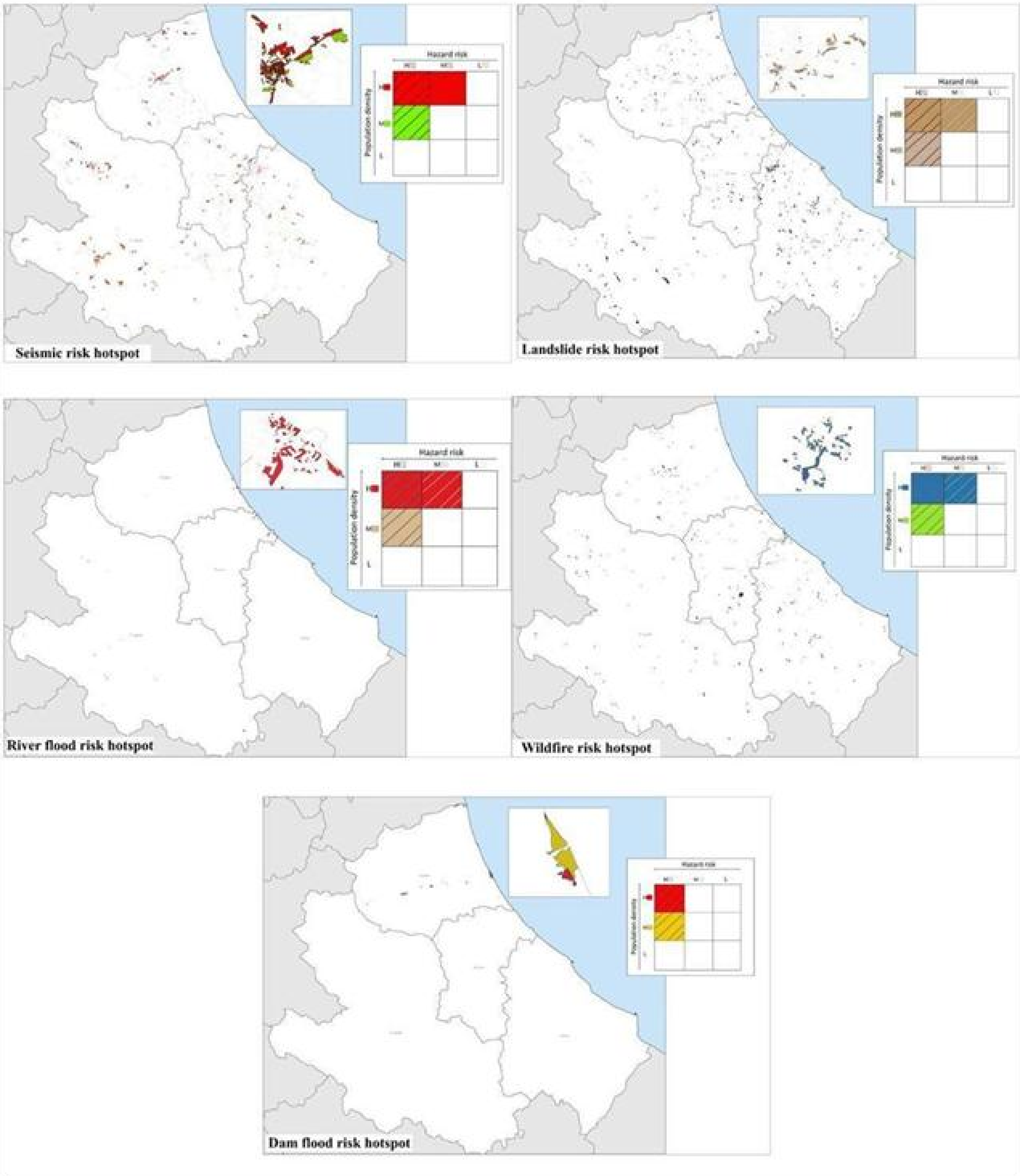

Fig.4. Hotspot areas for all risk companies in the Abruzzo region

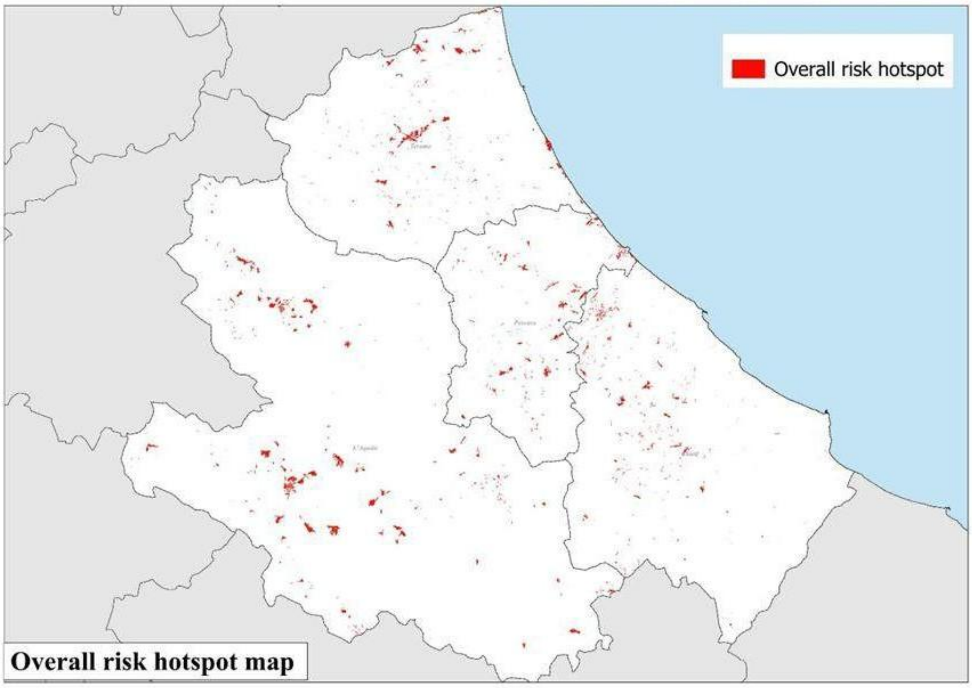

Fig.4.1. Overall risk hotspot area map in the Abruzzo region (multi-risk map)

3.1 Disaster Risk Governance in Abruzzo

The hotspot risk knowledge platform developed in the preceding sections is effective for evaluating the relevant dimensions of risk management and prevention of natural disasters, to obtain an all-round overview of the effect of hazards and their impact on the economy in the region. Disaster governance (Izumi et al., 2019) encompassing pre (preparedness, prevention, mitigation) and post (emergency response and recovery) disaster policies, are necessities for addressing the risk present in the region. Although, government-accepted indicators are designed and outlined for each disaster risk, which may determine the policies set up for addressing these risks (Ward &Hochrainer-Stigler, 2022), their primary goal is focused on reducing natural risk. Implementing intervention programs depends on several actions that are more or less formalized. For instance, the effectiveness of government interventions is dependent on the degree of policy adoption, and implementation by responsible institutional bodies. Such relevant policies and institutions are categorized in the top tier level of government (Marin et al., 2019).

Disaster risk governance in Italy is spread across several levels of government, however, the primary body responsible for risk reduction and response strategy is the National Civil Protection Service (NCPS) (Marin et al., 2019). The responsibilities of each level of governance are determined by the extent, intensity, and capacity of the civil protection service. These levels are categorized as 'type a' (municipal level), 'type b' (provincial and regional level), and 'type c' (national level). The responsiveness of each level to disaster risk reduction measures depends on their capacity and resource availability, therefore, if the lower level of governance is unable to respond to disasters the higher tier level would step in and support the response (Italian Civil Protection Department, 2024). The ongoing reconstruction work in the Abruzzo region indicates the vitality of tools that pinpoint areas where priority intervention is required given that the region is vulnerable to sudden hazard impact. Therefore, results from this study serve as useful to the reconstruction authorities and civil protection services in 'building back better' (UNISDR, 2017) and mitigating future disasters in the region.

4. Conclusion

This study sets out to develop a knowledge platform that identifies overall risk hotspots of natural events in the Abruzzo region in Italy. The region has over several years suffered the impact of many natural hazards, with most of these impacts occurring concurrently in the same year or within two to three years, causing numerous challenges to the civil protection service in charge of responding to disasters. This prompted the need to create a platform to identify hotspots in the region to enable planning risk reduction strategies. The primary concept in this study was the application of a single risk assessment method leading to a multi-risk scenario. The analysis revealed that the majority of the population is exposed to two or more risks, especially those residing in urban areas. Although multiple risks may be present in urban areas, the regional civil protection services, and the reconstruction authorities should consider prioritizing the risk that is more predominant to ensure the optimization of resources, and resilience in the case of future disasters. Estimations from the overall hotspot (multi-risk) map reveal that urban areas are more susceptible to record high casualty during disasters due to the exposure to high risk compared to less populated areas even though they are vulnerable to high hazard impact. The results also show that seismic, landslide, and flood hazards present more risk in the area, therefore, interventions should be targeted to reduce their risk.

The limitation of the study was majorly around access to available data, while this study may have centered on multi-risk assessment that often involves multiplication of hazard, vulnerability, and/or exposure, we had no access to vulnerable data primarily as a result of protection or privacy issues. Another

limitation was encountered in the methodology, which involved the creation of raster maps of the topic to generate the overall hotspot map, this was not possible due to the constraint of manipulating the population data to coincide with the geographic coverage of the hazards. This resulted in the adoption of a simpler method of overlaying the maps to identify the hotspots. In light of the outcome of this study further, research is encouraged to distinctively categorize the different risks existing in the study areas, since climate change impact affects the dynamism and intensity of hazards future studies could assess the degree of exposure to these intensified hazards. Consequently, future studies could focus on addressing these risk scenarios by determining the type of intervention to deploy for each risk and what measures could be implemented by the civil protection service to further strengthen the resilience of the region to these disasters. In conclusion, the knowledge platform developed from this study serves as a useful tool for decision-makers in planning, mitigating, preventing, and responding to emergencies or disasters.

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