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Cross-Sectoral and Multilevel Dimensions of Risk and Resilience Management in Urban Areas Enabled by Geospatial Data Processing

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Abstract: The growing complexity of cities and the unprecedented pace of urbanisation create exposure and vulnerabilities to extreme events and crises that are difficult to manage and plan for as widely acknowledged by the existing literature. In this paper, three main challenges to be tackled are identified based on the selected literature according to the interpretation of the authors based on extended research in the field. Those challenges relate to the multi-risk environment characterising many contemporary cities, the need to overcome sectoral approaches towards increased alignment of emergency and spatial planning at different scales, and the opportunities that derive from integrated risk and resilience management. Such challenges are evidenced in the Pozzuoli case study, a densely inhabited municipality of the metropolitan city of Naples, placed into a volcanic caldera, that has been analysed in the light of the above challenges for an extended period of time of about fifty years. The in-depth assessment of the quality of urban development has been enabled by geospatial data management. Advanced geospatial information systems are not only instrumental in depicting the history of urban development in the period of consideration but also as an enabler to tackle the above-mentioned challenges. In fact, such systems permit a much more dynamic and updatable assessment of multirisk conditions and provide the basis for shared knowledge among the large number of stakeholders that are responsible for different sectoral and comprehensive urban and risk-related plans.

Keywords: multirisk management; resilience; volcanic hazards; resilient urban development; geospatial data processing; emergency and urban planning coherence

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1. Introduction

Urban planning as a non-structural measure to mitigate, reduce and manage natural hazards has been on the agenda for decades [1,2] and is now fully endorsed by international organisations in several documents. In recent years, there has been growing interest in conducting research on how to make cities more resilient to increasing levels of stress and crises [3–5]. The role of cities in both mitigating and adapting to climate change has been widely acknowledged, as the unprecedented pace of urbanisation, rapid expansion and over-densification are likely to lead to increased casualties and losses in the future [6]. Despite the many papers and projects that have been written and conducted so far, the reality on the ground shows that a much greater effort is needed to translate good practices and recommendations into urban policies, programmes and projects. Among the reasons for the difficulties encountered are the unprecedented growth of the urban population and the increasing complexity of cities, which display multilevel interconnections and interdependencies between people, assets and infrastructures [7,8]. Considering cities as highly complex systems with interrelationships across multiple spatial and temporal scales has implications for the extent to which they should be analysed in terms of the material and immaterial resources that are exchanged, created or wasted, in both normal conditions and under exceptional circumstances, such as those created by disasters.

Drawing on a selective literature review, which is also based on the extensive experience of the authors, the challenges to be addressed are framed around the following three main pillars:

- The need to comprehend the urban environment as inherently multirisk, requiring a far more dynamic assessment than has been the case until recently [9];
- The need to complement risk and resilience management rather than opting for one or the other to address the spatial and temporal scales at which cities operate today [10].

The need to revise the current highly fragmented landscape of sectoral plans generated by sectoral governance to tackle at least some of the challenges arising from highly interconnected and interlinked systems and subsystems.

The in-depth case study of Pozzuoli within the larger context of the Metropolitan City of Naples, Italy, allows us to highlight how the failure to deal with the above-mentioned challenges has led to recurring mistakes in managing a highly multihazard environment, resulting in interventions that have not built up any resilience in the area. The development of the town and the creation of several different urban and emergency plans have been analysed for more than fifty years, a period that has witnessed repeated crises due to bradyseism, a volcanic phenomenon. This analysis was based on planning documents, legislation and reports developed by public administrations, and it was significantly enhanced by the advanced use of geospatial data processing. In fact, the latter made it possible to show the subsequent urban development, also in response to decisions taken in times of crisis. Earth observation and geospatial data management are discussed as key enablers to successfully address the challenges identified above as crucial to making cities more resilient. Current geospatial information systems allow for a much more dynamic and up-to-date assessment of both hazards and exposure. They also facilitate the sharing of data on the relationship between risks and urbanisation processes among a wide range of stakeholders, providing a common knowledge and information base to support various comprehensive and sectoral plans in a much more coherent manner.

The paper is organised as shown in Figure 1.

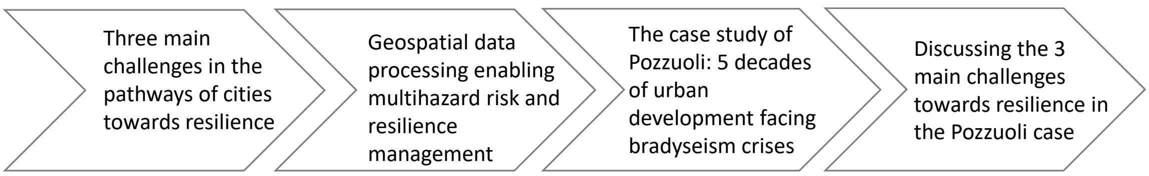

Figure 1. Logic development of the article across Sections 2–5.

In the second section, the three pillars identified above are discussed by drawing on the selected literature in order to frame those aspects that are considered crucial to improving cities' capacity to prevent, respond to and recover from extreme events caused by natural hazards and climate change. The third section discusses the potential role of advanced geospatial data management in addressing these challenges. The fourth section traces the urban development of Pozzuoli and the many comprehensive and sectoral plans and emergency interventions that have shaped its history over the last five decades. The fifth section discusses the main findings of the case study in light of the challenges described in Section 2. A short conclusion in section six provides a brief summary.

2. Tackling the Complexities of Urban Planning to Build Resilience

2.1. Unveiling the Dynamic and Multirisk Nature of the Contemporary Urban Environment

Although it has long been acknowledged that cities may be exposed to multiple hazards, and the concept of "na-tech", which refers to technological incidents triggered by natural hazards, dates back to 1994 [11], only recently has there been a real shift in thinking from single hazard to multihazard and multirisk assessments. It is now widely recognised that urban areas can easily become the site of compound, domino and cascading effects due to the presence of hazardous facilities and critical infrastructure.

As highlighted in the overview provided by Zschau [12], tools for appraising multihazard and multirisk conditions are still being developed, as it is not always easy to combine models that have been developed for single hazards without considering the possibility of a chain of interconnected or even independent events whose impacts may converge and overlap in the same territory at the same time.

In his overview, Zschau reports on the classification provided by Gill and Malamud [13,14], which identifies triggering, increased or decreased probability, and simultaneous occurrence as the main relationships. A fourth category may be added which is related to events, such as inherently multihazard volcanic eruptions, which involve a wide range of different phenomena that may occur over short or extended periods with varying durations [15,16]. Such phenomena include pyroclastic and lava flows, as well as tephra falls, all of which affect the built and natural environments and human and animal health in different ways [17]. Phenomena such as gas emissions, seismic precursors, bradyseisms and secondary hazards such as lahars may also have a severe impact. Uncertainties exist in both forecasting an eruption based on the occurrence of precursors and in estimating the total duration and severity of the phenomena associated with the volcanic activity once an eruption has occurred [18]. Only recently have engineers and urban planners become more aware of the potential impacts that diverse and differently acting phenomena may have on the built environment, as well as on urban and infrastructural systems. The understanding of such impacts still requires significant research [19].

2.2. Cross-Temporal Interplay between Risk and Resilience Management in Cities

The dynamic nature of the risks and changes that contemporary cities face and produce, along with the complexity arising from factors such as the strong path dependency of locational choices [20] has driven the creation of a substantial body of literature on urban resilience [21–24]. Some scholars [25] include what was known until recently as risk assessment and management in the scope of resilience management, while others view resilience as a new paradigm more suited to address the challenges of contemporary cities [21,23]. Resilience is a more appealing term to planners as it incorporates social, cultural and political components that are not always sufficiently addressed in risk assessment and management, which is often considered too technical and primarily focused on physical aspects, though not necessarily rightly so.

The interplay between risk and resilience management has received less attention than either resilience or risk management considered separately [26]. The approach proposed in this article supports complementarity rather than the separation of risk and resilience management. Traditionally, risk assessment and management tools have supported preventative measures aimed at reducing the extent and severity of damages caused by both natural and/or man-made hazards by addressing the three main components of the risk function (hazard, exposure and vulnerability).

In more general terms, resilience is understood as the ability to cope with significant levels of stress, including those caused by natural and man-made hazards, and find a new equilibrium following the disruption. Such understanding is underpinned by a dynamic interpretation of resilience that involves change and transformation. Resilience is seen as the ability to improve conditions following a disaster or crisis, as changes and transformations are more often achieved in the aftermath of an extreme event rather than beforehand [27].

Whilst some authors consider resilience to be more related to post-disaster recovery, others believe it is relevant across all phases of disasters and crises.

Frameworks specifically developed for cities often address the resilience of assets and infrastructures on the one hand, and social and economic resilience on the other, with few attempts to also account for the interconnections between the two [28]. According to the classic work of Bruneau et al. [29], infrastructural resilience is provided by resourcefulness, robustness, rapidity and redundancy. As for social and socio-ecological resilience, various authors have focussed on the characteristics, such as learning capacities [30–32], and participatory approaches [33] that make communities and decision-makers better able to cope, respond to and recover from disasters and crises. An important distinction is often made between resilience, which is intended to be a property of a system and the process that results in an enhanced ability to withstand and recover from severe stresses. Jabareen and Jabareen [34] suggest that the trajectory of cities is more important than their current state, considering that a system can be resilient to one type of hazard but not to others [35] and that the features contributing to a city's resilience may change over time. Such capacities can be gained or lost depending on the trajectory set for development and redevelopment [36]. The trajectory also depends on the ability to learn from failures, both by institutions and by communities. This can come from in-depth analyses of the causes of damage suffered in recent disasters or through the exchange of experiences and practices between cities and regions.

Therefore, pursuing an approach based on the complementarity between risk and resilience management may help overcome some of the gaps currently experienced in risk management (e.g., sector-specific approaches, technicality, limited capacity to include local communities in decision-making processes) while also fostering more integrated, collaborative and inclusive processes for risk reduction and urban development as recommended by UNDP [37].

2.3. Interconnections between Sectoral Planning Tools within the Framework of Cross-Sectoral Governance of Disaster Risk Reduction (DRR), Climate Change Adaptation (CCA) and Sustainability

Over the last few decades, a rather fragmented and complicated landscape of plans to address different topics has arisen. These aim to tackle emerging needs driven by social and economic development, as well as to respond to rapidly evolving threats. These plans address urban development, urban mobility, emergency management, adaptation to climate change, energy consumption, a shift towards renewable sources and the upgrading of residential and public buildings to name just a few. This landscape also responds to a logic of "adding on" instruments for addressing issues that are recognised as relevant, rather than considering synergies and interconnections that could instead create compound benefits and positive cascades. [38]. The need for at least some of those plans to be integrated has been discussed by various authors [39–41]. Improved coherence and better integration between plans, where relevant, are generally considered both horizontally and vertically [42,43]. Horizontally, plans developed by different municipal departments or organisations for different sectoral interventions should be aligned following a far more systemic approach. With regard to vertical coherence and coordination, plans developed for different sectors at different spatial scales, i.e., different levels of jurisdictions and/or plans of the same type at different levels, should be developed and updated, taking into account the potential impacts on plans and places up and down the scale.

A double-entry table (Figure 2) can be devised to depict the interrelations between different sectoral and comprehensive plans. Referring to the Italian planning legislative framework, the different types of either comprehensive or sectoral plans can be found in the rows, whilst in the columns the level at which such plans are prepared and put into effect. The continuous arrows highlight the binding relations between different types or levels of plans. The dotted arrows indicate the need for alignment that is recommendable albeit not mandatory. There are plans such as emergency or climate change adaptation that are developed at different levels, whereas some others, such as the strategic, are established by law only for metropolitan areas. Whilst in principle the vertical relationship also dictates what is binding for the lower level, sometimes there are legal obligations to consider plans at the same level but related to aspects that are prioritised over others.

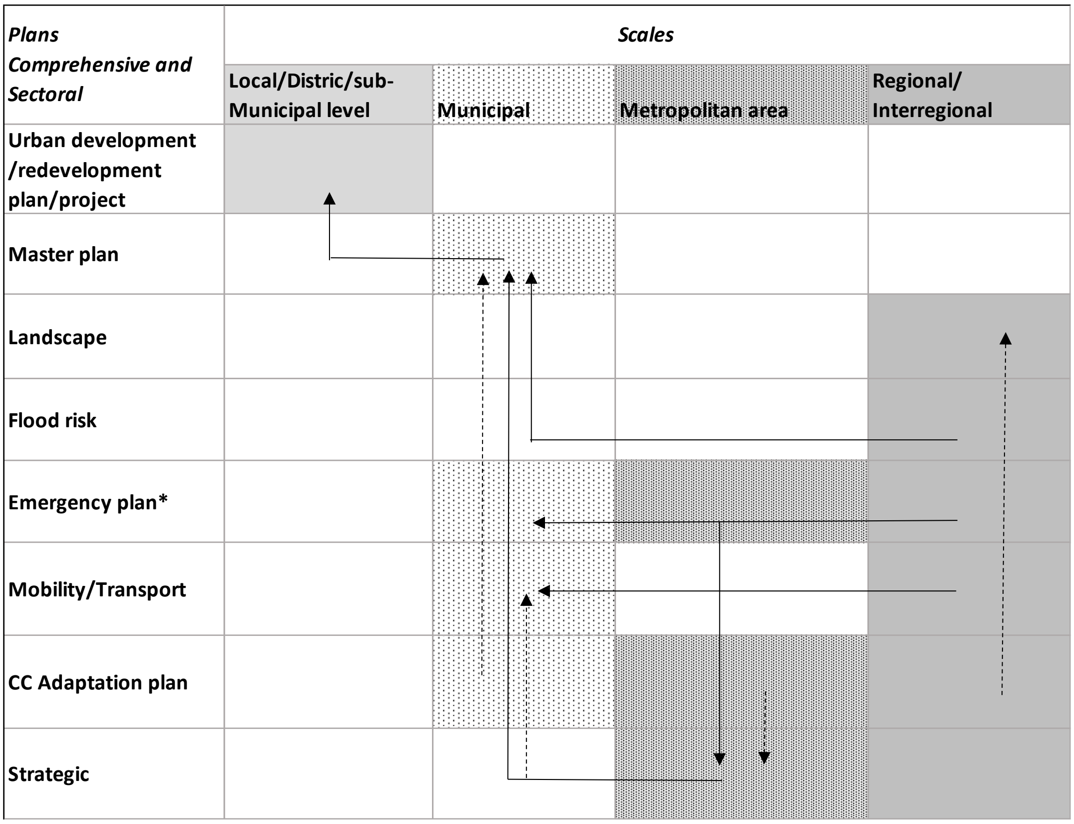

Figure 2. Comprehensive and sectoral planning. * it should also be noted that emergency plans can be also subdivided into general and sectoral (for waste, critical infrastructures, transportation management, etc.).

For example, the prescriptions of the flood risk plan established by the Flood Directive (2007/60/EC) as implemented in the Italian system are binding for the master, strategic and landscape plans. In Italy, the code of civil protection (Law 1/2018) establishes that spatial plans must be coherent with emergency plan provisions.

Non-binding, recommended relations are for example between the adaptation plans at different levels that should inform other sectoral and comprehensive plans. It must be noted though that the table shows an ideal situation; in reality, often some level plans are missing or not coherent with upper or lower-scale plans due for example to the different times when they were developed. The whole system is clearly very complex and managing inconsistencies in cross-scales and cross-sectors is a real challenge.

Strategic planning could be the right framework to consolidate a more integrated overview of actions and interventions needed in a city. It would enable the pursuit of multiple objectives while considering feedback loops and the implications of interventions across different areas, in line with a systemic perspective [44]. However, a cross-sectoral governance model is needed to translate this strategic thinking into individual actions for implementation. Without this, the strategic plan risks becoming an empty shell that obscures rather than resolves several potential contradictions among sectoral policies.

The Joint Research Centre (JRC) handbook on sustainable urban planning [45] explicitly states that cross-sectoral governance is essential for addressing the multiple social, economic, spatial and environmental dimensions of cities in a coordinated fashion. Cross-sectoral integration "produces added value from the joint consideration of multiple policies, building on governance capacity, funding and implementation instruments" [45] (pp. 127–128).

Ideally, plans that are well connected—either due to the urban area they focus on or the nature of the interrelated problems they address—should build on each other and find mutually reinforcing elements, so that multiple objectives can be achieved through a coherent set of interventions and decisions. Multiple benefits of a given intervention can be envisaged between land use, urban plans and emergency plans [46,47].

An important precondition for successful cross-sectoral governance is to build on shared knowledge [48]. Multiple stakeholders have the required knowledge and competencies to govern cities, including networked service providers, developers, grassroots organisations and planners. The knowledge they generate informs the various plans that guide the interventions and actions to be enacted in different sectors. The knowledge and information that underpin sectoral plans must be coherent to achieve synergic results. According to Cosens et al. [49], bridging knowledge on the functioning and characteristics of complex systems through appropriate governance structures and processes is the key challenge to achieving more sustainable and resilient settlements. Although the authors acknowledge the significant challenges posed by cross-sectoral governance, which in many ways questions current governmental arrangements, there is a growing recognition of the need to save time in resolving complex controversies surrounding urban development and redevelopment projects. This approach better addresses the multiple facets arising from the interaction of social, environmental and economic aspects of such interventions. These facets would ultimately benefit from a more systemic management approach that requires the different aspects across a number of sectors to be dealt with collectively instead of in the current fragmented or sequential manner, which delays decision-making processes.

3. Earth Observation and Geospatial Data Processing-Enabled Knowledge and Information for Cross-Sectoral Governance and Planning

The full potential of Earth observation and geospatial data processing in a GIS environment as a bridge and basis for shared knowledge needed in both urban and spatial planning and in disaster risk reduction has yet to be fully realised. GIS are regarded as tools that bring huge benefits in terms of the quantity and quality of constantly updatable geospatial data that can be processed, as well as the operations they enable to produce results that can be represented on maps.

With a potentially vast database associated with each land parcel, a number of queries and operations can be performed, from the simplest tasks, such as overlaying data layers, to more complex ones exploiting advanced geospatial analysis algorithms and artificial intelligence. A relevant application of geospatial data management relates to risk and crisis management [50]. Different aspects of each component of the risk function, namely hazard, exposure and vulnerability, can be assessed by using geospatial data processing and represented on maps to support multiple decision-makers. More recently, efforts to support resilience assessments through geospatial analysis have also been made. In this regard, for example, Arvidsson et al. [51], based on their practical experience and following an extensive literature review, concluded that "presenting critical infrastructure analysis results using geovisualisation methods to improve decision-making in a cross-sectoral context is deemed a worthy topic for future interdisciplinary research".

Using the Atlas of Urban Expansion Methodology to Assess Dynamic Changes in Exposure and Systemic Vulnerability in Cities

Regarding multirisk and multihazard assessments conducted through the use of geospatial data processing, a number of applications have been attempted by scholars [52]. Kappes et al. [53] have represented the "total" exposure of the built environment and infrastructures to multiple hazards, taking into account their interactions and a cautionary "worst-case scenario". GIS functionalities have been also used to represent complex interrelationships between hazards that occur over time and space [54]. Information systems and modern technologies enable more accurate monitoring of natural and man-made phenomena than in the past, providing services based on Earth observation, such as the European Copernicus programme. Complemented by supporting measures such as ground validation, hazard maps and analyses, planning decisions can be updated frequently, providing a more reliable source of information compared to the often outdated surveys and data that may be years or even decades old. The in-depth analysis of recent events has shown that hazard maps often fall short of identifying areas where severe damage occurred. Examples can be found in [55,56]. One significant obstacle to the integration of the currently available information is related to procedural issues. In many countries, hazard maps are certified by an authority and the certification process takes time. Once achieved, these hazard maps constitute the legal basis for planning. The temporal perspective of hazard monitoring and urban planning do not align as the former is updated far more frequently than the decision-making and implementation processes in planning. Nevertheless, it would be far better to plan on the basis of the most accurate picture of the current situation rather than relying on obsolete observations that are no longer valid when the plan is formulated or approved.

In terms of exposure, satellite imagery provides a continuously updated view of land cover changes and the development and configuration of urban settlements. Recent results from the Atlas of Human Settlement by the JRC of the European Commission [57] show that the footprint of the built environment can be identified with a high level of precision. This would allow the detection of new urbanised areas with a frequency that was not viable using traditional mapping methods based on aerial pictures, primarily due to their prohibitive cost. From satellite images, illegal neighbourhoods, which traditional maps do not show very often, can be also detected rather easily.

The intertemporal comparison of satellite images allows the assessment of changes in exposure and vulnerability in cities over time. To do this, we followed the methodology of the Atlas of Urban Expansion project [58,59], developed in the project conducted by the Marron Institute of Urban Management at New York University, USA. The methodology proposes a number of quantitative indexes measuring the modality of urban expansion. Indexes that calculate population density in the consolidated urban extent and expansion areas over different timeframes can be used to evaluate how population exposure has changed with respect to the most hazardous zones. Other indexes can be used as proxies of systemic vulnerability. The latter concerns accessibility to services which are potentially crucial during emergencies, such as the transport system, proximity to hospitals, fire service, etc. Some indexes have been adapted and applied to the case study of Pozzuoli within the metropolitan area of Naples.

4. A Case Study Example: Pozzuoli in the Phlegraean Fields

The municipality of Pozzuoli, with a current population of approximately 76,000, is situated in the Phlegraean Fields, one of the most critical areas within the Metropolitan City of Naples due to its exposure to multiple hazard conditions combined with a high population density and a rich historical, archaeological and natural heritage.

With a diameter of about 10 km, the Phlegraean Fields is the largest volcanic caldera in Europe (see Figure 3) and it partially emerged and partially submerged. The eruptive history of the area reveals a series of mostly explosive eruptions that occurred from vents scattered inside the caldera [60]. Compared to the volcanic areas characterised by a central volcanic system, such as Vesuvius, the Phlegraean Fields can have eruptive vents open in multiple locations across a much larger area. Moreover, the Phlegraean Fields, namely the area of Pozzuoli, are historically characterised by the phenomenon of bradyseism, a process in which the ground slowly rises and lowers.

Figure 3. An aerial view of The Phlegraean Fields—Source Google Earth (2024).

The case study analysis is structured across the four lines depicted in Figure 4.

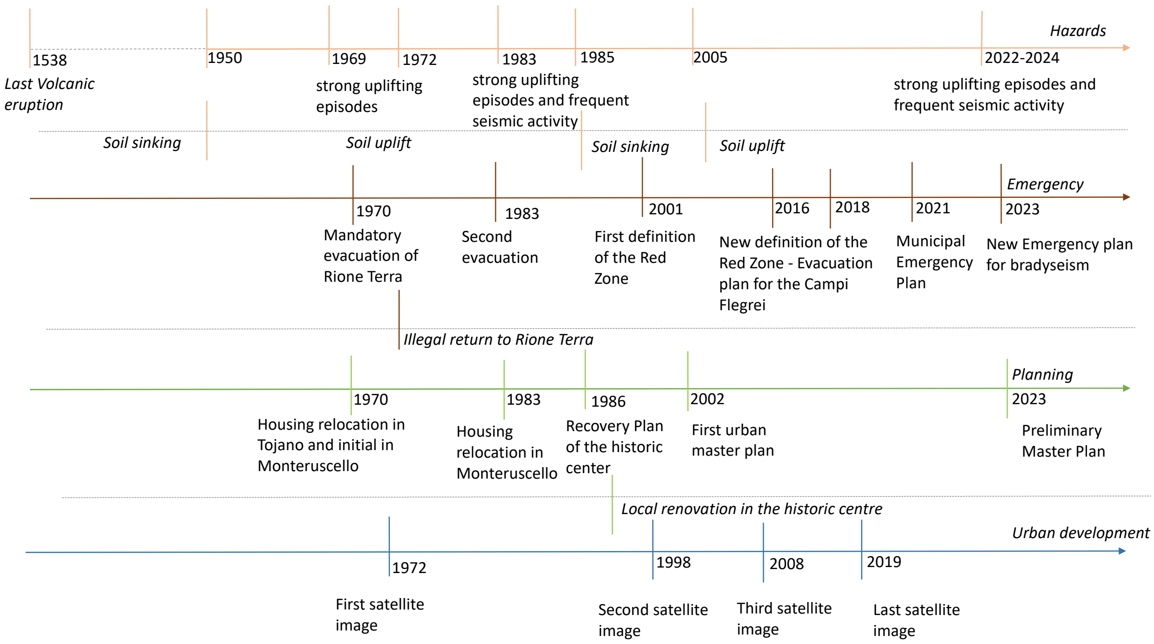

Figure 4. A cross-sectoral perspective of the Pozzuoli case study.

First, the multihazard environment and peak event occurrences will be described. Emergency planning will then be discussed, showing the complex interconnections between different authorities. Third, it will be shown how urban land use plans have often been adopted to respond to emergencies rather than provide a long-term vision for the area.

Finally, it will be demonstrated how the urban area has actually developed, following the methodology established by the Atlas of Urban Expansion.

4.1. The Multihazard Environment of the Phlegraean Fields

There are historic and prehistoric signs of explosive volcanic eruptions in the Phlegraean Fields, with the most recent event dating back to 1538 when the Monte Nuovo (literally the "new mountain") appeared. The area is also affected by slow vertical movements (in Greek, bradyseism), which periodically lead to episodes of unrest, particularly in the town of Pozzuoli. Bradyseism, reported since Roman times, involves the ground level sinking during certain periods followed by phases of uplift, normally at a rate of one centimetre per year: a relatively slow movement on a human timescale, but decidedly fast compared to geological timescales [61].

One of the most complete studies on the bradyseism phenomenon in the Phlegraen Fields was carried out by Antonio Parascandola (1947) [62]. He reconstructed the soil movements at the Pozzuoli Serapeum (an ancient temple located in Pozzuoli) over the last 2000 years, highlighting in detail the deformations that preceded the Monte Nuovo eruption. A long phase of ground-level sinking followed the 1538 eruption. Strong uplifting phenomena, accompanied by seismic crises, reoccurred between 1969 and 1972, and later between 1982 and 1984. These phenomena marked the end of "the slow sinking phase observed since the eruption of Monte Nuovo in 1538, [62,63] and the beginning of a prolonged phase of unrest" [64].

In recent years, following a period of slow subsidence recorded after the mid-1980s, a slow uplift began in the first decade of the 2000s [65], with a significant increase taking place since 2023. Based on the reports provided by the INGV-Osservatorio Vesuviano (https://www.ov.ingv.it/index.php/flegrei-stato-attuale (accessed on 4 October 2024)) the ground deformation monitoring networks confirm a radial geometry of the uplift centred in the Pozzuoli area, with a maximum average velocity of approximately 15 ± 3 mm/month since January 2023. The uplift recorded at the RITE GNSS station was approximately 117 cm since November 2005, with around 84 cm occurring since January 2016. Between 21 and 23 September 2023, a ground lifting of approximately 1 cm was recorded at the RITE GNSS station. From mid-April to 20 May 2024, the average speed value of uplift in the area of maximum deformation was approximately 20 ± 3 mm/month at the Rione Terra GNSS station (RITE).

Moreover, compared to the 516 events recorded in the period 1985–2011, May 2024 alone saw 1525 earthquakes recorded in the Phlegraen Fields, the largest number recorded in the last 40 years. The strongest of these had a magnitude of 4.4, making it the most energetic event recorded in the past four decades. Most of the recorded earthquakes and all the events with a magnitude higher than 3 took place in Pozzuoli. Recent events have damaged various buildings and prompted authorities to evacuate more than 700 inhabitants.

4.2. Emergency Planning on a National, Regional and Municipal Scale

The long sinking phase that followed the 1538 eruption reduced the awareness of potential volcanic events (bradyseism, eruption, etc.), not only among local communities but also among the scientific community and institutions, which, in the early 1970s, were totally unprepared to handle an emergency [66].

The strong uplift registered between 1969 and 1972 led to the "forced evacuation" of the historical centre of Pozzuoli, the principal municipality of the Phlegraean Fields. With the support of the army, in March 1970, about 3000 people were evacuated in just two days from Rione Terra, the historic nucleus of Pozzuoli. At the time, no risk monitoring networks were in place and therefore the decision to evacuate was essentially based on the visible rising of the ground reported by local fishermen. The evacuated area, a tufa promontory situated about 33 metres above sea level, was characterised by a high population density, building decay, low income per capita and widespread illiteracy, with fishing being the principal economic activity [67].

In the years that followed, the ground uplift slowed, but it worsened again between 1983 and 1984. Despite the events experienced just a few years earlier, both local communities and institutions proved to be largely unprepared to manage the latest emergency. The second bradyseism crisis was accompanied by intense seismic activity. Following particularly severe seismic shocks, a new evacuation order for about 20,000 Pozzuoli inhabitants was issued in October 1983. During the 1990s, a new phase of subsidence further delayed the development of a reliable emergency plan for the Phlegraean Fields.

In 2001, the key points of a National Emergency Plan for the Phlegraean Fields areas most at risk of a volcanic eruption were established, with the issuing of the first map of the so-called red zone (Figure 4). The scenarios that were considered referred to various phenomena associated with a volcanic eruption, such as lava and pyroclastic flows, gas emissions and tephra fall, but overlooked the bradyseism phenomenon. The Phlegraean Fields red zone included the whole territories of Bacoli and Monte di Procida, which are districts of the City of Naples and only part of the municipality of Pozzuoli. The large neighbourhood of Monte Rusciello, where inhabitants of Pozzuoli had been relocated following the bradyseism crises in the 1980s, was excluded from the red zone.

The 2001 plan was the beginning of a long process, aimed at improving the area's ability to respond to what are considered likely volcanic risk scenarios. The process ended in 2016 with the approval of the "Provisions for updating the emergency planning for the volcanic risk of the Phlegraean Fields". This document divided the Phlegraean Fields into two zones—red and yellow—according to the expected eruptive scenarios. It defined the alert levels and highlighted the need for an evacuation plan for all the municipalities within the red zone, where preventive evacuation was identified as the only safety measure for the population. It is worth noting that the red zone defined in 2016 was significantly bigger than the one established in 2001. The entire municipality of Pozzuoli, including both relocation neighbourhoods, is now part of the new red zone (see Figure 5).

In 2018, the Campania Region approved the evacuation plan designed to ensure the assisted or autonomous evacuation of more than 500,000 inhabitants living in the red zone within 72 h in the event of an emergency. With regard to assisted evacuation, the regional evacuation plan identifies waiting areas throughout the entire red zone with some assembly points located outside it. From these assembly points, the evacuated population is to be transferred to the reception points of the twinned Italian regions and then to designated temporary accommodations. How to reach the waiting areas identified by the regional authority has been established by each municipality.

The Municipal Emergency Plan of Pozzuoli first issued in 2015 had to be updated in 2021 to comply with the regional guidelines and the definition of the new red zone. The municipal territory was divided into sectors from which the resident population should evacuate at different times. In the updated municipal plan, a denser network of waiting points was established along with designated routes from various neighbourhoods and available means to reach the meeting areas outside the red zone. Despite addressing multiple hazards associated with a volcanic eruption, the Municipal Plan of Pozzuoli lacks any consideration of the potential impacts of a bradyseism crisis or the procedures for relocating the most affected inhabitants in such an event. It was only due to the pressure caused by the last ongoing crisis that the National Decree on "Urgent measures to prevent seismic risk connected to the bradyseism phenomenon in the Campi Flegrei area" was issued In October 2023. The Decree requires the creation of an emergency plan to manage the evacuation of the population from the most affected zones of Pozzuoli, where the bradyseism phenomena are most acutely felt compared to the rest of the metropolitan area.

(**a**)

(**b**)

Figure 5. The borders of the red zone in 2001 (**a**) and in 2016 (**b**). Source: Department of Civil Protection.

Following the Decree, some actions were undertaken by the National and Regional Civil Protection with the support of a network of scientific institutions. The area was divided into two subareas based on the location of the epicentres of seismic events with a magnitude of 2 or greater that have occurred since 1983. The second subarea was established based on ground uplifts exceeding 30 cm recorded since 2015 (see Figure 6).

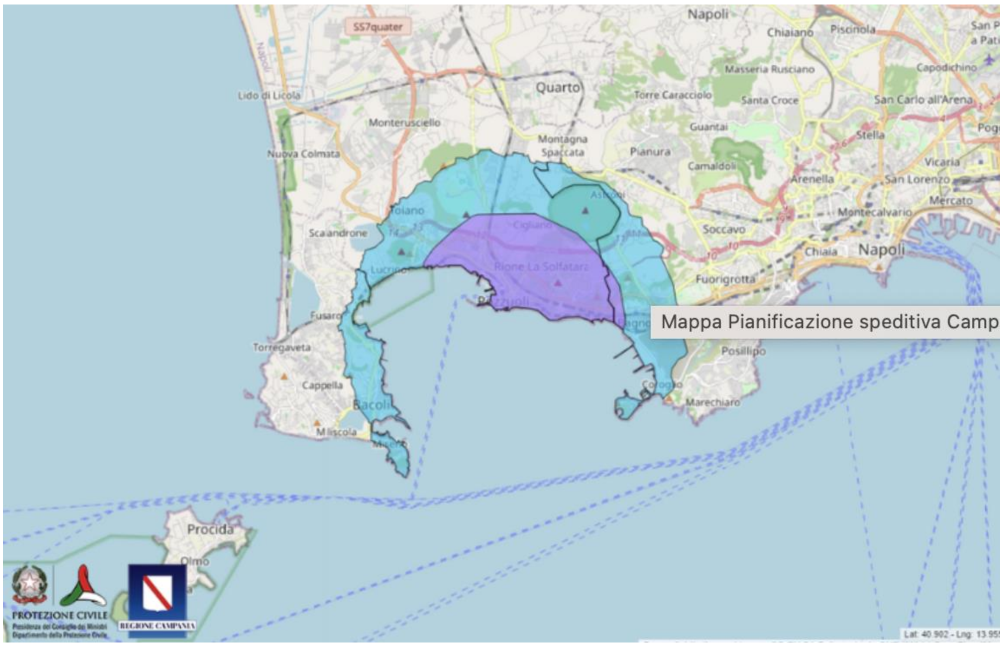

Figure 6. The large (blue) and small (violet) intervention areas.

An extraordinary plan was mandated for the analysis of building vulnerability in areas affected by bradyseism. A communication plan for the public was also developed. However, as of June 2024, the vulnerability analyses of the area were still in progress, and the most recent evacuation drill carried out in the municipality of Pozzuoli witnessed very limited participation from the local population.

4.3. Urban Planning: A Long History of Sectoral Plans

The planning decisions in the municipality of Pozzuoli have been strongly influenced by bradyseism crises and largely relied on sectoral plans in the absence of a general master plan capable of providing an overarching and cohesive urban planning framework. In the 1970s, following the "forced evacuation" of the Rione Terra quarter, the new Tojano neighbourhood was built on the outskirts of Pozzuoli. This can be considered the first "emergency town" built in the Pozzuoli area, as reported in a recent Strategic Orientation Document approved by the municipality of Pozzuoli in 2020. The new neighbourhood layout was outlined in the Public Housing Plan approved by the Ministry of Public Works in 1969 [67]. This Plan envisaged a second public housing neighbourhood, Monterusciello, the construction of which began in the 1970s (Figure 5).

During the 1970s, abandoned and unsafe buildings in the Rione Terra were demolished, and systematic looting of significant historical and archaeological heritage occurred. Meanwhile, a progressive, albeit illegal, repopulation also took place. In the aftermath of the 1980 earthquake, approximately 122 families lived illegally in the Rione Terra [68].

In 1983, the latest and larger evacuation led to the creation of the second "emergency city", Monterusciello, a lot larger than the first neighbourhood of Rione Toiano. The structure of the newly constructed neighbourhoods was completely different from that of the original town, leading to significant changes not only in the local economy, which was primarily based on fishing but also in the existing social and relational fabric [69].

Even though the bradyseism crises recorded between the 1970s and 1980s did not culminate in an eruption, they triggered a severe response [70], leading to the evacuation and rehousing of about 40,000 inhabitants of Pozzuoli [64] and incurring significant territorial, economic and social costs. The adopted development model, based on large new settlements situated far from the city centre and from each other, necessitated the redesigning of the transportation network. Law 887/84 established the creation of an integrated transport system that could also serve as a network of escape routes for the whole Phlegraean area.

Since no volcanic eruption occurred, it was decided to restore the historical city of Pozzuoli, including the Rione Terra nucleus, after several years. This task was assigned to a sectoral plan approved in 1986. Since then, restoration works were subsequently restarted and stopped a number of times. After about twenty years, Rione Terra was finally opened to visitors. It is a very attractive site due to its archaeological heritage and the quality of its landscape, which the municipality strived to preserve as a public asset.

The process of developing a new Master Plan for the city began in the mid-1970s and took more than twenty years to complete. When it was finally approved in 2002, the developmental model of the municipal territory had been already established and the recovery of the historical city was completed. The Plan also envisaged further residential development, albeit quite limited, in the Monterusciello area, which was excluded from the red zone perimeter outlined in 2001. The Plan also allowed volumetric increases of up to 20% in most of the agricultural areas to promote agritourism activities.

As for the Rione Terra, the 2002 Master Plan designated the area for cultural activities, small-scale artisanal crafts and commercial and tourist businesses to reflect its historical, architectural and environmental relevance. In 2021, the Municipal Administration issued a resolution entrusting the development of a large part of Rione Terra to a private company, with the aim of transforming it into a residential and commercial district. The company was also responsible for the subsequent maintenance of the properties. The choice to privatise such an important public asset sparked a wave of criticism. In August 2022, the newly elected municipal government revoked the tender, calling for a different governance model based on the declaration of Rione Terra as a common good [70]. The new governance model, still under discussion [71], is based on two key pillars: recognising Rione Terra as the cultural heritage of the local community and involving the entire community in the management of this important asset. It is an asset that undoubtedly represents a potentially substantial source of income, but which cannot be driven entirely by market rules.

Following the "Guidelines of the Metropolitan City of Naples for urban, territorial and emergency planning for the municipal administrations falling in the red zone at high volcanic risk" issued in 2017, the municipality of Pozzuoli has been developing a new Master Plan since 2021. This forbids any further increase in residential volumes while promoting the conversion of residential uses to non-residential ones. The recent approval of the new Campania Regional Law on urban planning issued in April 2024 may once again delay the final approval and entry into force of the new municipal Master Plan.

5. Geospatial Data Management to Assess the Extent and Quality of the Pozzuoli Urban Development

In order to understand how the town of Pozzuoli has actually developed over time on the ground, the methodology of the Atlas of Urban Expansion was applied. In line with this, the entire metropolitan area of Naples was analysed. This work was carried out in the context of a master thesis discussed in 2020 at the Politecnico di Milano [72]. Subsequently, the same method was applied to focus on the municipality of Pozzuoli. Since Naples was not among the 200 cities included in the Atlas of Urban Expansion project, the methodology had to be applied from scratch to obtain a relevant comparative assessment of the metropolitan area's expansion. This area is currently home to about 3 million people, with a population density of about 2500 inhabitants per square kilometre. As a second step, indexes were recalculated and the authors produced maps by zooming in on the area of Pozzuoli.

5.1. The Methodology Applied to the Metropolitan Area of Naples

No matter how clearly and transparently it is described, the application of a complex methodology always presents challenges. These challenges were addressed in order to adapt the Atlas of Urban Expansion [58,59] methodology to this case study. The Atlas explores the change in land cover, with respect to specifically defined classifications and indexes. The classifications are obtained by processing selected satellite imagery of the area of interest over different timeframes. Available land cover products, such as Corine Land cover, could not be used for two main reasons: firstly, because it does not cover the period before 1990, and secondly, to ensure compliance with the Atlas classifications and long-term consistency in the classification process. Multitemporal Landsat and Sentinel-2 cloud-free (with maximum 1% cloud coverage) satellite images dating from 1972 to 2019 ([73], see Table 1) were downloaded for the Naples metropolitan area. The images were then classified to obtain the first-level classifications of the Atlas: Urban, Open Space and Water in accordance with their definition. For example, a built-up pixel is categorised as Urban if it is surrounded by more than 50% built-up pixels. For satellite image processing, ENVI® software was used. Various supervised and unsupervised algorithms were tested for the first-level classification, including Iso Cluster, K-means and ISODATA for unsupervised classification, and Maximum Likelihood for supervised classification. Special care was taken in selecting the training set for the supervised classification: areas were chosen by photointerpretation, and their histograms were then analysed to verify their distribution and separability. Following this, 300 points were randomly selected and labelled through photointerpretation to be used as test points for evaluating the performance of the classification algorithms. The Gaussian Maximum Likelihood classifier was selected to process all images as it provided the best results, with an overall accuracy of 96% and a Kappa index of 92%. In comparison, K-means yielded an overall accuracy of 94% and a Kappa index of 89%. The output of the classification was carefully inspected for potential errors. In particular, some major errors were manually corrected, such as the incorrect classification of greenhouses as built-up areas; many of these greenhouses were actually seasonal agricultural structures covered with plastic, used to protect plants. An intersection operation was performed between the built-up classes over time, based on the assumption that built-up areas expand but do not disappear. This was completed to improve the comparability of the multitemporal classifications. Both photointerpretation and records showed that the demolition of illegally constructed buildings over time was negligible (accounting for 3% of illegal structures, [74]) with respect to the scale of this analysis.

Table 1. Satellite imagery used to explore the urban expansion of Naples.

Satellite Images	Date	Sensor	Grid Cell Size [m]	Number of Spectral Bands
S2B-20190811	11 August 2019	Sentinel 2B	10	7
LT05-20080731	31 July 2008	Landsat 5 TM	30	6
LT05-19980602	2 June 1998	Landsat 5 TM	30	6
LTO5-19840627	27 June 1984	Landsat 5 TM	30	6
LM01-19720809	9 August 1972	Landsat 1 MSS	60	4

After the first-level classification, subclasses were automatically selected by exploring the 1 km neighbourhood (considered a walking distance in the Atlas of Urban Expansion) of each pixel classified as Built-up or Open Space in ArcGIS. According to the Atlas, by grouping urban and suburban built-up areas, it is possible to define the urban cluster; then, clusters which are close to each other can be merged to obtain the urban extent. The urban expansion corresponds to the increased urban extent between two subsequent timeframes. Figure 7 illustrates the urban expansion of the Metropolitan City of Naples over time [73], showing the changes for each interval between available satellite images during the period of study (1972–2019).

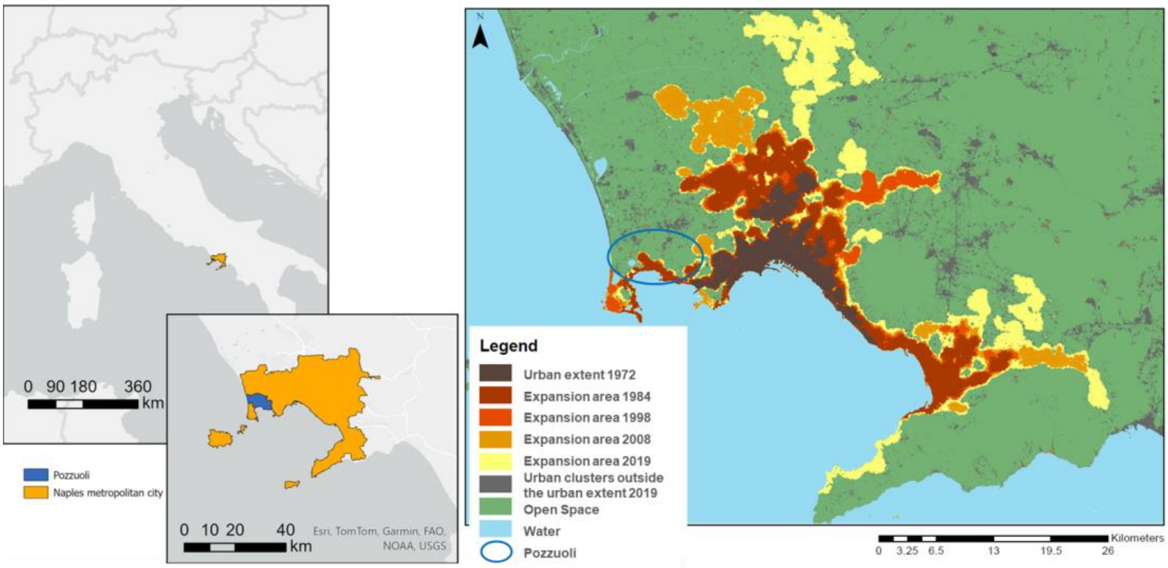

Figure 7. The urban extent of Naples in 2019, and its expansion areas from 1972. The overview maps also show the location of Pozzuoli, which is the paper's areas of study.

Subsequently, the land cover classification was performed according to the subclasses defined by the Atlas. The Built-up class is further divided into Urban (when a Built-up pixel is surrounded by more than 50% Built-up pixels), Suburban (when surrounded by 25–50% Built-up pixels) and Rural (when surrounded by fewer than 25% Built-up pixels). Open Space is further divided into Urbanised (including Captured, which are areas smaller than 200 ha surrounded by Built-up, and Fringe, which is the nearest open space that surrounds the built-up area) and Rural.

An assessment of cities' Fringes is proposed by the Atlas to characterise the degree of compactness of the new development with respect to the existing urban extent. This is completed by drawing a circle that includes cities' Fringes. The closer the shape of the city is to a circle, the more compact the urban development. In this regard, the following three classifications are considered: Infill, where new development occurs within the boundaries of the existing Urban Extent; Extension, where new development is contiguous to the previous Urban Extent; and Leapfrog, which represents development in areas that are distant from the existing Urban Extent. In the case of the latter, the shape of the new Urban Extent deviates the most from a circle.

Figure 8 shows that the Urban built-up classification experienced the largest expansion in the metropolitan area of Naples, with a fourfold increase in fifty years.

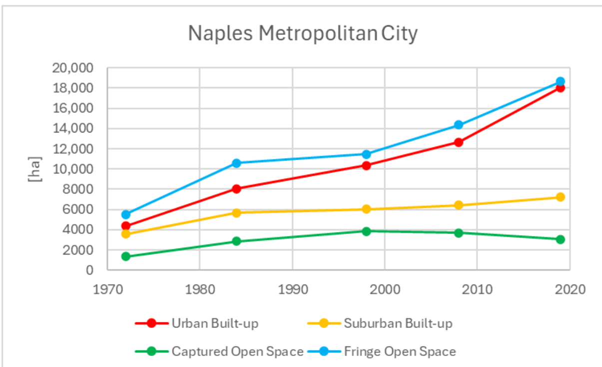

Figure 8. Urban expansion of Naples over the last fifty years through the Atlas indicators.

Figure 9 compares the growth of the built-up area (obtained by combining the three built-up classifications defined by the Atlas) with the changes in population according to census data [75] from 1971 to 2021.

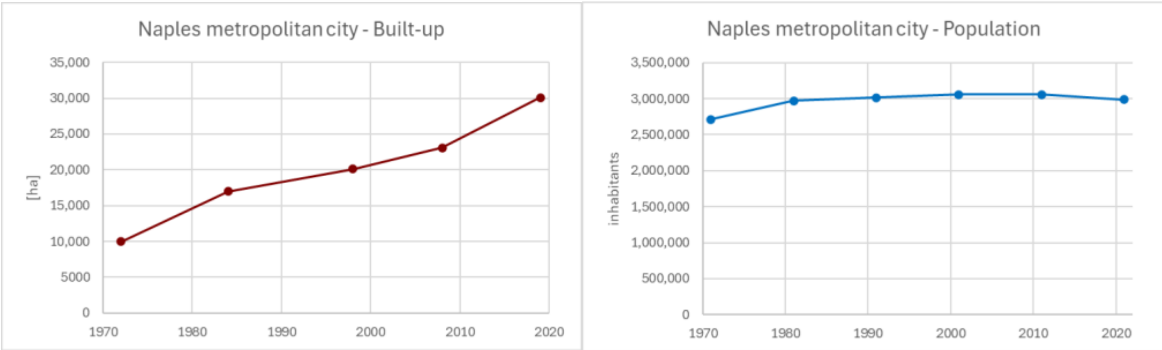

Figure 9. Behaviour of built-up areas (1972–2019) and population (1990–2020) of the Metropolitan City of Naples.

In line with the trend that was observed for most of the 200 cities analysed in the Atlas, the built-up area grows more than the population. Between 1990 and 2020, the Built-up area increased by 50% while the population barely changed, and between 2010 and 2020, the population even decreased slightly, coinciding with the faster growth of the Built-up area.

5.2. Zooming in on the Municipality of Pozzuoli

Figure 10 shows the urban expansion of Pozzuoli, measured at each timeframe throughout the analysed period of satellite images.

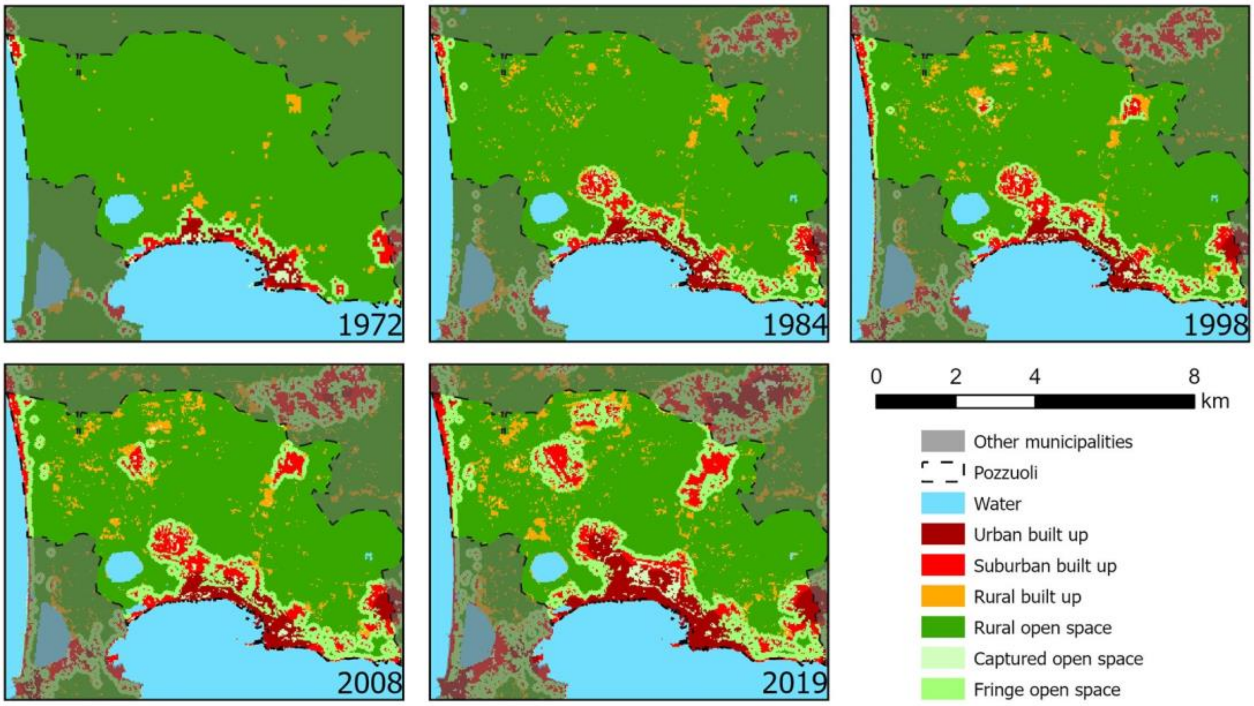

Figure 10. The urban expansion of Pozzuoli at each timeframe throughout the analysed period of satellite images.

The period between 1972 and 1984 marks the development of the Rione Toiano neighbourhood, which can be clearly distinguished from the pre-existing urban extent as a circular expansion in the north-western part of the city. In the subsequent period between

1984 and 1998, the new development of Monterusciello can be distinguished in the north-western part of what appears to be a large open-space area, rather far from the pre-existing built-up areas. Monterusciello can be seen more clearly in the 2008 image.

In order to characterise the type of urban expansion, two concentric hemicircles centred in the historic nucleus of Pozzuoli have been drawn, including, respectively, the first neighbourhood built in the 1970s, Rione Toiano, and the second one, Monteruscello, built in the 1980s, as can be seen in Figure 11.

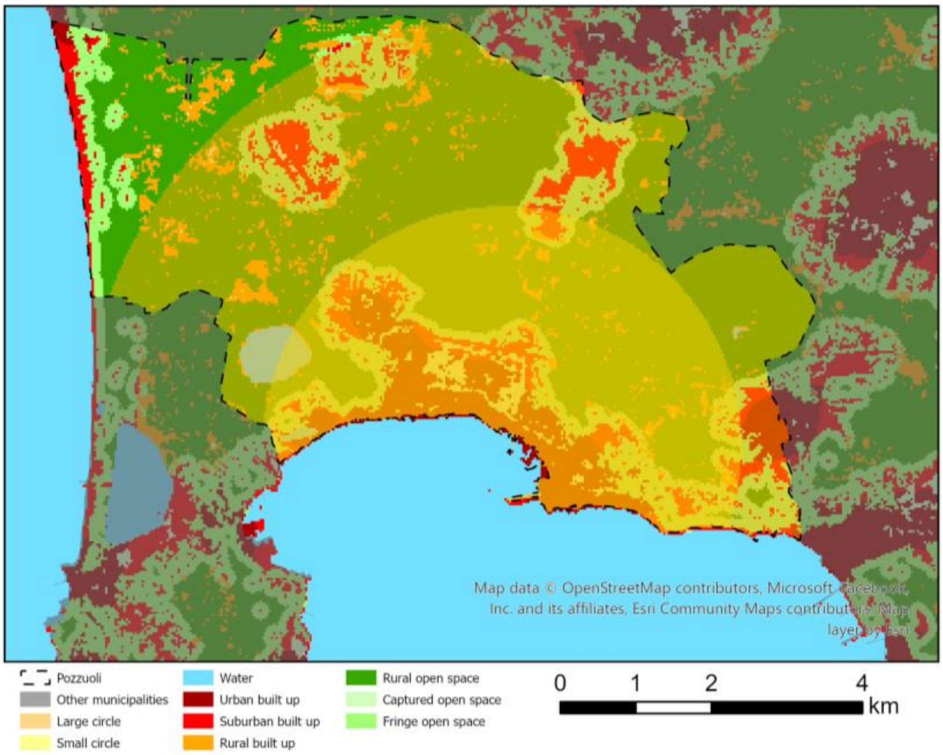

Figure 11. Hemicircles, including the subsequent urban expansion of Pozzuoli.

Qualitatively, it is clear that the compactness that characterises the historic town of Pozzuoli was already lost with the building of the first new neighbourhood, Rione Toiano, which can be considered an Urban expansion according to the Atlas categorisation. The newer Monteruscello area clearly corresponds to a Leapfrog type of expansion as it is totally disconnected from the previous Urban extent.

Quantitatively, the pixels corresponding to each subclass as defined by the Atlas have been computed for the two hemicircles. Results are shown in the graphs in Figure 12. A significant increase in suburban, urban built-up and fringe open space can be clearly observed in the outer hemicircle. Surprisingly, the greater increase occurred more recently between the years 2000 and 2019. The subclass that grew more is the Fringe open space.

Finally, the latter urban expansion was compared to the population trends in Pozzuoli, as shown in Figure 13.

Mirroring the trend of the entire metropolitan area of Naples, the built-up area in Pozzuoli has grown more quickly than its population. In fact, the built-up area almost doubled between 1990 and 2020 while the population remained relatively stable, even experiencing a slight decline between 2010 and 2020. In terms of risk assessment, it can be said that the population exposure in the area has, therefore, decreased in absolute terms over time, as has the population density. However, from the perspective of systemic vulnerability, leapfrog expansion makes it more difficult for the population living on the outer fringes to access essential services and/or to evacuate and also hinders the ability of emergency services to reach potential victims or people in need of assistance.

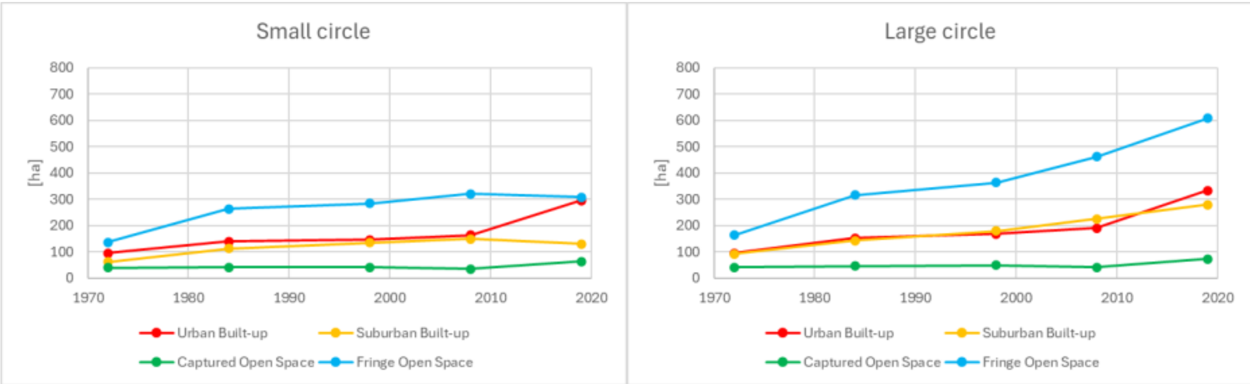

Figure 12. Expansion of the built-up area with respect to the two hemicircles outlined in Figure 11.

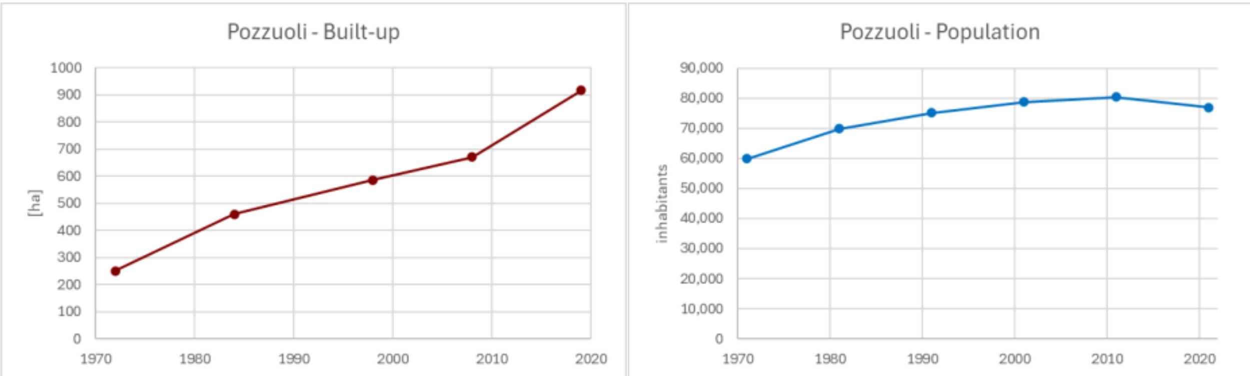

Figure 13. Behaviour of built-up area (1972–2019) and population (1990–2020) for the Pozzuoli Municipality.

Therefore, in order to better understand how this type of expansion has affected the current systemic vulnerability of the area, an analysis of the evolution of the road network in the overall period of interest was conducted. Figures 14 and 15 show the main roads at the end of the 1960s and the situation today, respectively. The main roads have been expanded and improved; the bypass motorway along the coast has been extended to the north to serve the Monterusciello area (the yellow line in Figure 15).

Despite such improvements, the number of available evacuation escape routes remains limited. According to the estimates made by Charlton et al. [75] for three test locations—Pozzuoli, Bacoli (Baia) and the western part of Naples (Agnano)—the total number of people exposed to the unrest scenario exceeds 61,000. However, the number of people in the evacuation zone is three times greater, surpassing 211,000. Considering the potential major damage that could affect both the road and electricity networks, they questioned the actual feasibility of evacuating such a large number of people by road from the three locations due to "the dense road network and rapid urbanisation" of the last decades.

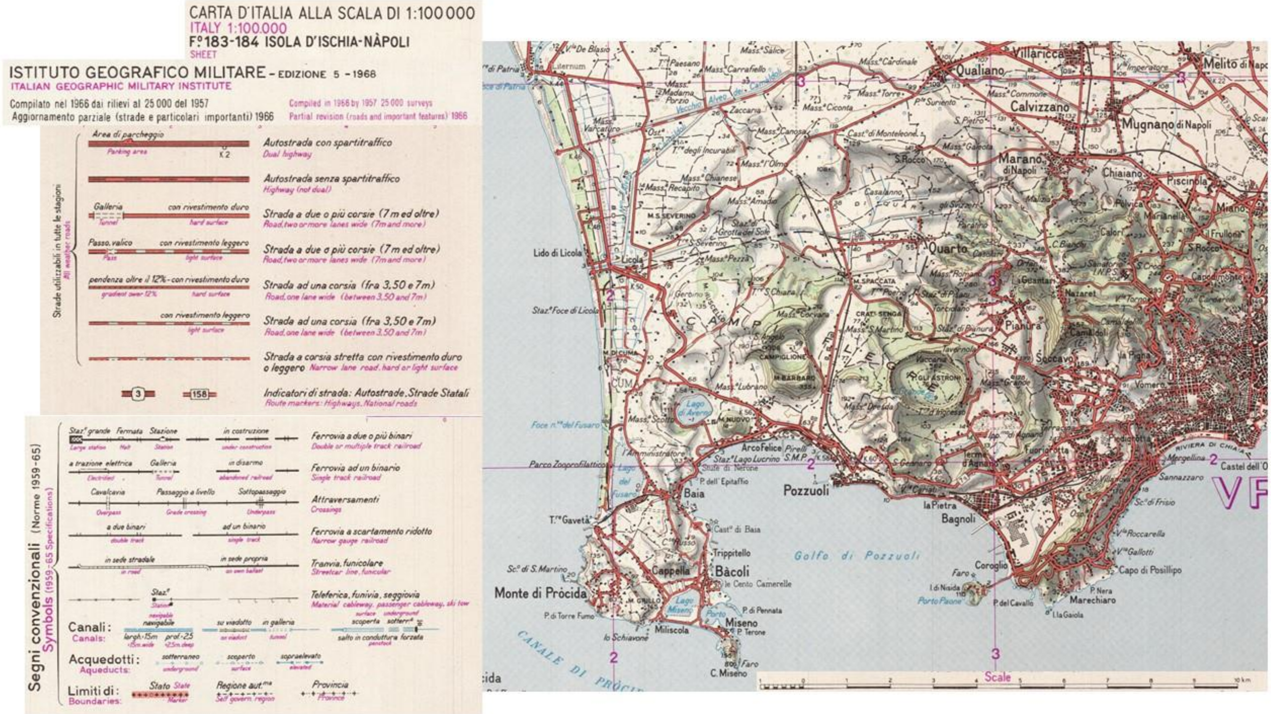

Figure 14. Map of Pozzuoli in 1968, produced by the Istituto Geografico Militare (Italian Military Geographic Institute).

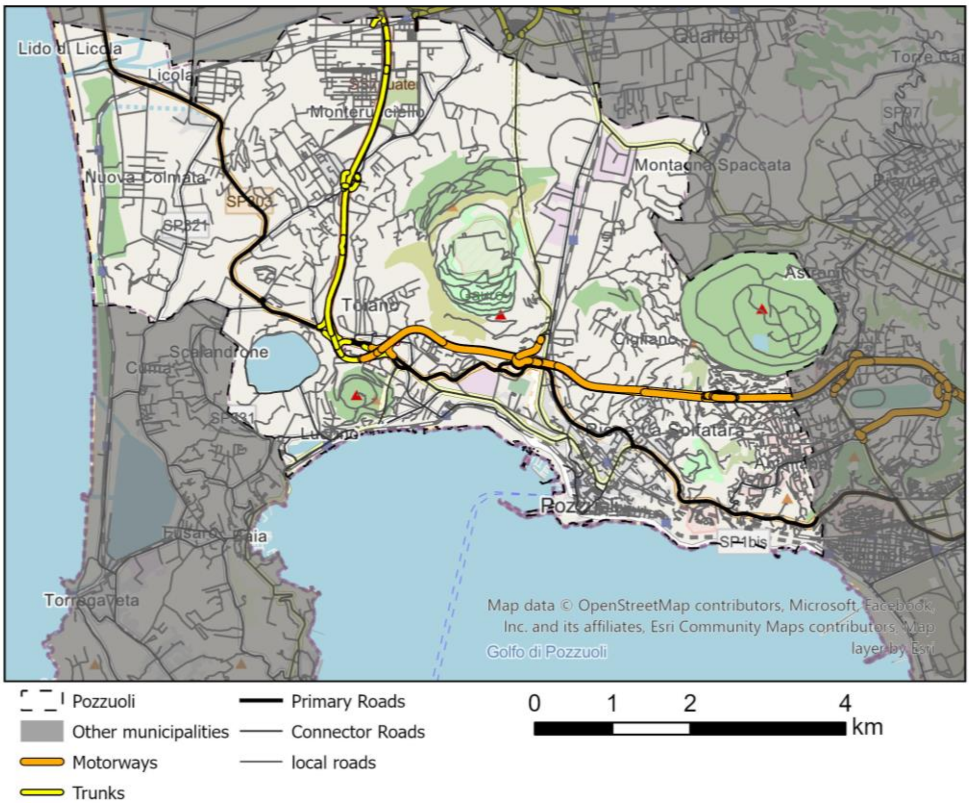

Figure 15. The Pozzuoli road network today, source: OpenStreetMap contributors.

6. Discussion

The Pozzuoli case study clearly illustrates the continuing difficulties in addressing the three pillars discussed here: tackling multihazard and multirisk characteristics of urban environments, integrating risk and resilience management and improving cross-sectoral and cross-scale urban governance and planning. The key role of data and information management in enhancing the capacities of complex urban environments to deal with the challenges of each pillar is discussed in the fourth and final sections of the following paragraphs.

6.1. Challenges in Tackling the Mutihazard Environment of Some Urban Areas and Its Dynamism

The inherent multihazard nature of the case study area has been inadequately addressed in both emergency response and spatial planning. Specifically, most spatial plans at the sub-municipal scale focussed on creating safe accommodation for the population evacuated from the areas affected by bradyseism while overlooking the volcanic threat that affects the whole area of the Phlegraean Fields. Whilst the new neighbourhoods of Rione Toiano and Monterusciello are located a considerable distance from the historical centre of Pozzuoli, they remain highly exposed to other volcanic phenomena. In fact, as the more recent hazard zone classification of the Phlegraean Fields area clearly shows, the entire Pozzuoli municipality is included in the red zone.

The emergency plans for the Phlegraean Fields, developed at national and regional scales between 2001 and 2016, and the Pozzuoli municipality's emergency plan of 2015, revised in 2021 to account for volcanic eruption, largely neglected the bradyseism phenomena. Only under the pressure of the latest bradyseism crisis did the National and Regional Civil Protection, in October 2023, identify the area most directly affected by the bradyseism phenomenon, mandating an emergency plan with evacuation provisions by early 2024. However, based on the information currently available online, the connections between this latter plan and the previous ones are not that clear. Scholars such as Newhall and Dzurisin [76] insisted on the need to consider all the potential hazards associated with the existence of volcanic hazards (e.g., volcano-tectonic seismicity, ground uplift, hydrothermal explosions, opening of faults and fractures, increased degassing and landslides) and their impacts caused by a phase of unrest, even in the absence of an eruption. This is something that still seems to be missing in the emergency planning for the Phlegraean Fields and the municipality of Pozzuoli.

The failure to jointly consider the multihazard phenomena and related risks is also evident in the lack of vulnerability analyses of the urban fabric. A special programme for the seismic vulnerability analysis of both private and public buildings was only initiated in the October 2023 act mandating the emergency plan for bradyseism.

6.2. Failures in Combining Risk and Resilience Management in Pozzuoli

The fifty-year history of risk management and planning in the Pozzuoli case study highlights numerous failures in meeting the crucial requirements of combined risk and resilience strategies.

Firstly, in the 1970s and the 1980s, the urban development of the Toiano and Monteruscello neighbourhoods was decided without an in-depth risk assessment of the area. The new neighbourhoods were more a response to the need for an urgent solution to a crisis rather than the reflection of a long-term strategy for the municipality, as evidenced by the term "emergency cities" explicitly used in official documents. The rapid relocation of the population from the historic nucleus of Pozzuoli during the two bradyseism crises in the 1970s and the 1980s disrupted the local community both economically and socially. The community lost its vital link to the sea, as its livelihood was primarily based on fishing. The displaced population felt alienated in the new modern urban blocks, so different from the historical landscape on the seaside, which they had to abandon. Shamsuddin [33] warns that it is not important only "for whom resilience is pursued, but also how they are involved, considered and treated". Moreover, the design of the new areas ignored any process of inclusion or participation of the displaced population, a vital step in fostering community resilience. Furthermore, the resulting urban pattern—consisting of the historic centre on the one hand and the two large neighbourhoods of Toiano and Monteruscello on the other—was rather fragmented. This fragmentation poses a significant challenge to potential assisted evacuation, as demonstrated by the qualitative and quantitative analysis performed using a historical series of satellite images.

Considering more recent decisions, the failure to learn from the rather challenging events experienced just a few decades ago is quite evident at both community and institutional levels. For the former, the memory of the bradyseism crisis of the 1970s and the 1980s has faded away. For the latter, institutions are still falling short of involving local communities in development decisions and even in properly communicating the emergency plan for both volcanic eruptions and the bradyseism phenomena. Both emergency plans would require the full commitment of local communities due to the complexity of the waiting area map and the concept of twinning with host regions. Even decisions that were made very recently in 2023 and in early 2024 confirm what was stated by Charlton et al. [75]: "physical science research has focussed on improving understanding of the hazards of an actual eruption" (. . .) while "less attention has been paid to the societal impacts from extended volcanic unrest and evacuation".

An important question that currently remains unanswered relates to the capacity of administrations and local communities to initiate a more resilient pathway for the future together. Breaking away from the crisis response approach that has been favoured thus far and instead envisioning longer-term strategies for the municipality of Pozzuoli as part of the metropolitan area of Naples would be a significant step towards a more resilient process [34]. Interesting projects aimed at reinforcing civil society and social engagement to improve the sense of security and well-being of communities have already been undertaken, for example, in Monterusciello [77]. Future projects for the area may also include preparedness and prevention as key goals.

6.3. A Fragmented Planning Landscape Challenging a Cross-Sectoral Systemic Approach to Risk in Urban Areas

Despite the fact that urban plans are required by law, the municipality of Pozzuoli has long suffered from a lack of comprehensive planning at the municipal level. The two neighbourhoods of Rione Toiano and Monterusciello were approved as sectoral housing projects in the absence of a larger vision for the area that only a comprehensive plan could have provided. Following the relocation of the population in the 1970s and 1980s, the historical nucleus was left without any clear provision for its future, a condition that provoked the illegal return of part of the relocated population. In more recent years, residents of Naples have moved to the area, attracted by its beauty and the economic convenience of the local housing market compared to the much more expensive City of Naples. The redevelopment of the abandoned areas in the historical centre of Pozzuoli, culminating in proposals for lucrative tourist accommodation that faced strong criticism in 2021, are just the latest episodes in a controversial and complex series of piecemeal interventions. This approach has occurred in the absence of a shared vision and plan for an asset that should be considered a public good and hold important cultural values for the local community.

Considering the interconnection at different spatial levels, as shown in Figure 2, it is also important to note the absence of a municipal urban plan for Pozzuoli and the lack of a larger-scale plan for the metropolitan area of Naples until 2016. Such a plan for the metropolitan area would have been necessary to provide the correct framework in which to assess the best areas for urban expansion in view of the volcanic risk from both Mount Vesuvius and the Phlegraean Fields. The decision on where to relocate the population evacuated from Rione Terra in the 1970s and 1980s should have considered alternatives throughout the metropolitan area rather than being restricted solely to the municipal boundaries of Pozzuoli.

As for cross-scale links, there is a noticeable disconnect between the national emergency plan for the Phlegraean Fields and the local emergency plans of Pozzuoli and all other municipalities in the caldera. In fact, there is a need to verify and assess to what extent the municipal evacuation provisions for various urban areas align with each other and with the larger-scale provisions, not only for the Phlegraean Fields but the entire metropolitan area of Naples.

Regarding the intersectoral interconnections and coherence between the different types of plans, as shown in Figure 2, the performed analysis illustrates a disconnect between land use and urban plans on the one hand and emergency plans on the other. In the early stages of the case study, during the 1970s and 1980s, the permanent relocation from the historic centre to the newly created neighbourhoods resulted from an urban development plan used as an emergency management tool, conflating the roles of the two.

Otherwise, urban planning largely ignored the risks in the area. The 2002 Pozzuoli Master Plan allowed for an increase in building volume in the Monterusciello area without any reference to the delimitation of the red zones or the waiting areas outlined in the 2001 Emergency Plan for the Phlegraean Fields. It was only in the guidelines for municipal administrations issued in 2017 that the Metropolitan City of Naples restricted residential development in areas exposed to high volcanic risk. The 2021 Preliminary Master Plan finally produced for the municipality of Pozzuoli following the guidelines has not yet been approved at the date of writing.

Neither of the most recent planning scenarios for the historic nucleus of Rione Terra adequately address the various hazards to which it is exposed.

Despite the difficulties in tracking the details of a rapidly evolving situation, there appears to be a mismanagement of the temporal axes between the urban development and redevelopment plans on the one hand and emergency plans on the other. Whilst in practice, they both influence each other, this influence is not explicitly considered in the various documents or in the regulations that are associated with them.

6.4. The Relevance of Shared, Coherent and Reliable Geospatial Datasets to Enhance Risk Mitigation and Resilience Capabilities

The advancement in geospatial data processing technologies provides nowadays the ground for significant improvement in the way not only data and information but also knowledge on hazardous phenomena and their impact on the built and natural environment can be managed and shared. In the case of Pozzuoli, geospatial information systems could be effectively used to provide a shared understanding of the multihazard and multirisk conditions that characterise the environment of the town and the entire metropolitan area of Naples. The comparison of satellite images at different time frames showing the dynamic changes in the built environment and the indexes measuring the type of urban expansion allowed highlighting the relevant contribution of geospatial data to a better understanding of (i) the changes that occurred over time in exposure and vulnerabilities (especially systemic vulnerability); (ii) the weaknesses of the leapfrog type of expansion both for liveability of urban areas and for emergency management; (iii) the spatial consequences of the complex dynamics between population relocation needs following hazardous events and the lack of both comprehensive planning at municipal scale and strategic planning at a supra-municipal scale. Tracing the history of the urban development of Pozzuoli permits not only to understand potential bottlenecks in the management of an evacuation but also what planning decisions have significantly changed the shape of the town, making accessibility and provision of services problematic in new settlements with increasing population density. This information is relevant not only for emergency plans but also for institutions to learn about mistakes made in the past and the need to rethink the relocation and distribution of residential and service areas in the entire metropolitan area of Naples, considering the interdependencies and interlinkages between the various historic and more recent settlements and the existing hazards.

7. Conclusions

In the first part of this article, we discussed the current challenges and complexities to be addressed in planning and managing urban environments exposed to multiple hazards.

The case study of the town of Pozzuoli in the Campania Region, Italy, highlights the drawbacks of failing to at least acknowledge and address such challenges. The confusion between emergency and land use plans, the lack of opportunities for the local population to participate in decisions about their future, and the failure of institutions to learn from even recent experiences serve as clear examples of what to avoid, as they lead to increasingly complex and difficult-to-solve problems.

Although hazard assessment and monitoring have improved over time, there has been very little focus on both physical and systemic vulnerability. Despite the fact that evacuation is still considered the only preventative measure in the event of an emergency, the total number of available escape routes is still too limited with respect to the high number of inhabitants.

The complexity of managing the whole Metropolitan City of Naples with its two active volcanoes can only be addressed through a strategic regional vision, which should focus on relocating key economic activities, services and populations towards safer areas, thereby reducing the housing burden in the highest-risk areas in the red zones.

To this end, a different understanding of spatial planning is needed: multiscale, more processual, following different temporal lines and horizons. To this aim, a different understanding of spatial planning is needed: multi-scale, more processual, following different temporal lines and horizons. One of the outcomes of the complex history traced on the urban development of Pozzuoli is that multi-risk assessments are better fit to support the longer-term strategic vision for development or redevelopment at metropolitan and city levels, whilst monitoring data should be used to support emergency management. However, the analysis also highlights the importance of aligning data and knowledge used in emergency and urban land use plans. This is certainly much easier today than used to be the case in the past, thanks to current geospatial data systems that can provide indeed both emergency and spatial planners with a common ground for decision-making, fostering more cooperative approaches [47].

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