

Mapping social risk areas to floods in Southern Italy: A spatial analysis for local emergency planning and place-based risk reduction policies

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ABSTRACT

Hazards develop into disasters when natural events impact on structures, infrastructure, and populations. Since both the physical and social components of disasters are influenced by spatial and temporal factors, understanding the interaction between natural hazards and the socioeconomic environment at the local scale remains a key challenge in disaster studies. In this paper, a multidimensional approach that merges population exposure, social vulnerability, alongside natural hazards, is proposed as a tool for local emergency planning and place-based risk reduction policies.

The case in point refers to flood hazard at a suburban scale across three metropolitan cities in Southern Italy: Bari (Apulia region), Naples (Campania region) and Reggio Calabria (Calabria region). By means of national open-source data, cartographic and statistical techniques are employed in order to map critical areas exposed to social risk as a consequence to floods at the enumeration area level. Five critical areas are identified in the city of Bari and Reggio Calabria, particularly within submunicipality 4 (Carbonara – Ceglie – Loseto) and 10 (Galina) respectively. In Naples, six critical areas are extracted from the analysis with the highest concentration of inhabitants at-risk found in submunicipality 10 (Bagnoli – Fuorigrotta). These outcomes can support disaster risk reduction strategies tailored to the exposure and vulnerability levels of specific population subgroups.

1. Introduction

Floods rank among the most devastating disasters, causing significant harm both to people as well as public and private infrastructure, ecosystems, cultural heritage, and economic activities [1]. They typically result from heavy rainfall, which causes water bodies to overflow their natural banks or artificial levees, submerging normally dry areas [2]. Floods can also be triggered by storm surges linked to tropical cyclones, tsunamis, or high tides in coastal regions [3].

According to the International Disaster Database (EM-DAT), 4,118 flood events—including riverine, coastal, and flash

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floods—were recorded globally between 2000 and 2024, with 480 occurring in Europe [4]. Notable examples are the catastrophic floods in Germany, Belgium, and the Netherlands from June 19–21, 2021, which resulted in overall losses of approximately US\$ 54 billion [5] or the 2023 floods in Northern Italy (Emilia-Romagna region) which caused an estimated US\$ 9.8 million in damages and affected 46,000 people [4].

The Sendai Framework for Disaster Risk Reduction 2015–2030 emphasizes (paragraph 23) that disaster risk management policies and practices should be grounded in a comprehensive understanding of disaster risk [6]. This includes assessing vulnerability, capacity, exposure of people and assets, hazard characteristics, and environmental factors [7]. Particularly, the Forensic Investigations of Disasters framework (FORIN) underlines that the extent of losses, damage, and adverse consequences from natural hazards is largely shaped by human actions and decisions, highlighting the critical role of social processes in generating “risk drivers”—dynamic conditions that intensify existing risks or introduce new ones at various levels [8]. Multidisciplinary investigations that merge social and physical data in risk analysis are essential for pre-disaster risk assessments, and also for allocating resources during the post-disaster period. This type of integration is becoming a priority and an urgent necessity in the context of climate change, as the Intergovernmental Panel on Climate Change (IPCC) highlights the intensifying nature of extreme weather events, signaling a new norm in our climate [9]. One of the methods that allows for gathering results from different investigations, is mapping that enables the combination of data layers from different sources and analyses, creating a spatially synthesized outcome. In the case of natural risks, this kind of tool provides a clear spatial representation of the most critical areas that may require special intervention during catastrophic events and special attention in risk reduction strategies. In this respect, the present research applies a multidisciplinary framework for risk analysis based upon the definition provided by the United Nations Office for Disaster Risk Reduction (UNDRR), which describes risk as the product of hazard, exposure, and vulnerability [10]. Generally, hazard is the potential for a natural or human-induced physical event, trend, or impact to cause loss of life, injury, health issues, property damage, social and economic disruption, or environmental harm [11]. Exposure refers to the inventory of elements (human beings, livelihoods and assets) in an area in which hazardous events can occur [10]. Vulnerability is defined as the susceptibility of exposed elements to the impact of hazards [12] and includes social, physical, economic, environmental and institutional aspects [13].

Particularly, this study explores the relationship between flood hazard and human population characteristics (population exposure and social vulnerability), starting with the assumption that the high level of loss to disasters is mainly associated to the vulnerability of population [14]. In this context, flood hazard can be defined as the exceedance probability of a given area to be potentially damaged by floods within a specified period of time [15]; population exposure is the number of people exposed to hazard and social vulnerability is the combination of demographic and socioeconomic factors that can (potentially) increase or attenuate the impacts on population [16–18]. Several studies have combined and mapped social vulnerability coupled with flood hazard in different countries so far, including Russia [19], the United States [20], New Zealand [21], Zimbabwe [22] and Europe ([23]; Aroca-Jiménez et al., 2022; [24, 25]) also focusing on locations in Italy [26], particularly in the Northern area [27–29]. However, one of the most complex aspects of risk analysis is the local-level study, often hindered by the lack of high-resolution spatial demographic or socio-economic census data. This results in a gap in local planning, which requires spatial investigations based on place-based natural hazard characteristics and demographic, social, and economic conditions at the enumeration area level [30]. For this reason, the present research follows a place-based geographic assessment of risks based on a specific location grounded in the “hazards of place” conceptual framework [31] and applied at the local level. The main aim is to quantifying and mapping – at suburban scale - the social risk level of three metropolitan cities located in Southern Italy (Bari, Napoli and Reggio Calabria) to detect the most critical areas and contributing to local emergency planning and place-based risk reduction policies. These areas have not previously been examined through multidisciplinary approaches at the local level and require comprehensive, in-depth analysis. For this reason, to address the social risk to floods in Southern Italy, this paper responds to the following research questions:

- i) How flood hazard, population exposure and social vulnerability are spatially distributed at the enumeration area level across the municipalities?
- ii) Which of the three elements (hazard, exposure, and vulnerability) has the greatest impact on the level of social risk?
- iii) What are the main critical areas within the municipalities under investigation?

The research employs an open-data-driven methodology by exploiting open-source platforms and software. Statistical and Geographic Information System (GIS) techniques are implemented in order to assist a combined spatial investigation of flood hazard along with population exposure and social vulnerability.

The rest of the paper is composed of 5 sections. The following sub-paragraph (1.1) provides information about the flood hazard characteristics of the selected municipalities. Section 2 describes the method used for the flood hazard assessment, population exposure and social vulnerability and the identification of social risk areas. Section 3 describes the findings obtained for the metropolitan city of Bari, Napoli and Reggio Calabria, while section 4 provides a critical analysis of the results and discuss the implication of mapping in the context of disaster risk reduction. Lastly, the conclusion (section 5) summarizes the main results and provides an overview of the limits of the research also suggesting a few recommendations for future studies.

1.1. Flood hazard in Southern Italy: the case of the metropolitan cities of Bari, Naples and Reggio Calabria

The last report of the Italian Institute for Environmental Research and Protection (ISPRA) highlights that around 94 % of Italian municipalities—approximately 7,400—are vulnerable to flooding [32]. Particularly, since 2013, Italy has experienced 38 flood events [33] causing significant damage to people and infrastructures. Mosaic layers are provided by means of data from the District Basin

Authorities and are freely available on the IdroGEO platform (Fig. 1). In particular, the ISPRA dataset defines the extension of the areas prone to be flooded, and accounts for three probability scenarios, as required by the Flood Directive (2007/60/EC):

- high probability
- medium probability
- low probability

According to the Italian Legislative Decree 49/2010, these scenarios correspond to areas that can be flooded with return periods ranging between 20 and 50 years (HPH—high probability or frequent floods), 100 and 200 years (MPH—average probability or infrequent floods), and greater than 200 years (LPH—low probability or extreme event scenarios), respectively. Under a high-probability flood scenario, about 15,712 people, nearly 62 cultural heritage sites (including architectural, monumental, and archaeological landmarks), and 2,298 buildings are at risk in the metropolitan city of Bari; about 54,792 people, nearly 102 cultural heritage sites and 9,364 buildings are at risk in Naples and about 79,994 people, nearly 275 cultural heritage sites, and 33,976 buildings are at risk for Reggio Calabria [35].

Bari is a coastal city located on the Adriatic coast and the capital of the Apulia Region hosting 316,226 inhabitants [34] and extending for 166 km². The territory is subdivided into 9 submunicipalities and 2081 enumeration areas (Fig. 1). The territory lies at

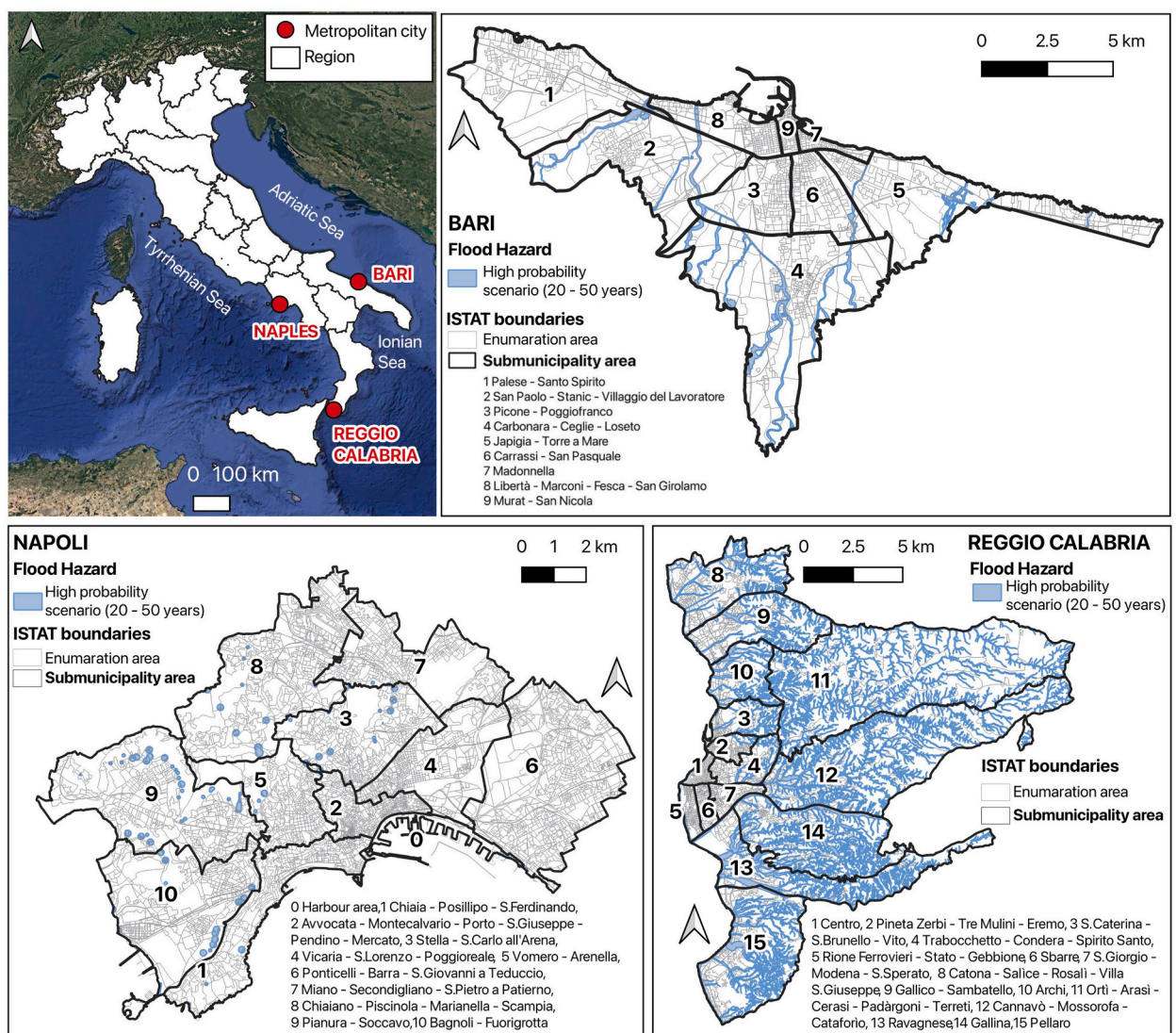


Fig. 1. Geographic setting of the metropolitan cities under investigation in Italy. The maps of Bari, Naples and Reggio Calabria are characterized by the spatial distribution of the submunicipalities and the enumeration areas collected from the Italian National Statistical Institute [34] overlaid with HPH scenario layer sourced from IdroGEO website [35]. Last update of enumeration areas and flood hazard layers refers to year 2021.

the confluence of several erosion streams (locally known as “lama” [ˈlaːma], plural: “lame”) that are key elements of water flow regulation (e.g., flood avoidance) [36]. Historical records indicate that floods have affected the area since the 16th century with the most destructive events occurred in 1905, 1915, and 1926 whose memory are still preserved through stone plaques placed along the affected streets (Santoro et al., 2023). In more recent years, a major flood event took place on October 22–23, 2005 causing damage to infrastructures, injuries and deaths (Moretti, 2005).

The metropolitan city of Naples, which lies on the Tyrrhenian coast, is the capital of Campanian Region and extends for 117,3 km². The territory it is characterized by 913,704 residents [34] and it is subdivided into 11 submunicipalities and 5726 enumeration areas (Fig. 1). The entire area is currently exposed to multiple sources of natural hazard, such as flooding, landsliding, coastal cliff instability and volcanic hazard [37]. Naples, despite not being crossed by any permanent watercourse, has always been one of the area most at risk of flooding [38] also due to chronic neglect and the inadequate capacity of drainage networks [39].

Reggio Calabria, located on the Tyrrhenian coast of the Calabria Region (Fig. 1), extends for 238.96 km² with a total population of 169,679 inhabitants [34]. The territory is subdivided into fifteen submunicipalities and 2882 enumeration areas (Fig. 1). The territory is characterized by near-behind coastal and mountainous morphologies and by the presence of “fiumare” site of torrential and regimes [40,41]. Most of the river basins are very small, so the response to precipitation is rapid and flooding is frequent [42,43]. According to Vazzana [44], 523 flood events have occurred in Calabria over the past 50 years, affecting 227 locations across the region, whose effects were exacerbated by the presence of riverbank cementation or excavations.

2. Materials and method

GIS and statistically-based approaches were employed to carry out the multidimensional analysis for each metropolitan city. As shown in Fig. 2, four main operational steps were carried out: a flood hazard assessment (blue color), a population exposure calculation (green color), a social vulnerability evaluation (pink color) and the integration of the results to elaborate social risk maps (red color) to identify critical areas. Flood hazard data were provided from the ISPRA dataset (IdroGEO platform), while population and building information, needed for the population exposure and social vulnerability evaluation, were obtained from the ISTAT dataset (see caption in Fig. 1).

The analysis was based on open-source data and it was applied at the enumeration area level. The enumeration area represents the smallest statistical unit at the sub-municipality scale in Italy, and is a valuable resource for developing high-resolution maps to support

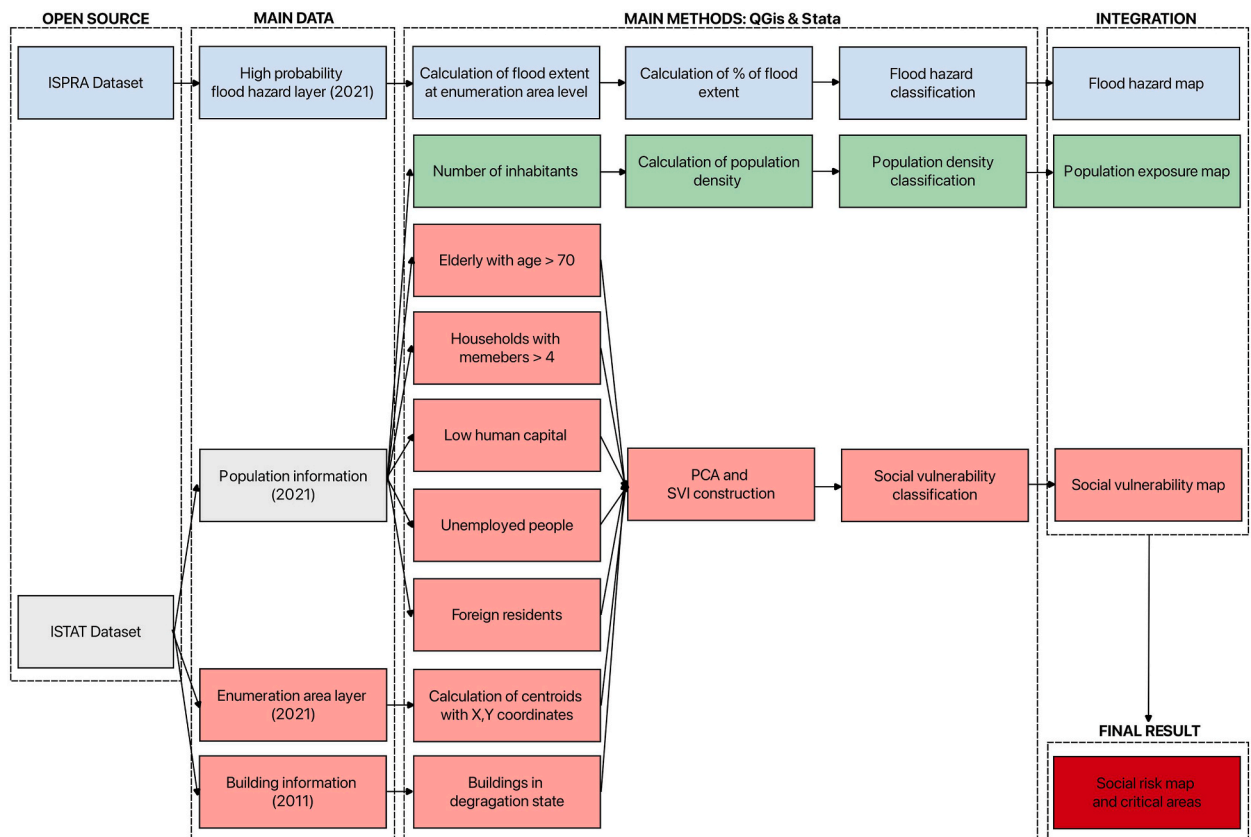


Fig. 2. Operational workflow. PCA = Principal Component Analysis; SVI = Social Vulnerability Index.

risk management strategies at suburban level.

In order to provide the spatial distribution of flood hazard, the percentage of the territory potentially affected by a HPH scenario was determined by computing the layer extent for each enumeration area and comparing the result with the total extent in m², [45,46]. The percentage value was then attributed to one of six natural breaks [47] and reclassified on a scale from 0 to 5 (FH0 no hazard, FH1 very low, FH2 low, FH3 medium, FH4 high, FH5 very high).

As concerns population exposure, the population density of each enumeration area was calculated as a ratio between the number of inhabitants and the total extent of the enumeration area. The results were then attributed to one of six natural breaks and reclassified on a scale from 0 to 5 (E0 no population density, E1 very low, E2 low, E3 medium, E4 high, E5 very high).

Lastly, for the social vulnerability evaluation, population data were collected on key demographic and socioeconomic dimensions. These variables were then merged with housing condition data from the 2011 Census and with spatial coordinates (X, Y) of the barycenter of each enumeration area, in order to build a composite indicator measuring social vulnerability. The index incorporates ten variables across four dimensions which are summarized in Table 1. In particular, the sociodemographic dimension includes the share of individuals over 70 years old, households with more than four members and the share of foreign residents; the socioeconomic dimension is represented by the share of male and female residents with at most a lower secondary education and the share of unemployed males and females; the housing conditions dimension is characterized by the share of residential buildings in poor or very poor states of preservation. To consider the spatial dimension of each territorial units (i.e. enumeration area), we also included the centroid coordinates (X, Y) of the enumeration areas computed by QGIS (3.32 version).

A Principal Component Analysis (PCA) [48] was performed through STATA to synthetized the ten variables into three principal components (PCs). For each enumeration area, the composite social vulnerability index was constructed by using the retained PCs, weighted by their eigenvalues [49]. Finally, the index was standardized using the min-max approach to produce the potential Social Vulnerability Index (SVI), classified into six ranges using the natural breaks approach [47] and reclassified on a scale from 0 to 5 (SV0 no population, SV1 very low, SV2 very high, SV3 medium, SV4 high, SV5 very high).

By means of a raster calculator (a GIS-based raster-analysis tool), the flood hazard levels were combined with the population exposure and social vulnerability classes and the results were categorized by the use of six quantiles from very low to very high social risk. Finally, the enumeration areas with high and very high levels were grouped into critical areas.

3. Results

3.1. Bari

Fig. 3 shows the spatial distribution of the risk components across the metropolitan city of Bari. Specifically, Fig. 3A shows the result of the flood hazard assessment, where hazard levels for each enumeration area are determined based on the percentage of land potentially affected by floods in the event of HPH. The figure reveals that most enumeration areas (1,928) are not located in flood-prone zones (FH0). However, areas at risk—primarily found outside the downtown area (133 enumeration areas)—mainly exhibit very low (FH1), low (FH2), and medium (FH3) flood hazard levels. The submunicipality most affected by flood hazard is submunicipality 4, which includes the suburban districts of Carbonara, Ceglie, and Loseto.

Concerning the population exposure, Fig. 3B shows that the highest population densities—categorized as very high (black), high (violet), and medium (blue)—are predominantly concentrated in the city center, particularly in submunicipality 9 (Murat, San Nicola), followed by the suburban districts in submunicipalities 8 (Libertà – Marconi – Fesca – S. Girolamo), 6 (Carrassi – San Pasquale), and 3 (Picone – Poggiofranco). High levels of population exposure are also observed in submunicipality 2 (S. Paolo – Stanic – Villaggio del Lavoratore).

As regards social vulnerability, the majority of enumeration areas (507) fall into the medium social vulnerability class (SV3), followed by lower vulnerability (SV2 = 504) and higher (SV4 = 230) vulnerability classes. Fig. 3C illustrates the distribution, with green areas representing lower vulnerability, primarily concentrated in the central and eastern sections of the map. In contrast, dark pink areas, which indicate higher vulnerability, are predominantly located in the western part of the map, particularly across Submunicipalities 1 (Palese-Santo Spirito) and 2 (San Paolo-Stanic-Villaggio del Lavoratore).

By overlaying the different layers shown in Fig. 3, the final spatial distribution of the risk classes reveals that only a small number of

Table 1
Dimensions and variables selected for the construction of the SVI.

DIMENSION	VARIABLE
Sociodemographic	1. Elderly with age >70
	2. Foreign residents
	3. Households with members >4
Socioeconomic	4. Low human capital (males)
	5. Low human capital (females)
	6. Unemployed males
	7. Unemployed females
Housing condition	8. Buildings in degradation state
Spatial	9. X coordinate
	10. Y coordinate

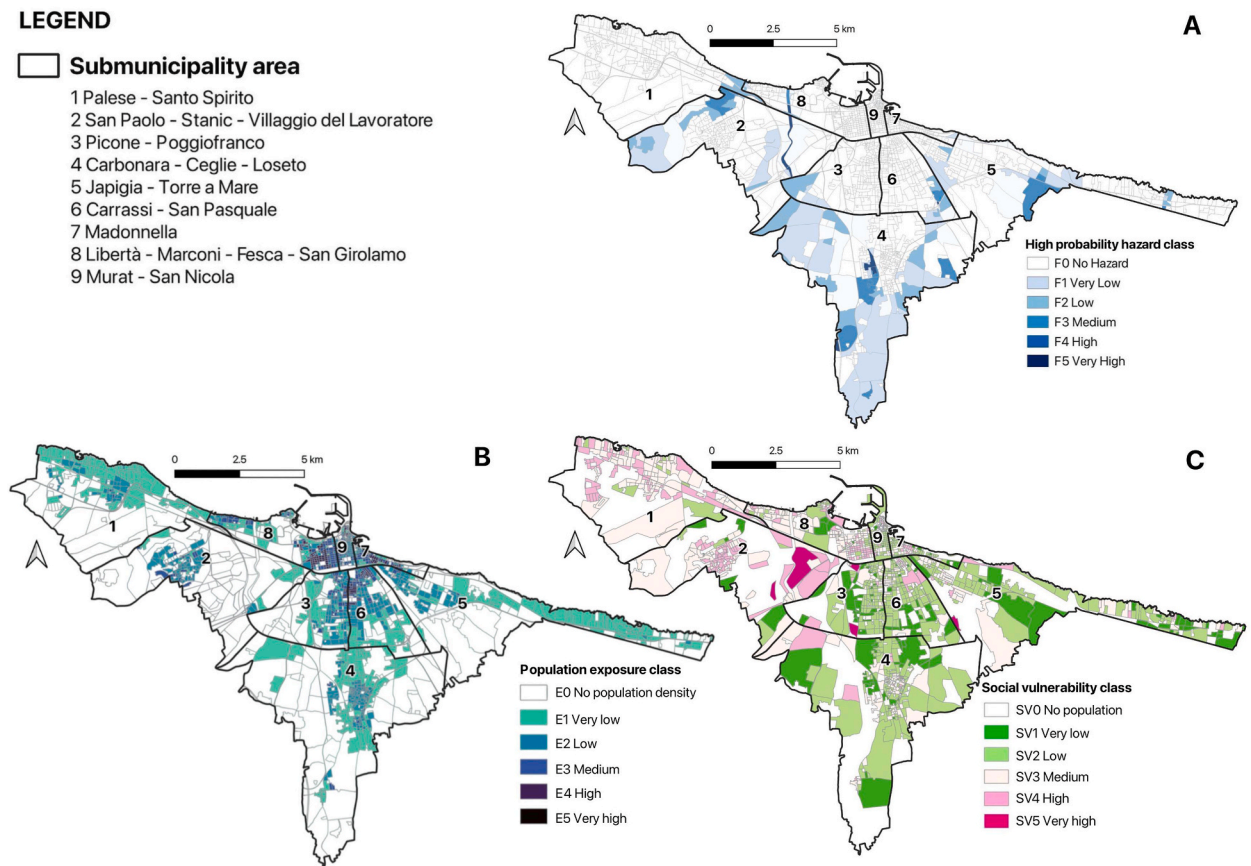


Fig. 3. Spatial distribution of HPH scenario (A), population exposure (B) and social vulnerability (C) classes across the metropolitan city of Bari at enumeration area level. On the top left the identification of the submunicipality areas.

enumeration areas (33) exhibit a significant level of risk (Fig. 4). Similar to the flood hazard distribution, Submunicipality 4 (Carbonara, Ceglie, Loseto) contains the highest concentration of enumeration areas with elevated risk levels (high and very high), which are identified as critical areas (marked with red circles in Fig. 4) and require particular attention. Specifically, the integration of these components for the city of Bari highlights five critical areas with high or very high social risk levels:

- Hot-spot A located in submunicipality 4,
- Hot-spot B also situated within submunicipality 4,
- Hot-spot C selected in submunicipality 2,
- Hot-spot D at the border between submunicipalities 1 and 2.
- Hot-spot E located in Submunicipality 5 (Japigia – Torre a Mare).

A higher-resolution investigation of these critical areas, using Google satellite images, provided as a background in QGIS, further revealed that these “hot spots” are situated near various erosion streams (“lame”—see Section 1.1) that traverse the municipality (Fig. 4). Hot-spot D is located near Lama Balice, hot-spot C close to Lama Lamasinata, hot-spot B between Lama Lamasinata and La Marchesa, hot-spot A in Lama Picone and hot-spot E near Lama San Giorgio. Therefore, there is a correspondence between the presence of lame and high level of risk not only in terms of hazard but also due to specific social condition.

3.2. Naples

The flood hazard assessment (Fig. 5A) carried out for the city of Naples shows that most of the enumeration areas (5,542) are located in no flood-prone areas (FH0) followed by very low (FH1 = 100), low (FH2 = 35), medium (FH3 = 20), high (FH4 = 18) and very high (FH5 = 11) classes. However, submunicipality 3 (Stella – S. Carlo all’Arenella), 5 (Vomero - Arenella), 8 (Chiaiano – Piscinola – Marianella – Scampia), 9 (Pianura – Soccavo) and 1 (Chiaia – Posillipo – S. Ferdinando) register the presence of enumeration areas affected by flood hazards mostly concentrated in the western part of the metropolitan city.

Concerning the population exposure, Fig. 5B shows that the highest population densities—categorized as very high, high and

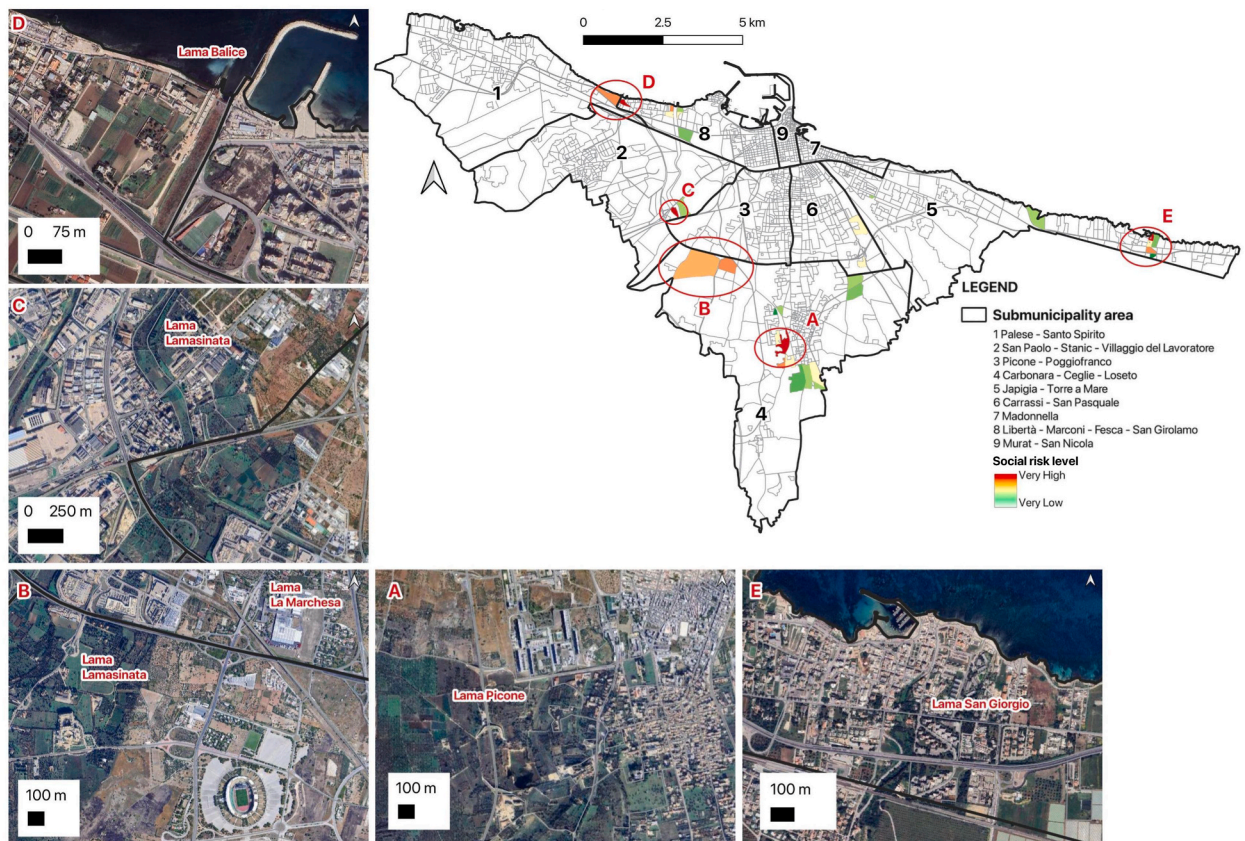


Fig. 4. Spatial distribution of the social risk levels to flood hazard across the metropolitan city of Bari at enumeration area level with the identification (red circle) and zoom of the critical areas.

medium, are predominantly concentrated in the enumeration areas of the city center. Submunicipality 2 (Avvocata – Montecalvario – Porto – S. Giuseppe – Pendino – Mercato) is characterized by clusters located around it and across submunicipality 7 (Miano – Secondigliano – S. Pietro a Patierno) and 8. In this case, 2074 enumeration areas are classified as very low exposure (E1), 1601 as low (E2), 477 as medium (E3), 64 as high (E4) and 3 as very high (E5).

The findings derived from the social vulnerability investigation reveals that the majority of enumeration areas fall into medium social vulnerability classes ($SV3 = 1004$), followed by high ($SV4 = 850$), low ($SV3 = 820$), very low ($SV1 = 771$) and very high ($SV5 = 312$). Particularly, most of lower social vulnerability classes characterize the enumeration areas located within submunicipality 1, 5 and 2, while higher classes are registered in the suburban peripheral districts and particularly clustered across submunicipality 6 (Ponticelli – Barra – S. Giovanni a Teduccio), 7 and 8.

Fig. 6 illustrates the final overlay among the layers, revealing that most of the enumeration areas exhibit high and very high social risk levels, distributed across six critical areas:

- Hot-spot A located in submunicipality 10 (Bagnoli, Fuorigrotta),
- Hot-spot B situated within submunicipality 9 with few enumeration areas at the border of submunicipality 10,
- Hot-spot C selected in submunicipality 8,
- Hot-spot D also within submunicipality 8,
- Hot-spot E located in the middle of submunicipality 2, 3 and 5,
- Hot-spot F in submunicipality 3.

Submunicipality 9 shows the highest number of enumeration areas affected by high-risk levels. The risk spatial distribution (Fig. 6) follows the pattern of the hazard classes (Fig. 5A) with population exposure and social vulnerability affecting the level of risk.

3.3. Reggio Calabria

The metropolitan city of Reggio Calabria shows extended areas affected by significant classes of flood hazard (Fig. 7A) especially outside the city center (submunicipality 1 and 2). However, in terms of numbers, most of the enumeration areas (1,868) fall into the no

LEGEND**Submunicipality area**

- 0 Harbour area
- 1 Chiaia - Posillipo - S.Ferdinando
- 2 Avvocata - Montecalvario - Porto - S.Giuseppe - Pendino - Mercato
- 3 Stella - S.Carlo all'Arena
- 4 Vicaria - S.Lorenzo - Poggioreale
- 5 Vomero - Arenella
- 6 Ponticelli - Barra - S.Giovanni a Teduccio
- 7 Miano - Secondigliano - S.Pietro a Patierno
- 8 Chiaiano - Piscinola - Marianella - Scampia
- 9 Pianura - Soccavo
- 10 Bagnoli - Fuorigrotta

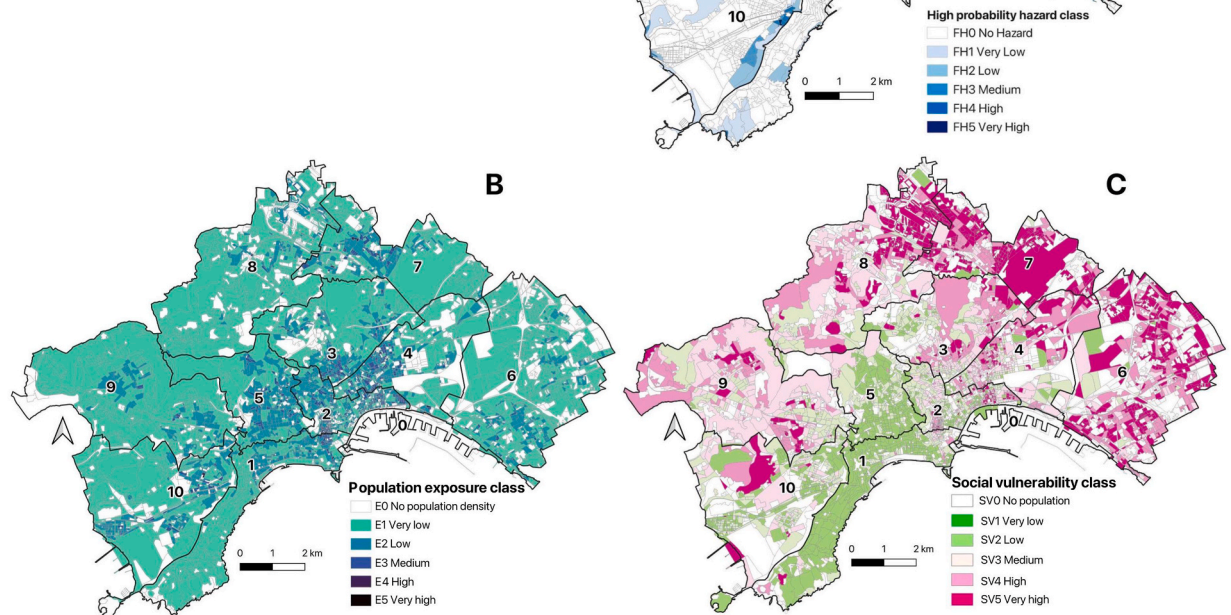


Fig. 5. Spatial distribution of HPH scenario (A), population exposure (B) and social vulnerability (C) classes across the metropolitan city of Naples at enumeration area level. On the top left the identification of the submunicipality areas.

hazard classes (FH0) followed by low (FH2 = 331), very low (FH1 = 295), medium (FH3 = 182), very high (FH5 = 115) and high (FH4 = 91) classes. The highest classes can be recognized along the submunicipality borders that often correspond to the presence of “fiumare” (see section 1.1) particularly within submunicipality 13 (Ravagnese) and 15 (Pellaro).

On the contrary, as shown in Fig. 7B, the population exposure classes are concentrated along the coast from submunicipality 8 (Catona – Salice – Rosali – Villa S. Giuseppe) to submunicipality 15 (Pellaro) with highest classes clustered across the suburban districts of the most central areas in submunicipality 1 (Centro), 2 (Pineta Zerbi – Tre Mulini – Eremo), 3 (Santa Caterina – San Brunello – Vito), 4 (Trabocchetto – Condera – Spirito Santo), 5 (Rione Ferrovieri – Stadio – Gebbione), 6 (Sbarre), 7 (San Giorgio – Modena – San Sperato). Very low classes of population exposure (E1) are registered in 685 enumeration areas, followed by medium (E3 = 566), low (E2 = 564), high (E4 = 188) and very high (E5 = 1) classes of population density. The rest fall into E0 class (878).

As resulting from the social vulnerability investigation, Fig. 7C shows that the lower classes (SV1 and SV2) are mostly located in the southern and central part of Reggio Calabria across submunicipality 2, 4, 1, 5, 6, 7, 13 and 15, while higher classes (SV4 and SV5) in the piedmont zone and northern part of the metropolitan city in submunicipality 3, 8, 9 (Gallico – Sambatello), 10 (Archi), 11 (Orti – Arasi – Cerasi – Podàrgoni – Terreti), 12 (Cannavò – Mossorofa – Cataforio) determining two different social vulnerability patterns. 789 enumeration areas are characterized by medium social vulnerability (SV3), 514 by high (SV4), 434 by low (SV2), 149 by very high (SV5) and 65 by very low (SV1) classes, while most of them (951) fall into SV0 class.

Fig. 8 illustrates the final outcome of the local spatial analysis that integrates the physical and social components. The map reveals that the spatial distribution of risk classes identifies five critical areas with high or very high social risk levels:

- Hot-spot A located in submunicipality 13,
- Hot-spot B positioned in submunicipality 12 and 4,
- Hot-spot C entirely within submunicipality 3,
- Hot-spot D in submunicipality 10,

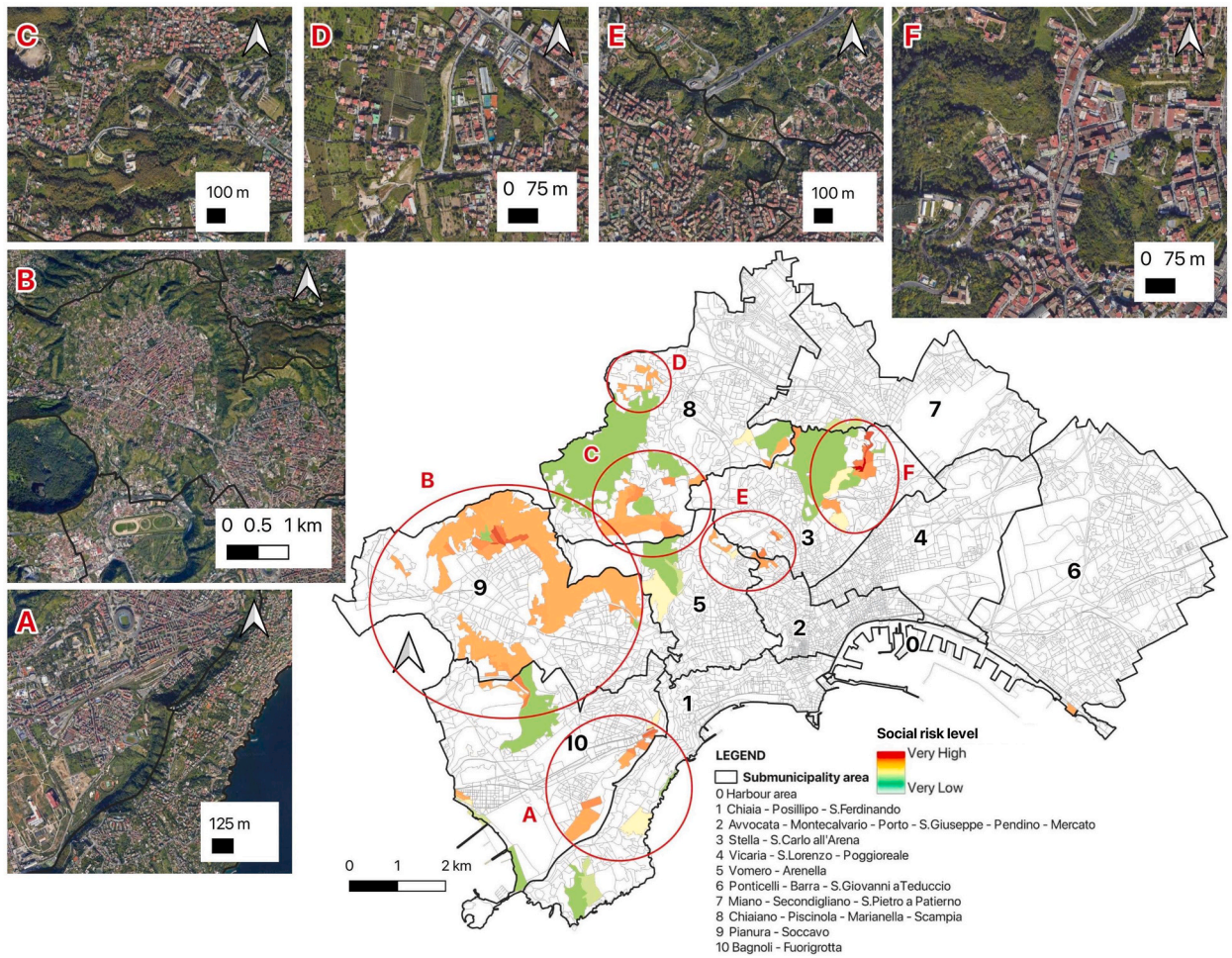


Fig. 6. Spatial distribution of the social risk to flood hazard across the metropolitan city of Naples at enumeration area level with the identification (red circle) and zoom of the critical areas.

- Hot-spot E based in submunicipality 8.

Particularly, submunicipality 10 includes the highest number of enumeration areas at high risk, while the general risk level distribution follows the population exposure map (Fig. 7B).

4. Discussion

4.1. The interaction between risk components on the spatial distribution of critical areas

Starting from the case of the metropolitan city of Bari and taking into account the population exposure map (Fig. 3B) with the flood hazard distribution (Fig. 3A), an opposite spatial pattern emerges, indicating that most of the population resides outside flood-prone areas. However, certain enumeration areas, located in the submunicipality 4, 5, and 8 are exceptions, where flood hazard and population density overlap. As highlighted in Section 3.1, there is a correspondence between high risk levels and the presence of erosion streams ("lame"). However, what emerges from the spatial distribution of the individual risk components is that social vulnerability likely amplifies these risk levels in these areas, especially considering that exposure and hazard are almost reversed. This result demonstrates how the levels of social vulnerability can strongly influence risk, and the location of critical areas suggesting a vicious circle of marginality. In fact, despite the low population density in flood-prone areas, the few people living there are characterized by high classes of social vulnerability, calling for a careful design of mitigation actions.

In the case of Naples, the comparison between the population exposure map (Fig. 5B) with the social vulnerability map (Fig. 5C) suggests that areas with higher population density tend to have lower classes of social vulnerability, whereas higher vulnerability is concentrated in peripheral and less populated areas. The social risk spatial distribution (Fig. 6) follows the pattern of the hazard classes, highlighting the strong hazard-dependent nature of the analysis, with population exposure and social vulnerability affecting

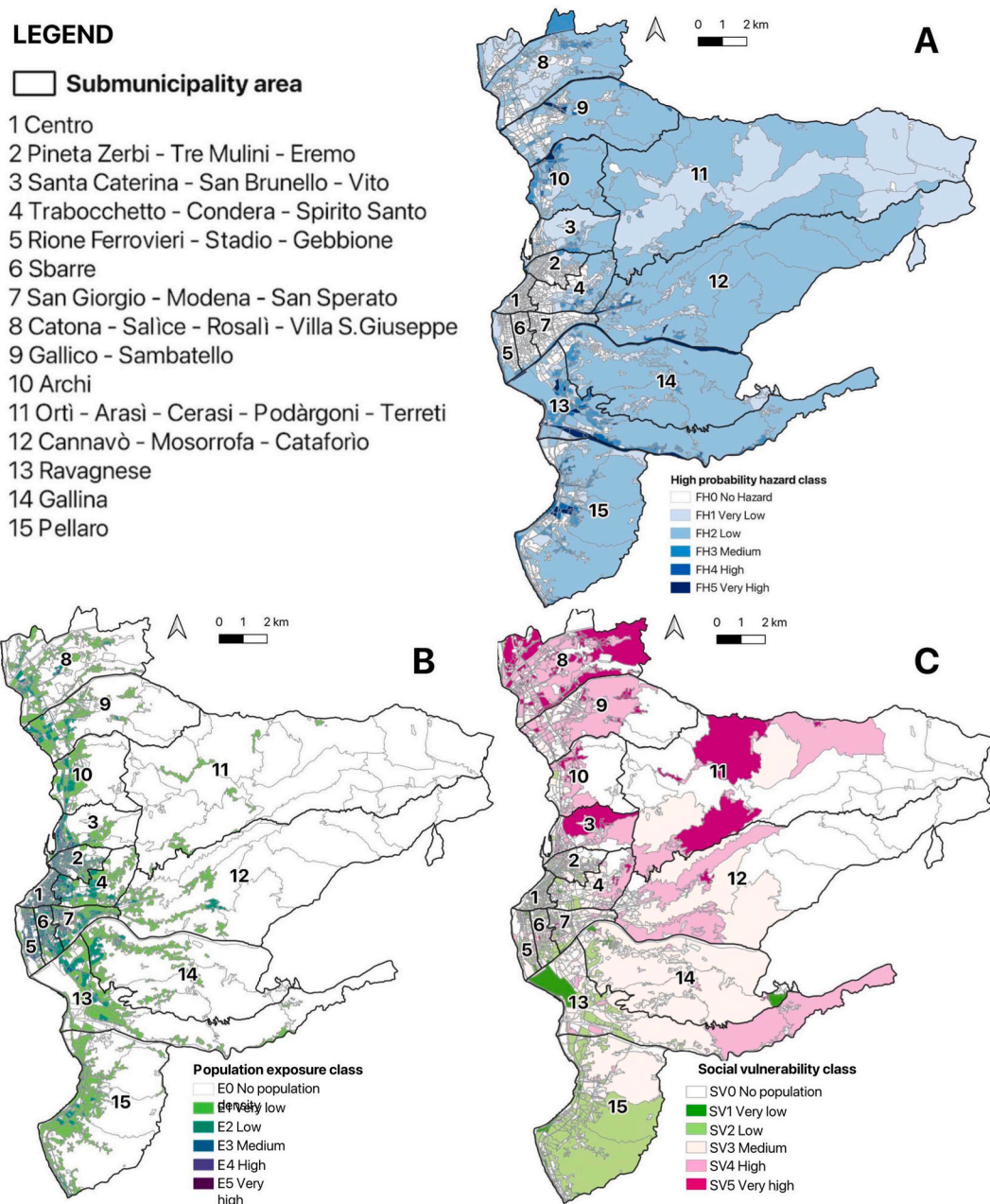


Fig. 7. Spatial distribution of HPH scenario (A), population exposure (B) and social vulnerability (C) classes across the metropolitan city of Reggio Calabria at enumeration area level. On the top left the identification of the submunicipality areas.

the level of social risk (toward low-risk classes or high-risk classes).

In the case of Reggio Calabria, by comparing the social risk map (Fig. 8) with the population exposure map (Fig. 7B), a spatial overlapping emerges highlighting that the population density along the coast could play a significant role in risk management strategies.

The difference outlined in the three metropolitan cities underlines the importance of combining hazard, exposure and vulnerability in risk analysis, as each component can significantly influence the location of critical areas to be taken into account for mitigation actions. In the case of Bari is social vulnerability, for Naples is flood hazard, while in the case of Reggio Calabria, population exposure plays a significant role in the spatial distribution of social risk levels. These results prove the importance of merging social and physical conditions at the local level to evaluate areas most at risk in order to adopt an effective risk management protocol [50–54].

As shown in Table 2, by extrapolating the number of inhabitants from each enumeration area located in the critical areas with high and very high social risk levels, 2,335 people are registered as the most at risk in the metropolitan city of Bari (mostly concentrated in

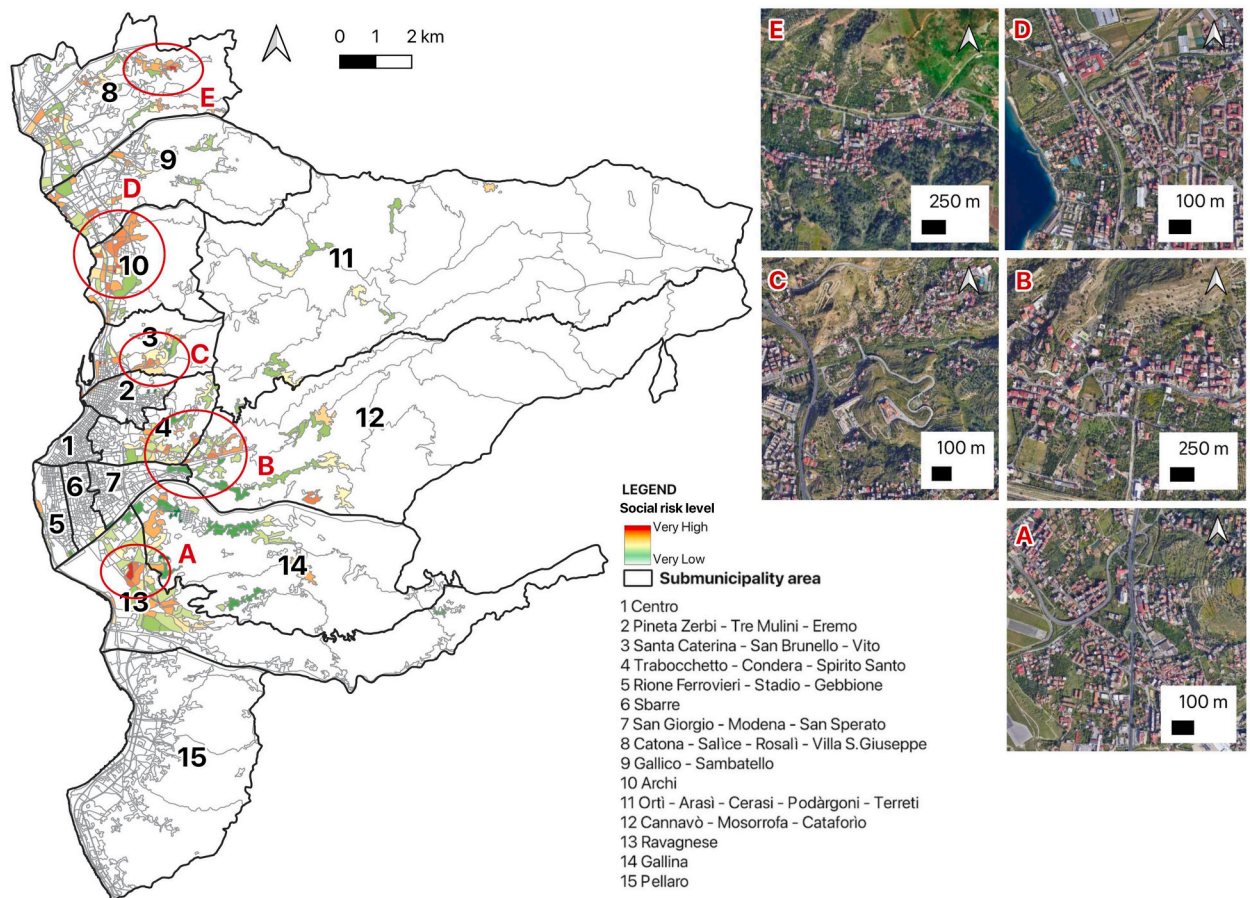


Fig. 8. Spatial distribution of the social risk to flood hazard across the metropolitan city of Reggio Calabria at enumeration area level with the identification (red circle) and zoom of the critical areas.

submunicipality 4, critical area B). A higher number of people at risk is noted in the metropolitan city of Naples, where 17,136 inhabitants are the most affected especially across the enumeration areas of submunicipality 10, critical area A. Lastly, the city of Reggio Calabria shows 10,368 inhabitants with high and very high level of social risk, predominantly concentrated in submunicipality 14, critical area A. By correlating Table 2 with the maps depicted in Figs. 4, 6 and 8 it is possible to localize the affected part of population, project for local emergency plan and optimize resource allocation during recovery efforts [17,55].

4.2. Place-based approaches in local disaster policies, methodological constraints and recommendations

The maps developed in this research enabled the identification of priority areas (research question iii), offering valuable insights for local authorities in formulating long-term, urban flood-resilience strategies [56]. Localized mapping of hazards, exposure, and vulnerability (research question i) is crucial—not only for highlighting the most critical areas but also for understanding the key elements that contribute to social risk (research question ii). This understanding forms the foundation for planning sustainable mitigation measures and implementing place-based risk reduction policies.

Applying a place-based approach across diverse urban contexts at the local level yields tailored results that support the development of risk reduction strategies aligned with the specific characteristics, traditions, and vulnerabilities of each territory [57].

Prioritizing place-based approaches requires a shift from top-down disaster governance to models that emphasize community participation, local capacity, and knowledge—elements that are fundamental to building genuinely resilient communities [58]. Empowering local actors enhances the sustainability of prevention and preparedness efforts by ensuring that risk communication is culturally appropriate and accessible. This, in turn, facilitates quicker response times and better coordination during emergencies, ultimately reducing both human and economic losses [59]. Local communities are often the first to face the impacts of disasters and possess rich, context-specific knowledge of their environments, including traditional coping mechanisms, collective memory of past events, and well-established social networks that can be quickly mobilized during crises [60]. When this local knowledge is integrated with scientific and institutional frameworks, it results in disaster risk reduction strategies that are more relevant, inclusive, and effective [61]. Furthermore, supporting local networks—such as volunteer groups, civil protection services, and community-based

Table 2

Number of inhabitants located in the enumeration areas of the critical zones at high and very high risk. The submunicipalities and the critical areas highlighted with red color are those characterized by the highest number of people at risk.

METROPOLITAN CITY	CRITICAL AREA	SUBMUNICIPALITY	SOCIAL RISK LEVEL	N° OF INHABITANTS	% POPULATION	
Bari	A	4 Carbonara-Ceglie- Loseto	Very High	299	12.80	
	B		High	45	1.92	
				596	25.52	
	C	2 San Paolo-Stanic- Villaggio del lavoratore	Very High	516	22.09	
	D	1 Palese-Santo Spirito	High	142	6.08	
		8 Libertà-Marconi- Fesca-San Girolamo	Very High	465	19.91	
	E	5 Japigia-Torre a Mare		150	6.42	
			High	122	5.22	
Total				2,335	100	
Napoli	A	10 Bagnoli-Fuorigrotta	Very High	1,635	9.54	
			High	2,869	16.74	
	B	9 Pianura-Soccavo	High	312	1.82	
			Very High	1,629	9.50	
	C	8 Chiaiano-Piscinola- Marianella-Scampia	High	2,501	14.60	
				2,781	16.22	
				595	3.47	
				1,221	7.12	
				787	5.59	
				145	0.84	
	D	5 Vomero-Arenella		2,781	16.22	
				595	3.47	
	E	2 Avvocata- Montecalvario-Porto-S. Giuseppe-Pendino- Mercato		1,221	7.12	
		787		5.59		
F	3 Stella-S. Carlo all'Arena		145	0.84		
			1,058	6.17		
		Very High	1,603	9.35		
Total				17,136	100	
Reggio Calabria	A	14 Galina	Very High	984	9.48	
		13 Ravagnese	High	2,158	20.81	
				261	2.51	
	B	12 Cannavò-Mosorrofa- Cataforio	High	355	3.42	
		4 Trabocchetto- Condera-Spirito Santo		Very High	421	4.06
		C	3 Santa Caterina-San Brunello-Vito	High	588	5.67
				High	681	6.56
	D	10 Archi	High	811	7.82	
			Very High	431	4.15	
	E	8 Catona-Salice-Rosali` - Villa S.Giuseppe	High	1,157	11.16	
			High	1,994	19.23	
			High	306	2.95	
			Very High	221	2.13	
	Total				10,368	100

monitoring systems—helps ensure that disaster management efforts are decentralized, responsive, and adaptable.

Although the method emphasizes the utility of maps for identifying the most critical areas, it is important to underline some limitations. The findings provided in this study are strictly related to the use of enumeration areas as a territorial statistical unit. While this cartographic base is essential for local-level research, enumeration areas vary significantly in size, with some delineating inhabited centers, while others encompassing only road segments or specialized areas defined by distinct geomorphological features, such as lakes, maritime islands, marshes, lagoons, fishing valleys, and uninhabited mountains [62]. Consequently, relative or comparative analyses within the same territory become challenging also due the modifiable areal unit problem (MAUP) effect [63,64]. To partially address this issue and ensure consistency across spatial units, incorporating grid cells of uniform resolution would be beneficial [20,65, 66]. However, the use of grids presents certain limitations, as they are based on estimations and therefore inherently subject to a

margin of error. Another limitation is the lack of some census data at the sub-municipal level (such as the presence of people with special needs or characterized by low-income class), which are essential to build emergency and recovery planning. Therefore, it is strongly recommended that researchers enhance data collection efforts and expand socio-economic datasets to enable more detailed vulnerability analyses. This would support the application of rigorous statistical methods, which are fundamental to quantitative investigations.

As a final remark, it should be of great help to obtain multi-hazard data, especially in urban context where different hazard coexists as the case of Naples [67] or Reggio Calabria [68] to provide more detailed information for local multi-risk emergency planning.

5. Conclusion

This research underlines the value of multidisciplinary methodologies that integrate both physical and socio-demographic data to support risk analysis, emergency planning, and disaster policy development at the local level. A spatial investigation grounded in a place-based approach was conducted in three metropolitan areas of Southern Italy—Bari, Naples, and Reggio Calabria—focusing on their suburban territories.

In Bari and Reggio Calabria, five critical areas were identified, notably within Submunicipality 4 (Carbonara-Ceglie-Loseto) and Submunicipality 10 (Gallico), respectively. In the metropolitan area of Bari, 2,335 individuals were identified as being at highest risk. In Reggio Calabria, the analysis revealed 10,368 residents facing high to very high levels of social risk. In Naples, six critical areas emerged from the analysis, with the highest concentration of at-risk inhabitants (17,136) located in Submunicipality 10 (Bagnoli-Fuorigrotta).

When comparing the spatial distribution of hazard, exposure, and vulnerability, the most influential factor in social risk levels varied across cities: social vulnerability was the key driver in Bari, flood hazard was most significant in Naples, and population exposure played the dominant role in Reggio Calabria. These findings highlight the necessity of integrating both social and physical dimensions into local-level risk management strategies.

The study further emphasizes the relevance of a place-based approach in shaping disaster policies that are tailored to the unique characteristics, traditions, and vulnerabilities of each territory. Such approaches encourage community participation, leverage local capacities, and draw on context-specific knowledge—essential components for fostering truly resilient communities.

Lastly, the proposed methodology offers the flexibility to be extended into multi-risk assessments that account for overlapping hazards and diverse vulnerability factors, including physical vulnerability (e.g., structural and building fragility). This represents a key direction for the future development of this research.

CRedit authorship contribution statement

Isabella Lapietra: Writing – original draft, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Federico Benassi:** Writing – review & editing, Investigation, Data curation. **Anna Paterno:** Writing – review & editing, Formal analysis, Data curation. **Thaís García-Pereiro:** Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Pierfrancesco Dellino:** Writing – review & editing, Supervision, Investigation, Funding acquisition, Data curation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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