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NEW CHALLENGES FOR XXI CENTURY CITIES

Multilevel scientific approach to impacts of global warming on urban areas, energy transition, optimisation of land use and emergency scenario

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The cover image shows a composition of two photos of the Temple of Serapis in Pozzuoli (Italy). Giuseppe Mazzeo took them in January 2009 and March 2025. At the top, the 2009 image shows the temple flooded, with the pavement not visible. In the down, the 2025 image shows the temple’s pavement dry and exposed. The Temple of Serapis is one of the leading visual indicators of the bradyseism phenomenon in the Phlegraean Fields. The bradyseism phase, highlighted by comparison, started in the first years of this century, as shown by the data published by the National Institute of Geophysics and Volcanology (INGV) on the website dedicated to the phenomena (https://www.ov.ingv.it/index.php/il-bradisismo).

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Campi Flegrei and the Metropolitan Area of Naples. Emergency planning in a high-risk territory

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Abstract
The territory surrounding the city of Naples is characterized by three active volcanic risk sources: Vesuvius, Campi Flegrei, and the island of Ischia. The objective of this study is to examine the characteristics of emergency planning in response to volcanic risk. The methodology of the paper consists of three steps. The first step identifies the fundamental elements of this type of planning using international studies and national frameworks. The second step analyzes the emergency plan for Campi Flegrei, focusing particularly on its primary objective: the evacuation of the population in the event of a volcanic eruption. Additionally, this section examines the recent worsening of bradyseism in the Pozzuoli area, which, due to its location, has increased experts' attention on the entire Campi Flegrei region. The third step involves a coherence analysis between the contents of the Campi Flegrei emergency plan and the guidelines outlined in the international studies and national frameworks introduced in the first step. The main results of the analysis highlight the strengths and weaknesses of the plan. Another significant finding confirms the close relationship between emergency planning and territorial planning. The current situation of the metropolitan area of Naples has been influenced by territorial plans that have paid insufficient attention to the risks present in the region. The next steps of the research emphasize the necessity for the new metropolitan plan to serve as an active tool for addressing territorial vulnerabilities. This should be approached with a focus on integrating risk mitigation into broader spatial planning initiatives.

Keywords
Campi Flegrei; Emergency planning; Territorial planning.

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1. Introduction

The territory surrounding the city of Naples is distinguished by its remarkable attractions which have historically acted as catalysts for settlement. Today, more than three million inhabitants are concentrated in the area, with nearly half directly affected by volcanic risks due to the presence of three active sources: Vesuvius, Campi Flegrei, and Ischia Island (Chester et al., 2000; Mazzeo, 2009; Mazzeo & Polverino, 2023). The three volcanic systems could be activated at any time with a hypothetical considerable destructive force: buildings and infrastructures could suffer considerable damage, while the number of victims and injured could be equally significant. The volcanic risk of Vesuvius and the Campi Flegrei has led to the delineation of two red zones, encompassing the areas directly affected by a potential eruption (Fig.1).

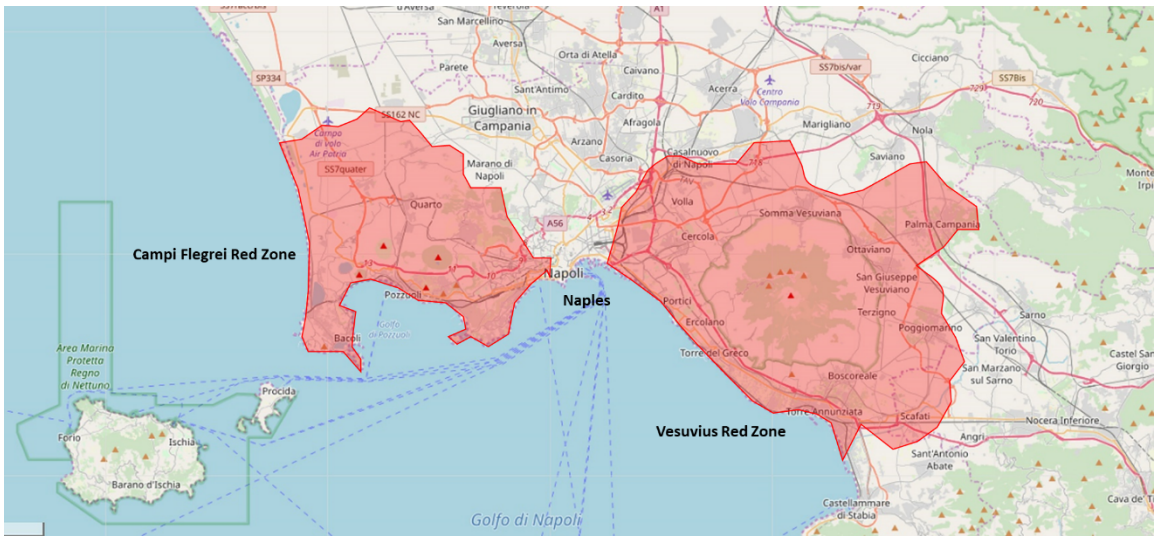

Fig.1 Metropolitan area of Naples. The Red Zones of Campi Flegrei to the West and Vesuvius to the East. The city of Naples is in the middle of the two areas

In this area the volcanoes are active geo-morphological structures that can generate both effusive eruptions (lava flows descending along the slopes) and explosive, or sub-Plinian eruptions. The greatest damage scenario follows an explosive eruption, where the main phenomenon is the formation of an eruptive column that generates pyroclastic flows consisting of a mixture of volcanic material and gases. These high-temperature flows move at high speeds with such destructive power that the only protective measure considered effective is the preventive and complete evacuation of the at-risk area (INGV, 2019).

A secondary phenomenon in this eruptive scenario is the fall and accumulation of ash, which can cause the collapse of structures and roofs. This phenomenon is linked to the pattern of stratospheric winds which, at the latitude of the area, predominantly blow from West to East. This means that the risk of ashfall on the city of Naples is greater in the event of an eruption of the Campi Flegrei rather than an eruption of Vesuvio.

The existence of such a significant risk represents a potential critical issue of national importance. For this reason, attention to possible responses in terms of emergency planning has greatly increased over the past years. Despite this attention leading to the creation of two emergency plans, doubts remain about the quality of the planning and its applicability, specifically whether it can provide an effective and substantial contribution when transitioning from a phase of peace to one of emergency.

The area concentrates both natural and anthropogenic risks. In addition to volcanic risk, there are hydrogeological and seismic risks, as well as an anthropogenic risk due to the presence of activities and a high population density. With over 3 million inhabitants on 1,171 square kilometers, the region ranks first in Italy for population density.

These figures alone necessitate careful territorial planning. However, this has only been partially achieved, resulting in largely chaotic and unregulated development (Papa & Mazzeo, 2014). The scale of illegal

construction is one of the main causes of the area's vulnerability (Mela et al., 2017). This is compounded by an infrastructure network that developed over time in response to settlement processes, rather than guiding them (Cascetta, 2001), posing significant challenges even during regular use. Human actions have therefore added a substantial level of settlement vulnerability to the existing natural vulnerabilities.

The scientific literature on volcanic risk planning encompasses various analytical factors. It starts from encyclopedic analyses, as in Aspinall et al. (2015) and in Wei (2021), to the value of uncertainty in emergency planning cases (Hicks et al., 2014; Norton et al., 2015), to volcanic risk management processes (Pareschi et al., 2000; Bonadonna et al., 2021; Brown et al., 2021). A significant portion of the literature over time has focused on the Neapolitan area, with particular attention to emergency planning (Rolandi, 2010; Baxter et al., 2008; Tomasone et al., 2022; Troise et al., 2022; Moraci et al., 2024; Sgambati & Stiuso, 2023), also in relation to sociological and anthropological factors (Gugg, 2018).

The aim of the paper is to analyze and evaluate the emergency planning tool developed for the Red Zone of Campi Flegrei. To achieve this result, a comparative methodology is used. This approach is based on the analysis of various national and international sources, from which the main elements that should be included in an emergency plan are extracted. These general elements are then compared with the contents of the emergency plan for the Campi Flegrei. The analysis has two objectives: to identify the differences and similarities and to qualitatively assess the coherence between them.

Starting with the introduction, the paper is organized as follows. Chapter 2 of the paper analyzes a range of national and international studies and sources focused on the content of emergency plans. Chapter 3 addresses the emergency plan for the Campi Flegrei and the phenomenon of bradyseism. Chapter 4 outlines the findings of the comparison between the general elements and the specific elements of the emergency plan for the Campi Flegrei and it discusses the results obtained. Chapter 5 highlights the minor role of the Territorial Plan of the Metropolitan City of Naples in the evolution of emergency planning.

2. Elements of a volcanic emergency plan

The development of an emergency plan related to volcanic risk falls within the broader topic of emergency planning that has evolved over recent decades. Both studies in areas such as planning and forecasting volcanic phenomena, and the experiences accumulated by national and international civil protection agencies have contributed to it. Together, these have enabled the formulation of guidelines aimed at creating emergency tools based on a high level of involvement of the communities affected by these phenomena (Quarantelli, 1982; Quarantelli, 1985; Lindell & Perry, 1992; Rockett, 1994; Alexander, 2003, Garau et al., 2023). According to Perry and Lindell (2003), there are a series of criteria that recur more frequently and are present in the emergency planning systems of some nations (Emergency Management Australia, 1998; New Zealand Government, 2002), namely:

- An accurate understanding of threats and the most likely human responses;
- Effective planning, to be translated into appropriate actions by civil protection;
- The recognition that natural phenomena occur in dynamic environments, implying that it is impossible to foresee all eventualities that may arise from an event;
- The necessity for emergency planning to be based on coordination among the various organizations involved;
- The necessity for plans to include substantial training;
- The provision for continuous and rigorous drills to test response operations;
- Awareness that emergency planning creates or encounters conflicts and resistance;
- Awareness that planning and management are distinct phases, so the true test of a plan is its actual implementation.

These general criteria must be specified in relation to the different types of risks to be addressed, such as hydrogeological risk (Hervás, 2003; Menoni & Pesaro, 2008) or seismic risk (Carreño et al., 2007).

Due to its characteristics, the listed criteria have even more specific significance in the case of volcanic risk. On one hand, it is precisely localized; on the other, it can cause significantly greater damage than other natural phenomena. Moreover, studies on volcanoes lead to the construction of scenarios that generally have greater accuracy compared to other risks. According to the Federal Emergency Management Agency (FEMA, 2020), a volcanic eruption can contaminate water sources, damage machinery and equipment, reduce visibility due to smog and harmful gases affecting lower-lying areas, and make breathing difficult while irritating the skin, eyes, nose, and throat.

To counter the harmful effects of a volcanic event, the only possible protection is to flee the threatened areas. Mass evacuation and other protective measures are more effective if planned and organized in advance. Mass evacuation, in fact, involves significant disruptions to the daily lives of a large number of people and can only be implemented when the risks associated with living in the dangerous areas are deemed unavoidable.

According to the United Nations (UN, 1985), the preparation of emergency plans in areas with volcanic risks requires the presence of some basic preconditions:

- A general awareness within the exposed community of the danger and the risks to life and property;
- The willingness to undertake collective action to reduce these risks;
- The existence of a regulatory framework to plan, organize, and implement appropriate protective measures at both national and local levels, including, if necessary, the evacuation of threatened areas and assistance to displaced persons;
- Sufficient scientific knowledge of the volcano to allow the development of eruption scenarios;
- The ability to recognize warning signs of an imminent eruption through visible signs of activity or scientific monitoring of the volcanoes, allowing for the possibility of taking appropriate actions.

Under these conditions, it is possible to develop a plan based on the following basic criteria (UN, 1985):

- Identification and mapping of hazardous areas;
- Creation of a register of valuable movable assets (excluding easily transportable personal effects);
- Identification of safe areas that can serve as shelters for the evacuated population;
- Identification, maintenance, and use of evacuation routes;
- Identification of assembly points for people awaiting transportation;
- Inventory of transportation means and traffic control systems;
- Preparation of shelter areas;
- Inventory of rescue personnel and equipment for search and security operations;
- Characterization of necessary hospital and healthcare services;
- Security of evacuated areas;
- Warning procedures;
- Procedures for drafting and disseminating public notices;
- Drafting of emergency communications;
- Provisions for updating the plan.

Overall, the ability of a plan to handle an emergency situation fundamentally depends on its components and specific characteristics such as completeness, operability, effectiveness, flexibility, speed, and rationality (Cheng & Qian, 2010).

The evolution of emergency planning has led to significantly more advanced results compared to the early experiences, with tools that have gradually moved away from simply predicting the means necessary to deal with an emergency. Consequently, although they continue to be structured as civil protection plans, they increasingly incorporate territorial content. This evolution is evident in the Directive of the President of the

Council of Ministers dated April 30, 2021, Guidelines for the Preparation of Civil Protection Plans at Various Territorial Levels (DPC, 2021).

The technical annex to the Directive defines the content of the plans. The core of the plan is the definition of optimal territorial and organizational scopes, which includes the geographical delineation of the areas covered by the planning and the organizational criteria, in terms of entities responsible for planning and managing emergencies. Once the scope is defined, the technical annex specifies the content of the civil protection plan at different scales. It must include:

- Introductive elements. Approval, update data and a summary of the main contents;
- Territorial framework. Key information on the physical layout of the territory, the meteorological and climatic regime, urban settlements, infrastructure, the productive system, urban and territorial planning, and the main natural and anthropogenic risks;
- Hazard and risk scenarios must be identified for planning purposes. This identification is a forecasting activity that serves both the warning and alert phases, as well as the construction of the Civil Protection Plan. The Civil Protection Code (Legislative Decree Nr. 1/2018) frames this activity as dynamic and evolving, anticipating a response that adapts to technological and organizational developments and requires continuous monitoring in specific cases. This applies to all territorial levels and covers events related to one or more types of risk, as outlined in Article 16 of the decree. For volcanic risk scenarios, reference must be made to national directives, operational guidelines, and plans issued for each specific volcano.
- Intervention model. It includes the organization of the civil protection structure, strategic elements, and operational procedures. It consists of organizing the civil protection structure, strategic and operational elements of civil protection planning, and operational procedures related to the actions of entities participating in emergency management.

3. Case study: Campi Flegrei

Campi Flegrei is a volcanic area. The caldera of Campi Flegrei was shaped by a series of major volcanic eruptions, the last one in 1538, forming a system of characteristics cones. A specific volcanic phenomenon of the caldera is the slow and continuous uplift and subsidence of the ground. This phenomenon goes by the name of bradyseism (from Greek βραδύς bradýs, "slow" and σεισμός seismós, "shake"). It occurs as a bell-shaped deformation of the inner caldera, which has a radius of a few kilometers, roughly centered at the town of Pozzuoli (Iervolino et al., 2024). Since the beginning of the last century, there have been periods of rapid rise and slow subsidence, as between 1982 and 1984, with uplift rates of several centimeters per month, and accompanied by seismicity featuring thousands of earthquakes, the largest of which had magnitude equal to 4.2.

After a period of slow subsidence without recorded earthquakes, there has been a steady rise in ground level since 2011. This uplift accelerated in 2018, reaching rates of about 2 cm/month in 2024 with about 9,000 recorded earthquakes, most of which since 2022, with peaks of about 1000 earthquakes per month, with largest one (Md = 4.4) in May 2024.

3.1 The Emergency Plan for Campi Flegrei

The Emergency Plan for the area of Campi Flegrei follows the guidelines of the twin plan for Vesuvius. The reference text for the Vesuvius emergency plan is the Decree of the Civil Protection Department dated February 2, 2015, which provides guidelines to the components and operational structures of the National Civil Protection Service for updating emergency plans related to the precautionary evacuation of the population in the Red Zone of the Vesuvius area. The plan identifies the risk zones and establishes operational intervention phases based on a reference scenario and specific alert levels.

Like the Vesuvius area, the Campi Flegrei region is also divided into a Red Zone and a Yellow Zone (Civil Protection Department, 2019a, 2019b).

The Red Zone, to be evacuated as a precaution in case of eruptive activity, includes the entire territories of Pozzuoli, Bacoli, Monte di Procida, Quarto, 7 Municipalities of Naples, and part of Marano di Napoli and Giugliano in Campania (Fig.2). The population of the Red Zone amounts to approximately 500,000 inhabitants.

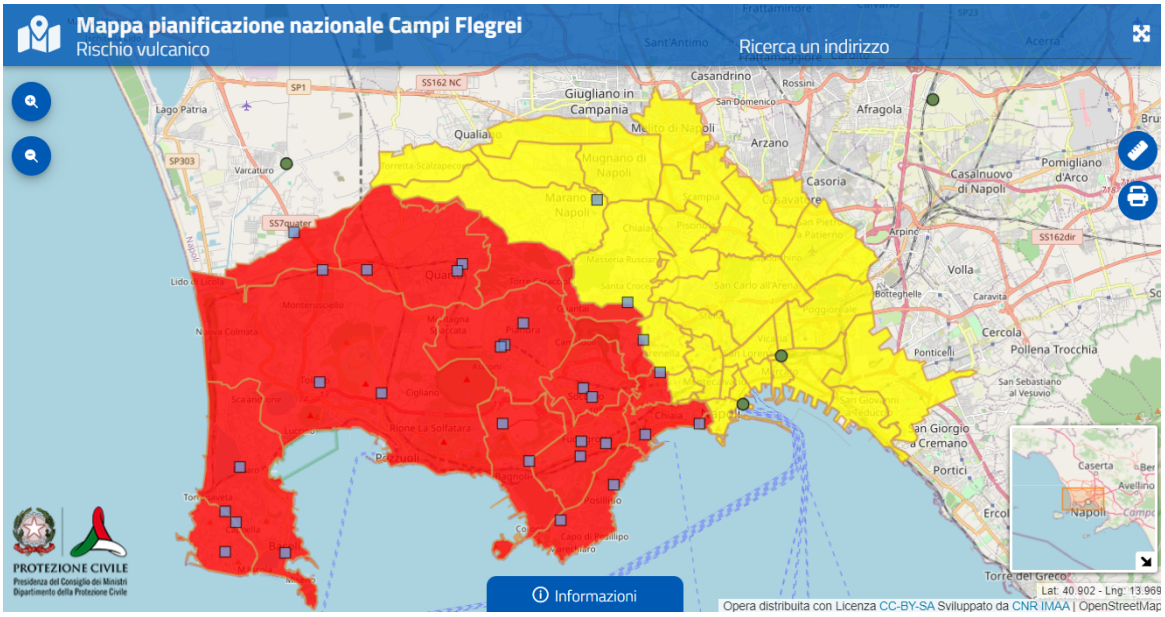

Fig.2 Red and Yellow Zones of Campi Flegrei

The most recent delimitation is the result of an update to the emergency planning with the redefinition of the Red Zone and the inclusion of the spread of pyroclastic flows as a risk factor due to the high probability of this phenomenon. This update has consequently led to the provision for precautionary evacuation in the event of renewed eruptive activity.

The Decree of the President of the Council of Ministers (DPCM) dated June 24, 2016, provides guidelines for updating the emergency planning. The Red Zone requires precautionary evacuation to safeguard human lives from the effects of an eruption. The evacuation can be carried out using private or Civil Protection resources, utilizing predetermined routes that include first-level gates and meeting areas (Galderisi et al., 2021) (Fig.3). To ensure subsequent assistance to the population, each Municipality of the Red Zone is twinned with a Region or Autonomous Province according to a distribution detailed in a specific annex.

The Yellow Zone is the area identified by studies as being exposed to the fallout of pyroclastic material. It includes the area that fall within a load curve of 300 kg/m² (a thickness of 30 cm), with an additional 5% probability of exceeding this load value. For this area, it will be necessary to adopt specific measures to safeguard the population, based on diverse, dynamic, and context-specific operational strategies at the time of the emergency. This is because its delimitation cannot be determined in advance, but only during the event. Ash accumulations of less than 30 cm may still affect areas outside the Yellow Zone. For this reason, municipalities are identified where ash accumulations of more than 5 cm are expected, with an additional 5% increase for exceeding the load threshold of 50 kg/m².

For the development and updating of emergency plans and evacuation plans for the population of the Red Zone of the Campi Flegrei, the guidelines contained in the provision for the Vesuvius area (DPCM February 2, 2015) are also valid, with appropriate adaptations to the territory of Campi Flegrei.

Each of the components and operational structures to which the guidelines provided by the Head of the Civil Protection Department are addressed were required to draft, update, and adapt their respective emergency plans within six months of the publication of the DPCM.

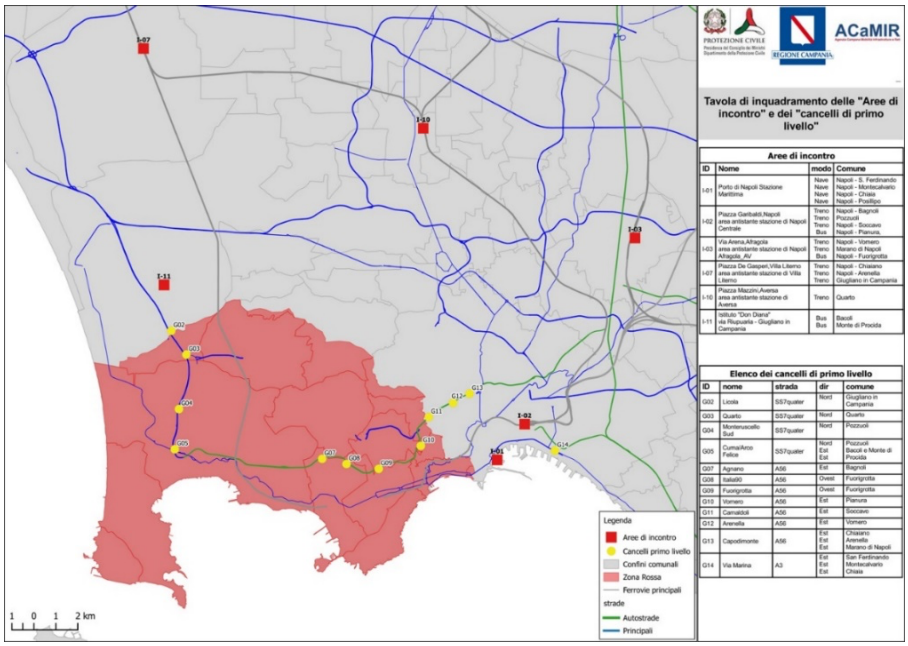

Fig.3 Campi Flegrei Emergency Plan-First level gates and meeting areas

The alert levels provided are four: base level, attention level, pre-alarm level, and alarm level. In case of activation, the National Commission for Major Risks, Volcanic Risk Sector, proposes moving to the next alert level based on monitoring data and technical-scientific reports from the Department of Civil Protection. The levels of attention, pre-alarm, and alarm correspond to significant variations in precursor signs detected by the monitoring system, which may indicate the approach of an eruptive phase.
Once activation starts, the duration of each level cannot be determined in advance. The transition to the next alert levels will occur based on the evolution of monitored parameters.

Alert level	Level activation time	State of the volcano	Actions planned for the population
Base	Undefined	No significant changes in the monitored parameters	No action
Attention	Undefined (a few months)	Significant variation in monitored parameters	Updating population data. Assessment and quantification of transportation, housing, health and psychosocial needs
Pre-alarm	From months to weeks	Further significant variation in the monitored parameters	Voluntary evacuation to autonomous alternative accommodations. Establishment of gates. Regulation of access to the Red Zone. Preparation of measures to be implemented in the third level
Alarm	From weeks to days	Appearance of phenomena / trend of monitored parameters that indicate a pre-eruptive dynamic. Event in progress	Population evacuation within 72 hours. Private traffic prohibited on the main evacuation network

Tab.1 Alert levels and activation times

In the absence of direct data on activation times, scientific literature is consulted, and precursor phenomena observed at other volcanoes are considered, hypothesizing that behavioral similarities may exist. These similarities could help transform seemingly random phenomena into signals that warrant close monitoring (Cashman & Giordano, 2008).

One consequence of this situation is that the times reported for pre-alarm and alarm may vary significantly (either more or less) compared to what is indicated in Tab.1. Another consideration is that the times refer to the beginning of the eruptive phase, which represents zero hour. However, they do not provide any information on the duration of the eruptive events, the relative state of alert, or the subsequent progression of the phenomenon.

Based on the variation of some monitoring data and the assessments made on multiple occasions (from December 2012 to January 2017) by the Major Risks Commission, the Civil Protection Department deemed that the alert level in the Campi Flegrei area should be raised from Green to Yellow (Fig.4).

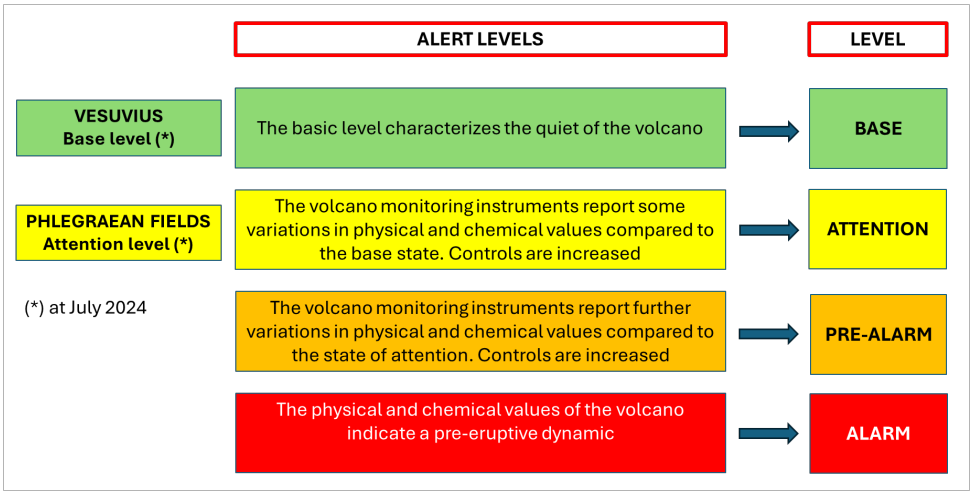

Fig.4 Alert levels for volcanic risk as Italian Civil Protection Department Alert state for volcanic area of Vesuvio and Campi Flegrei (July 2024)

Among these indicators are the size and rate of uplift of the ground level at monitoring points located in specific sites of the volcanic system. Other indicators include seismic activity originating in the area and measured CO_2 flows. The National Institute of Geophysics and Volcanology (INGV) issues weekly and monthly bulletins reporting the trends of these indicators (Fig.5).

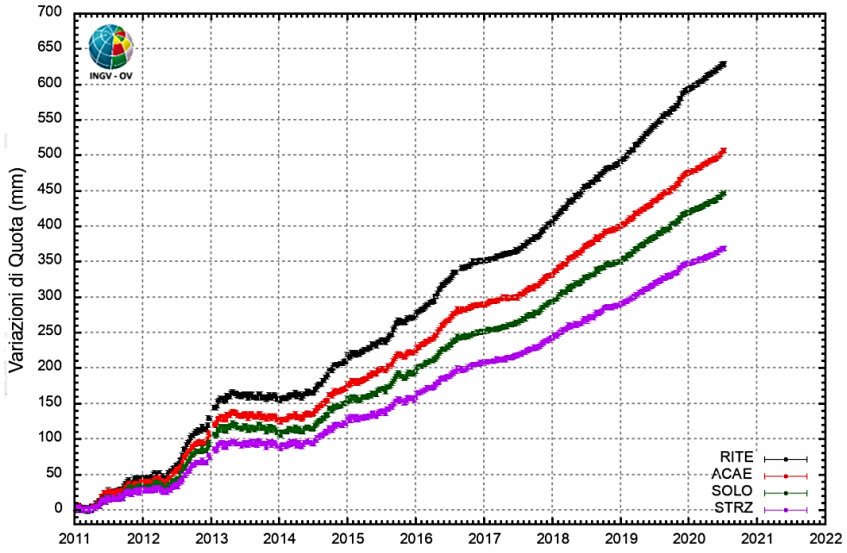

Fig.5 Time series of altitude variations of the RITE (Pozzuoli – Rione Terra), ACAE (Accademia Aeronautica), SOLO (Solfatara) and STRZ (Pozzuoli - Cimitero) stations from 01/01/ 2011 to 11/07/2020

In October 2019, a national civil protection exercise named Exe Flegrei 2019 was held to test the emergency response system. The exercise scenario simulated a significant variation in monitoring parameters and the

development of phenomena leading to a transition from the current state of the volcano (Yellow alert level) to a pre-alarm phase (Orange alert level), and eventually to an imminent eruption risk state (Red alert level). Without delving into organizational considerations that will need to be evaluated by Civil Protection, the exercise highlighted the limited involvement and participation of the population, despite the efforts of the involved entities to publicize the event.

In the session held on 17th September 2024, the Naples City Council approved the Resolution N. 284/2024 (July 11th) "Approval of the updated Municipal Evacuation Plan for the Volcanic Risk of the Campi Flegrei, the list of Civil Protection emergency areas, and the related layout of emergency signage."

The main contents of the Plan are not related to the ongoing bradyseismic crisis, but to a potential volcanic risk, which, at present, is not real. The evacuation plan involves 481,000 residents in the Campi Flegrei, of whom 286,000 live in the Red Zone of the City of Naples. The document outlines a pre-alarm phase, which may last months or even years, during which citizens can voluntarily leave, and an alarm phase, during which mandatory evacuation must take place within 72 hours. This evacuation can be carried out either with assisted transfer or through self-organized means.

The scale of the evacuation flows and timelines has been estimated with great caution, to be able to handle any unforeseen events or emergencies. According to the Plan, there will be 17 interchange areas, 29 bus routes, and 571 stops. The routes were planned in collaboration with Neapolitan Mobility Company (ANM), aiming to follow conventional paths. Specific signs will be placed on road signage. From the neighborhoods, citizens will move along designated routes leading to the seven gates located at the Port, via Marina, and the Naples Ring Road, from which they will be transported to regions paired with different city areas.

3.2 Bradyseism risk in Campi Flegrei

Since the second half of 2023, the Campi Flegrei has once again become a primary focus for Italian Civil Protection due to the resurgence of bradyseism risk, which, while related, should not be confused with volcanic risk. This resurgence has been marked by a significant increase in seismic events in the area (Fig.6).

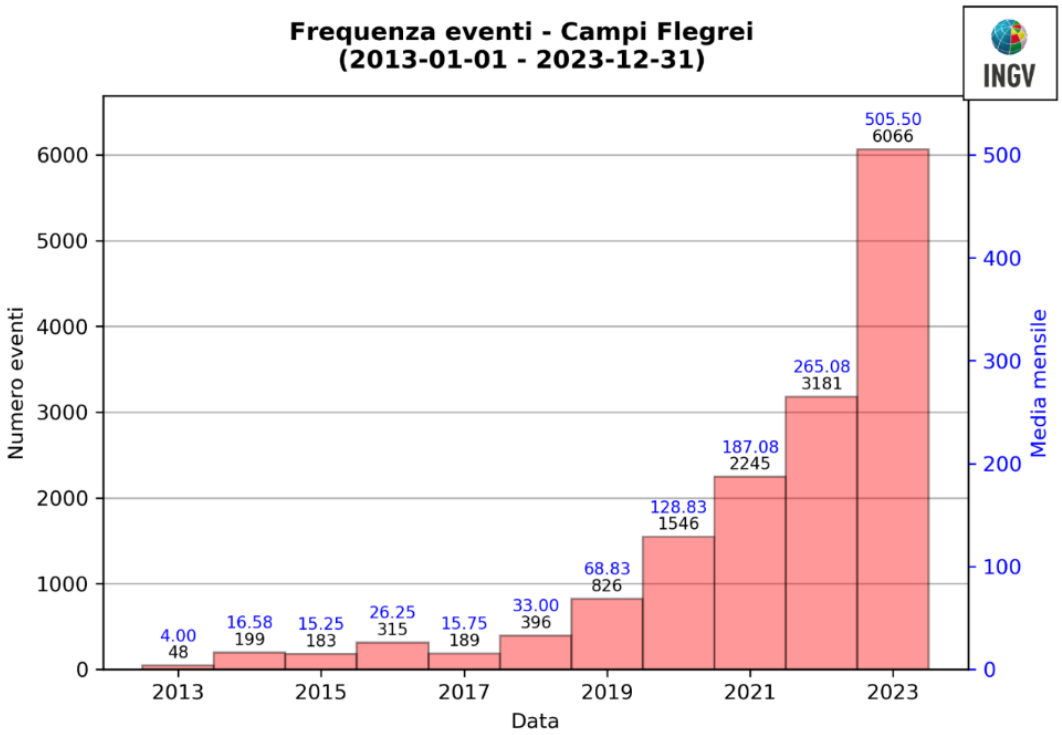

Fig.6 Frequency of seismic events in Campi Flegrei (2013-2023)

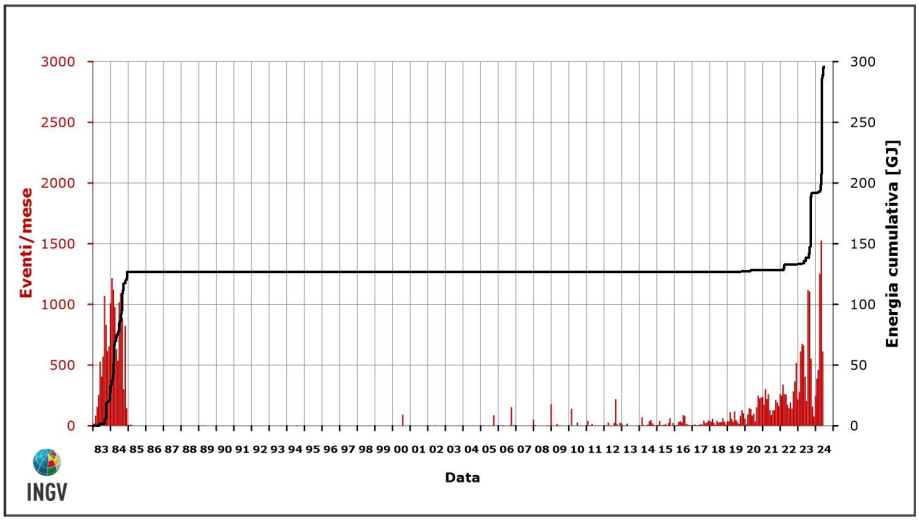

Fig.7 Earthquakes frequency in Campi Flegrei from 1983to present The black line represents the cumulative energy released

On September 26, 2023, a magnitude 4.2 earthquake occurs, followed by a magnitude 4.0 earthquake on October 2, 2023. On October 3, 2023, the Commission for Major Risks convened to discuss the strengthening of monitoring systems. The yellow alert level for the Campi Flegrei was confirmed, but the Commission highlighted the need to deepen monitoring and analysis due to the complexity of the issue and the potential evolution of the volcano's dynamics. The number of events continued to be high in 2024 (4,482 events until June, averaging 747 per month), with increasing magnitude in the months leading up to May, when it reached a peak of 4.4 (20/5/2024), very close to the maximum peak of 5.0 predicted by experts for the area (Fig.7). The tremors caused noticeable but not significant damage to the buildings in the affected areas, particularly in Pozzuoli. This series of events has created a situation of great alarm among the population and has forced the central government, through a series of acts, to address the ongoing emergency.

On October 12, 2023, Decree-Law No. 140 was published (converted into Law 183/2023) as the first response to the ongoing bradyseismic crisis, with both structural and non-structural prevention measures. The provision outlines the main actions that the Civil Protection System must implement to effectively respond to a complex risk situation.

On December 12th, 2023, the Emergency Expeditive Plan was approved (Fig. 8). Provided by Art. 4 of Law 183/2023, this planning arises from the need to define a specific strategy and operational procedures to respond to the effects and possible consequences of bradyseism. The expeditive plan was prepared by the Civil Protection Department, in coordination with the Campania Region, the Prefecture of Naples, and the local authorities and administrations, based on the hazard assessments developed by the Competence Centers.

There is a strong difference between bradyseismic risk and volcanic risk.

The current crisis is fundamentally bradyseismic, meaning it is due to the process of the earth surface uplifting in the Campi Flegrei area with its epicenter in Pozzuoli (Carlino, 2018). The term describes the slow vertical movements of the ground caused by pressure changes in the underground magma chambers. This movement generated frequent seismic events, localized in restricted areas. Seismic events are, therefore, a consequential risk. When they exceed certain magnitudes, they can cause damage to structures, property, and people. The volcanic risk is different and currently nonexistent in the area. However, it must still be considered because the Campi Flegrei is a volcano and historically, in addition to bradyseismic crises, it has caused the ejection of material and the formation of volcanic craters. If this situation arises, the only response is the evacuation of the population.

On July 2, 2024, Decree-Law No. 91 was published. It regulates seismic retrofitting interventions on public and private buildings, aimed at ensuring the functionality of transport infrastructure and essential services in the Campi Flegrei. The decree foresights the appointment of an extraordinary commissioner. Interventions are

approved to maintain schooling in Pozzuoli and to assist the population displaced by the May 20, 2024 earthquake.

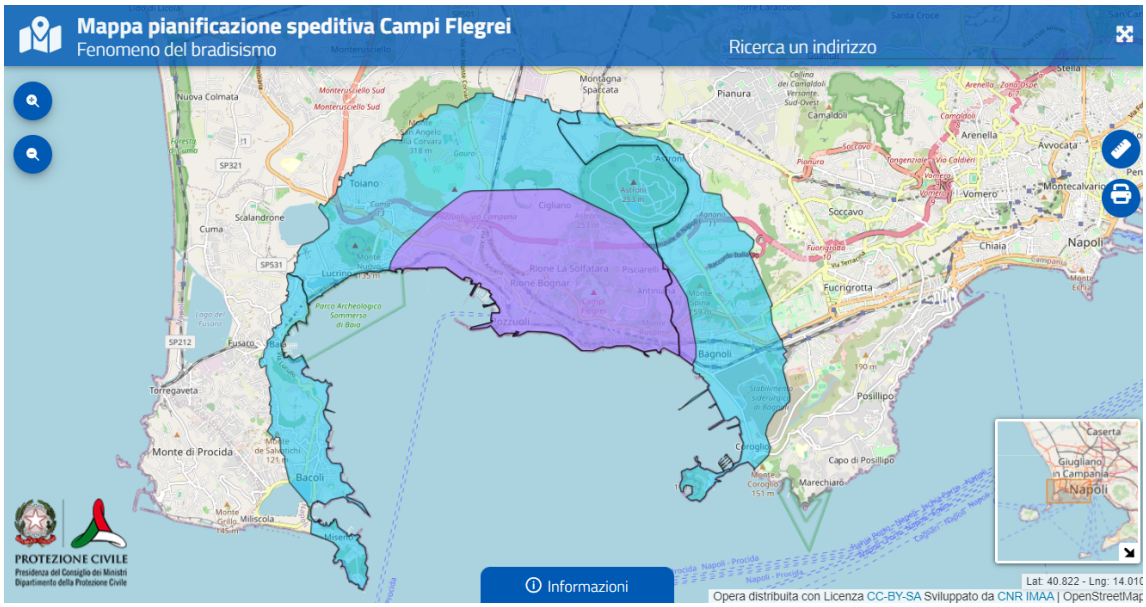

Fig.8 The Emergency Expeditive Plan map of the Campi Flegrei with the Intervention Zone (blue) and the Restricted Intervention Zone (purple)

As part of the Emergency Expeditive Plan a zone of intervention has been identified within the Municipalities of Pozzuoli, Bacoli, and Naples (specifically, the Bagnoli district and parts of the Soccavo/Pianura and Posillipo municipalities) that are most affected by the bradyseismic phenomenon and consequently by seismic activity and ground deformation. This "zone of intervention" was delineated based on the following criteria:

- The location of earthquake epicenters with a magnitude duration equal to or greater than 2, which have occurred in the Phlegraean area since 1983;
- Ground uplift equal to or greater than 10 cm since 2015 (corresponding to approximately 20 cm since 2006). The zone includes a total population of 84,961 people and an estimated 15,516 residential buildings.

Within this zone, a more "restricted intervention zone" has been identified, where the most significant effects could be widespread if the bradyseismic phenomenon continues or intensifies. This restricted zone was identified based on:

- The location of earthquake epicenters with a magnitude duration equal to or greater than 2 which have occurred in the Phlegraean area since 1983;
- Ground uplift equal to or greater than 30 cm since 2015 (approximately 45 cm since 2006), and it includes parts of the municipalities of Pozzuoli and Naples (specifically, the Bagnoli district). This area encompasses a total population of 33,653 people and an estimated 6,929 residential buildings.

Within the intervention zone, specific activities are carried out as outlined in article 2 of Law 183/2023 which mandates the implementation of an extraordinary plan for analyzing the vulnerability of both public and private buildings.

4. Coherence analysis and discussion

4.1 Methodology

The article aims to assess the effectiveness of the emergency plan for the Campi Flegrei by relating it to insights derived from scientific research and regulatory guidelines. To this end, a base sample considered

significant for comparison with the case study was selected. The methodology adopted is therefore comparative. This methodology is commonly applied to analyze and evaluate similarities and differences between two or more entities, phenomena, concepts, or groups, or to define possible analogies between a sample system of elements and an actual case. From operational perspective, the first step is to identify the sources to be used as a basis for determining the general elements of the emergency plan. From these sources, the elements deemed necessary for an emergency plan are extracted. The next phase involves analyzing the emergency plan of the case study. Finally, a comparative verification is conducted between the significant theoretical elements and the actual elements present in the emergency plan. The result is a qualitative coherence assessment that defines a potential effectiveness value of the plan based on parameters within the sources used as points of comparison.

4.2 Coherence analysis

After analyzing the fundamental elements of the emergency plans related to Vesuvio and the Campi Flegrei, it is considered useful to carry out a coherence analysis between these plans and some checklists that represent the state of the art at national and international levels.

Evaluating an emergency plan has very particular characteristics as it can only be done on the structure and predictions of the plan (ex-ante evaluation). As noted by some authors (Quarantelli, 1985), the effectiveness of an emergency plan can only be assessed (ex post) when it is actually implemented and produces, if it produces, the desired effects. For this reason, a coherence analysis is proposed rather than a true evaluation, while acknowledging that the subject deserves further in-depth study in a different specific context, also based on recent contributions from evaluative research (Núñez et al., 2015).

Previously, the criteria for the formation of an emergency plan were presented, and within the vast technical-scientific production, three systems of elements were examined in depth. The first proposed by Perry and Lindell (2003), the second by the United Nations (1985), and the third contained in the directive of the President of the Council of Ministers of 2021.

Each of these three documents proposes a structure of the emergency plan composed of a system of elements: 8 for the first, 14 for the second, and 4 for the third.

To provide a coherence assessment, the plans were evaluated based on three criteria: one general and two specifics to the emergency plan. The criteria are as follows:

- *Overall Relevance:* This criterion refers to the significant characteristics of importance, particularly concerning the achievement of the aims for which the plan was constructed. The relevance indicator pertains to the emergency plan as an object, specifying an overall and general condition.
- *Presence/Absence:* This criterion evaluates whether specific elements are included in the plan. It uses a binary scale (YES/NO) with the possibility of intermediate values.
- *Capacity/Effectiveness:* Closely linked to the presence/absence criterion, this evaluates the plan's ability to operate autonomously or in coordination with other actions. It measures both the suitability of actions to achieve the specified goals and their effectiveness in rendering the intended outcomes achievable up to a valid conclusion.

The coherence analysis is qualitative and derives from the analysis of the plan.

Tab.2 summarizes the assessment according to the factors considered by Perry and Lindell (2003). The analysis highlights that 5 out of 8 factors are absent, and among the other 3, only 1 has high capacity/effectiveness. Consequently, the two emergency plans do not meet the characteristics of Perry and Lindell's study.

Tab.3 presents the analysis of coherence with the model developed by the United Nations (UN, 1985), which requires the presence of 14 factors. In this case, the analysis shows that only 4 out of 14 factors are absent. Of the remaining 10 factors, only 3 are directly included in the plans, while the other 7 are present but in an

indirect manner (e.g., by referring to external elements not directly under the control of the two emergency plans). Regarding capacity/effectiveness, only in one case does it assume a high value, while in other cases, the assessment ranges from low to medium. Consequently, the two emergency plans only partially meet the characteristics contained in the United Nations model.

Tab.4 presents the analysis of coherence according to the factors contained in the 2021 Directive. The analysis highlights that, out of 4 factors, 3 are present in the plans with high capacity/effectiveness for two elements and medium for one. It follows that, in this case as well, there is a partial correspondence of the two plans with the guidelines contained in the Directive, despite a higher level of affinity.

Factors	Overall relevance	Presence/ Absence	Capacity/ Effectiveness
1. Accurate knowledge of threats	High	No	Zero
2. Effective planning of actions	High	No	Zero
3. Recognition of the dynamism of natural phenomena	Medium	No	Zero
4. Coordination between organizations	High	Yes	High
5. In-depth training activities	High	Yes	Medium low
6. Forecasting of testing phases	High	Yes	Medium low
7. Awareness of conflict and resistance created	High	No	Zero
8. Emergency planning and emergency management differences	High	No	Zero

Tab.2 Vesuvio and Campi Flegrei Emergency plans Relevance, presence and effectiveness of the necessary elements for Perry and Lindell (2003 § 2)

Factors	Overall relevance	Presence/ Absence	Capacity/ Effectiveness
1. Identification and mapping of dangerous areas	High	Yes - Direct	High
2. List of valuable movable property	Medium	No	Zero
3. Identification of safe territories that can serve as asylum	High	Yes – Direct	Medium
4. Identification of evacuation routes	High	Yes – Indirect	Low
5. Identification of collection points for people	High	Yes – Direct	Medium low
6. Vehicles and traffic control	High	Yes – Indirect	Medium low
7. Arrangement of asylum areas	High	Yes – Indirect	Zero
8. Inventory of personnel and equipment	High	Yes – Indirect	Zero
9. Hospital and health services	High	No	Zero
10. Safety of evacuated areas	Medium	No	Zero
11. Notice procedures	High	Yes – Indirect	Medium low
12. Procedures for drafting and disseminating public notices	Medium	No	Zero
13. Emergency communications	High	Yes – Indirect	Low
14. Provisions for updating the plan	Medium	Yes – Indirect	Low

Tab.3 Emergency plans of Vesuvio and Campi Flegrei. Relevance, presence and effectiveness of the necessary elements for UN (1985) (§ 2)

Factors	Overall relevance	Presence/ Absence	Capacity/ Effectiveness
1. Introductory elements	Medium	Yes	Medium
2. Territorial framework	High	No	Zero
3. Definition of hazard and risk scenarios	High	Yes	High
4. Intervention model and strategic elements	High	Yes	High

Tab.4 Vesuvio and Campi Flegrei Emergency plans Relevance, presence and effectiveness of the necessary elements for Directive of the Prime Minister of 2021 (DPC, 2021 § 2)

4.3 Discussion

The results obtained provide a basis for proposing several discussion points – some specific, others more general – while also addressing the limitations encountered in applying the methodology.

A first point of discussion concerns mobility. The intervention strategy for the Red Zones involves the precautionary evacuation of most of the population outside the Campania Region because, according to the most probable scenarios, the devastation within the zones, although not quantifiable in advance, poses a very serious risk to the population.

This means that the mobility network (Fig.9) could experience an inevitable surge in usage during the emergency phase, when it will need to evacuate an exceptional number of people within a 72-hour period, all of whom will likely be affected by the peak. The consequences of such a surge are foreseeable, though not desirable. Adding to this is the fact that pre-eruptive events (such as seismic swarms) could be equally disastrous, substantially compromising the network infrastructure. The issue of the number and type of disruptions to road and rail connections is vaguely mentioned in the plan.

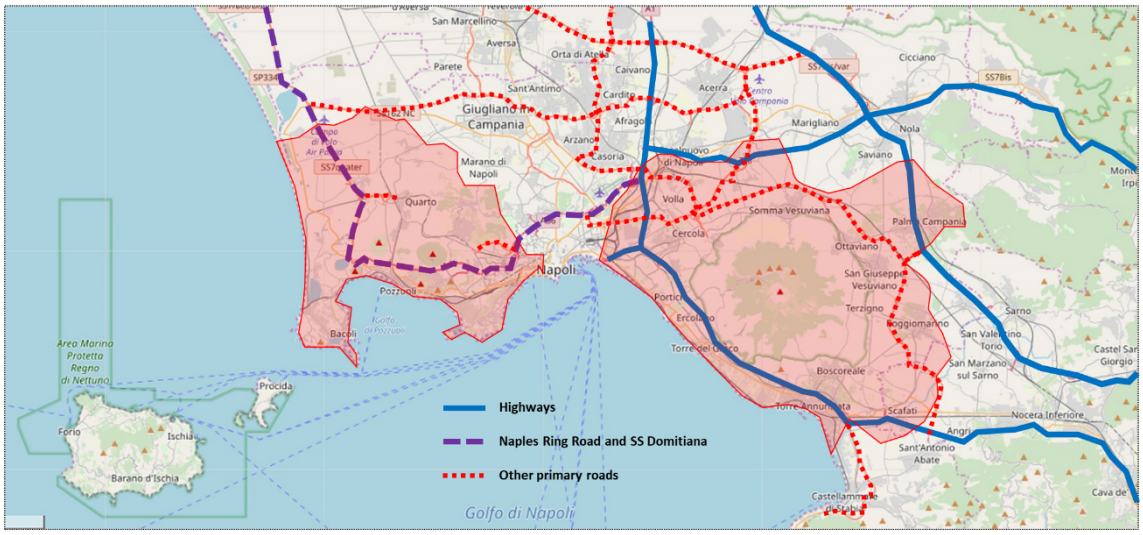

Fig.9 The primary road network of Metropolitan area of Naples as strategical network for the precautionary evacuation

A second issue is that the plan do not mention the damage that people might suffer during the activation phase, should the primary phenomenon be accompanied by other equally harmful events for the population and property. The mention of pre-eruption seismic vulnerability is not followed by any indication of its potential impacts. Obviously, the potential damage is correlated with the magnitude of probable earthquakes, but also with the high level of vulnerability of the building stock, characterized by old age and poor quality of materials and construction techniques.

A third issue is that the plan say nothing about the phase following the end of the emergency. This phase should involve a careful assessment of damage and the identification of areas where a substantial portion of the population can return, while ensuring that the twin-site facilities continue to function until all displaced persons have returned. However, nothing is said about the environmental conditions that these people might face, in terms of the lack of services, infrastructure, and the quality of water, air, and soil.

A fourth point of discussion concerns behavioral and psychological considerations. A significant attitude of fatalism is prevalent and seems to be a defining trait of the population living in the area. This is reflected in a clear sense of indifference, driven by the belief that volcanic risk is unmanageable and secondary to other, more pressing concerns (Ricci et al., 2013). While this attitude can be seen as both understandable and surprising, it highlights an inherent fatalism, a generalized distrust of scientific knowledge, and a persistent adherence to a system of rules rooted in the awareness of living in a high-risk environment.

In addition to this attitude, it should be noted that the necessity of setting up evacuation measures for such a large number of people, to be implemented at an uncertain point in time, seems objectively beyond the strategic vision of a national leadership class that bases its institutional and administrative decisions on much shorter time horizons and views the preparation of long-term tools aimed at managing territorial risk as an absurdity in itself.

Finally, the plan must work to build more prepared communities, given the fundamental role of the local community in constructing urban resilience (City of Chicago, 2019; Tira, 2021). The community must be able to access resources, utilize services and communicate easily even during an emergency. Residents need to be equipped with relationships, skills, and knowledge base to anticipate and -if necessary- face challenging situations.

5. Synergy between the Emergency Plan and the Metropolitan Plan of the Municipality of Naples

A specific point of discussion in the coherence analysis of Campi Flegrei's Emergency Plan concerns the very concept of the plan itself. If a "plan" is a complex structure that guides a multi-year transformation process (Alexander, 1997), in civil protection it becomes a low-complexity tool aimed at the evacuation and accommodation of a significant number of people affected by a disastrous event. In a systemic view of the territory, it can be hypothesized that even emergency plans could evolve to become complex tools, both strategic and operational in nature (Di Lodovico & Di Ludovico, 2018; Bojanić Obad Šćitaroci et al., 2021).

The strategic aspect lies in the fact that these plans involve an extensive system of stakeholders and institutions working toward a precise aim to be achieved through a series of actions that are refined over time and implemented only once, when needed, with the aim of completing the tasks within a limited number of hours. At the same time, they have the potential to guide a process of territorial decongestion over time. This would involve reducing the urban load (number of inhabitants), the scale of existing buildings, and, overall, the vulnerability of the territory through specific redevelopment programs.

The operational aspect of the plan lies in its function as a tool for monitoring and acting on potential crisis points within the territory during an emergency. Road and rail segments, interchange nodes, and urban areas with highly vulnerable buildings are all territorial elements that need to be continuously monitored and upgraded with the goal of increasing resilience (Fox-Lent et al., 2015), eliminating vulnerabilities, and improving the quality of both the building stock and infrastructure. These activities can also lead to updated scenarios for the use of the network in the event of an emergency (e.g., load testing), aimed at assessing the time required to transfer citizens from the area to internal gathering points and, subsequently, to external exit points.

In general, emergency planning is more efficient in a territory with a low value of exposed elements. Given that the territory in question has extremely high exposure values, it can be asserted that its activation could face critical conditions that might compromise its effectiveness.

Reducing the level of vulnerability is the task of ordinary planning, in accordance with the provisions of emergency planning. This crucial activity should be entrusted to ordinary planning through actions such as the improvement of the building stock, relocation actions (Mileti & Passerini, 1996), or flexible functional change actions (De Lotto et al., 2013). In the area this issue is mentioned as a contextual condition but not as a constraint from which obligations and provisions derive.

The Territorial Coordination Plan of the Metropolitan City addresses volcanic risk in the section on territorial risks, although with indications now outdated by the evolution of emergency tools. It notes that the territory is affected by the volcanic complexes of Vesuvius and the Campi Flegrei and, regarding operational aspects, states that "the [Plan] develops guidelines coordinated with the Operational Strategic Plan for the Red Zone of Vesuvius (...) and defines guidelines for the absolute containment of settlement increases in the highest

risk area of the Phlegraean caldera (Municipalities of Monte di Procida, Bacoli, and Pozzuoli)" (Città Metropolitana di Napoli, 2008). In the Strategic Plan of the Metropolitan City of Naples, the issue is present in the "Environmental Safeguarding" guideline, "Safe City" axis, "Civil Protection Interventions" action, without other indications (Metropolitan City of Naples, 2018).
From what has been mentioned, it follows that the metropolitan planning tools are, as of now, clearly inadequate in supporting and facilitating critical processes, such as the activation of emergency planning tools.

6. Conclusions

This paper aimed to delve into the topic of emergency planning in the specific context of volcanic risk.
To this end, the study explored some fundamental aspects of this type of risk and its significance for a territory. It then reviewed contributions from international literature on the development of emergency plans, expanding the analysis to include institutional inputs (such as those from the United Nations) and the latest regulatory developments in Italy. A key outcome of this section was the identification of a set of elements that various sources deem essential in the formulation of emergency plans.
The analysis of the form and content of the national emergency plan for Campi Flegrei serves as the link to the final section of the paper, which focuses on evaluating the plan's coherence using checklists and evaluation criteria. This part of the study highlighted the extent to which the plan aligns with what could be considered potential international standards. The overall result is insufficient, indicating a need to revise the plan to enhance its effectiveness, bearing in mind that this analysis was conducted ex ante.
From the examination of Tab.s 2, 3, and 4, the situation appears far from positive. Despite the recognized high hazard and the extreme vulnerability of people and property, the emergency plan for Campi Flegrei seem to consist of weak and generic guidelines, given the potentially catastrophic scale of the events.
Specifically, the plan raises questions regarding the clear definition of emergency management, the feasibility of evacuating the entire potentially affected population within a short timeframe, the functionality of the road and rail networks, and the lack of projections concerning the scale of probable (or acceptable) human losses. Analyzing the plan, another fundamental shortcoming for its success becomes evident: the knowledge of the territory on which they operate (Di Ludovico et al., 2021).
Earlier, the question was raised about whether emergency planning tools should also include this content. Even if the answer were negative, the need for such knowledge remains undeniable. For instance, it can be assumed that an external urban planning tool could monitor the condition of networks, levels of service and efficiency, critical points, and the state of structures useful in an emergency, planning the necessary upgrades in close coordination with emergency planning.
While the analysis acknowledges the efforts made by Civil Protection in this area, it also underscores the need to align the plan with best international practices, as recognized by the latest national regulations. Most importantly, it highlights the necessity for such planning to recognize the importance of having a foundational knowledge of the territory and being able to act proactively to improve its overall resilience. This aims to reduce the evocative burden highlighted by Heiken in 2013, namely, that there are too many volcanoes for too many people in that part of Italy.

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Image sources

Fig.1, 9: From Author on OpenStreet Map;

Fig.2, 3, 8: Department of Civil Protection;

Fig.4: From Author;

Fig.5: INGV, http://www.ov.ingv.it/ov/bollettini-campi-flegrei/Bollettino_Flegrei_2020_07_28.pdf;

Fig.6: INGV, https://ingvvulcani.com/2024/02/19/ speciale-vulcani-2023/;

Fig.7: INGV, Surveillance Bulletin, Campi Flegrei, June 2024.

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