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multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

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1. Technical references

Project Acronym	RETURN
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* PU = Public

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RE = Restricted to a group specified by the consortium (including the Ministry Services)

CO = Confidential, only for members of the consortium (including the Ministry Services)

1.1 Document history

Version	Date	Lead contributor	Description
0.1	xx.xx.xxxx	First name Last name (Partner short name)	First draft
0.2			Critical review and proofreading
0.3			Edits for approval
1.0			Final version

2. Abstract

For the hazard related to the impact variables of pyroclastic density currents of Vesuvius and Campi Flegrei, maps have been constructed by interpolating the safety values, calculated at various points across the dispersal area (Mele et al., 2024; Dellino et al., 2024; Mele et al., 2025). They show how impact parameters change as a function of distance from the volcano. The maps are compared with the red zone, which is the area that the National Department of the Italian Civil Protection has declared to be evacuated under conditions of an impending eruption.

For the ash fallout hazard of Vesuvius and Campi Flegrei (Massaro et al., 2023), maps have been extracted from probabilistic numerical simulation, representing the expected mass load at long term (50 years return times). In the simulation, the initial conditions of mass eruption rate and particle characteristics have been used, considering typical scenarios of the two volcanoes and a statistical distribution of winds.

For the test case of Multirisk analysis at Campi Flegrei, requested by the project coordination for an up to date assessment pending the actual bradeisismic crisis, maps combining hazard, physical vulnerability, and expected physical and economic damage have been elaborated. In this framework, different hazard components—including seismic shaking, ashfall load, and pyroclastic flow impact—are integrated with territorial exposure and building vulnerability models. Hazard intensity maps are combined with vulnerability functions derived from the CAESAR II methodology (Zuccaro et al., 2021) and with the vulnerability indices developed within the project deliverables. This integration enables the estimation of expected physical damage and economic losses across the built environment.

The resulting multirisk maps include spatial distributions of expected unsafe buildings, lost buildings, vulnerability indices, damage indices, and cost indices for the considered hazards. These outputs provide a comprehensive representation of potential impacts at territorial scale and support the identification of areas where the interaction of multiple hazards may amplify expected losses. The Campi Flegrei application represents a demonstrative test case aimed at supporting updated risk assessments in the context of the ongoing bradyseismic crisis and contributes to the development of operational tools for multihazard risk management and emergency planning.

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4. Elaborating of probabilistic hazard and impact maps

4.1 Hazard maps

4.1.1. Hazard maps of pyroclastic density currents

VESUVIUS

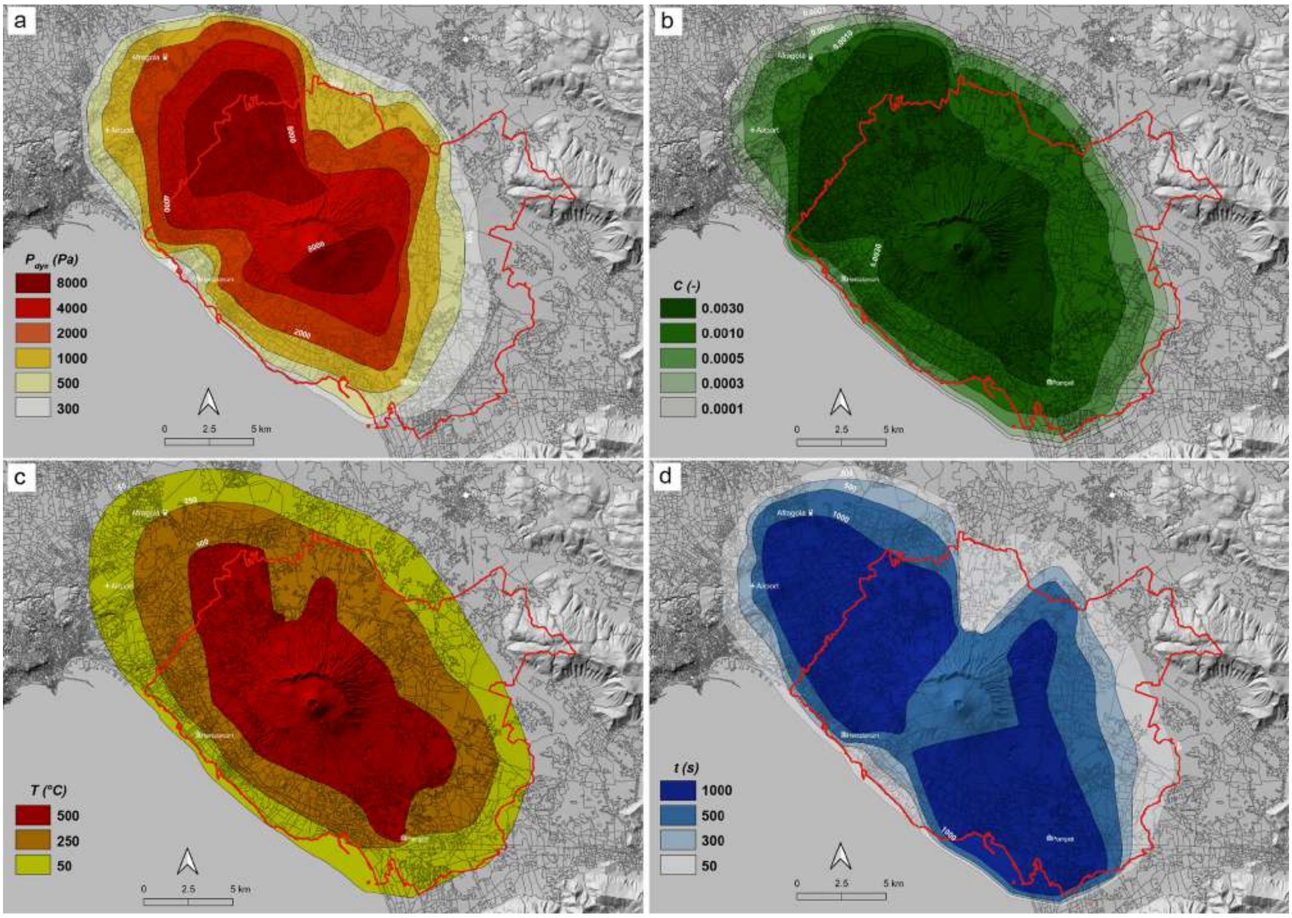


Figure 1. Hazard intensity maps of pyroclastic density currents at Vesuvius calculated at the 84th percentile (16% exceedance probability). The red solid line represents the boundary of the red zone proposed by the Italian National Civil Protection Department (2014). a) Dynamic Pressure (Pa) integrated over the basal 10 m of the current. b) Particle volumetric concentration integrated over the basal 2 m of the current. c) Flow temperature (°C) in the basal 2 meters of the current. d) Average flow duration (s). The digital elevation model (Tarquini et al., 2023), territorial bases and census variables (Istat, 2011) are used as the topographic base for data set visualizations.

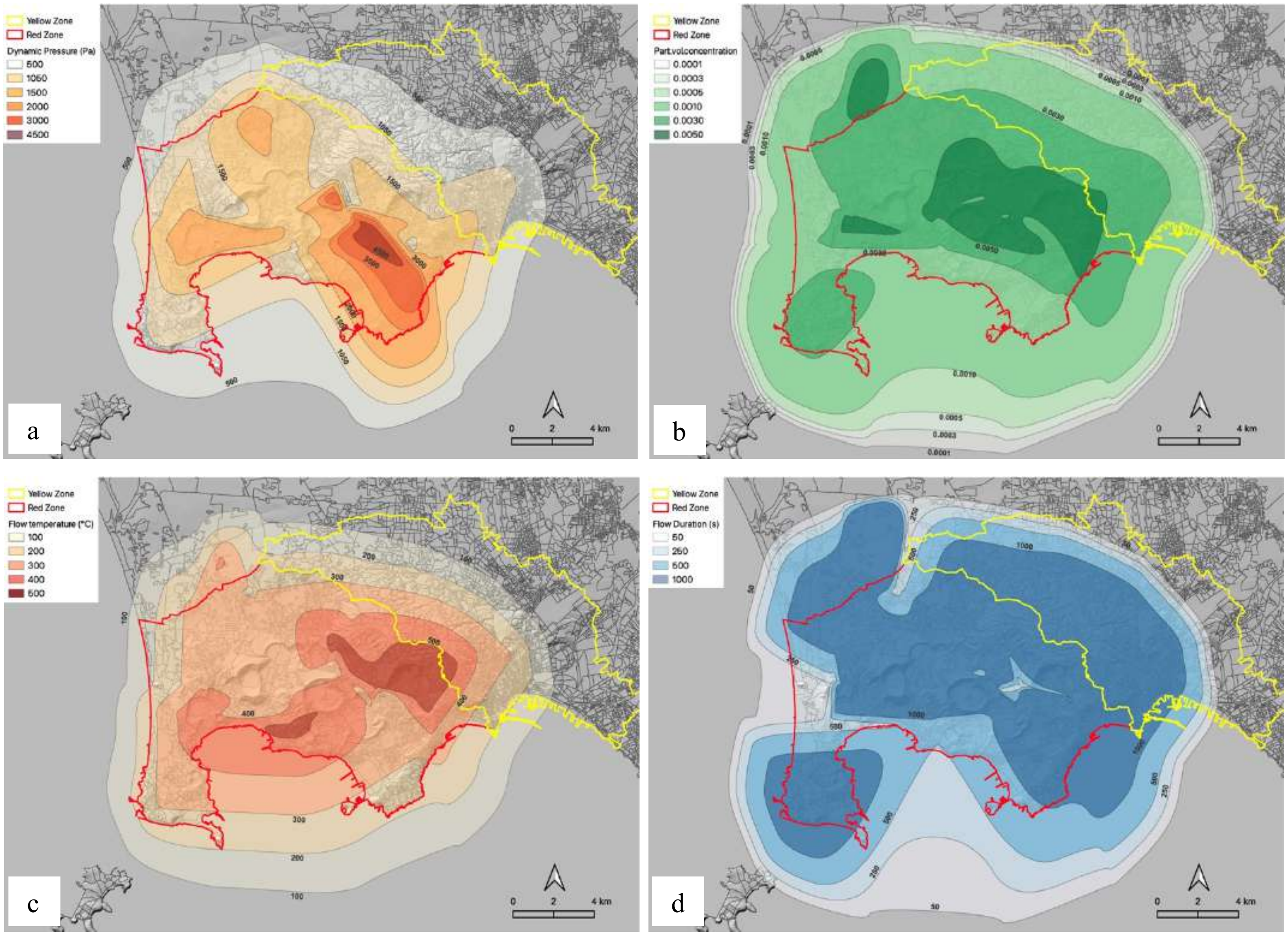


Figure 2. Hazard intensity maps of pyroclastic density currents at Campi Flegrei calculated at the 84th percentile (16% exceedance probability). The red and yellow solid lines represent the boundary of the red and yellow zone proposed by the Italian National Civil Protection Department (2014). a) Dynamic Pressure (Pa) integrated over the basal 10 m of the current. b) Particle volumetric concentration integrated over the basal 2 m of the current. c) Flow temperature (°C) in the basal 2 meters of the current. d) Average flow duration (s). The digital elevation model (Tarquini et al., 2023), territorial bases and census variables (Istat, 2011) are used as the topographic base for data set visualizations.

4.1.2. Hazard maps of ash follout

VESUVIUS

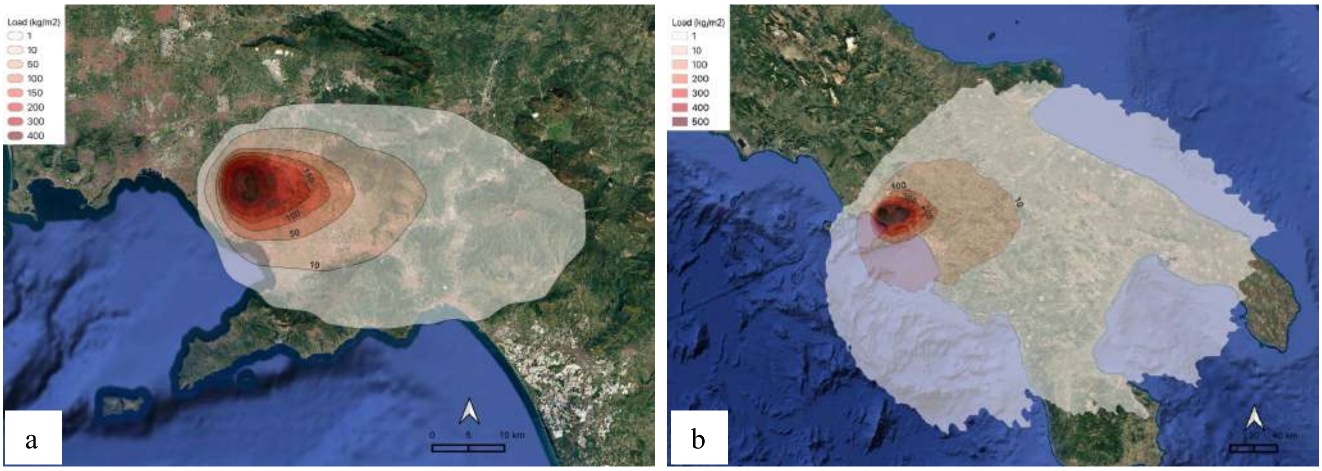


Figure 3. Long-term hazard maps at Vesuvius, reporting the mean hazard intensity (tephra load, kg/m^2) in 50 years with the probability of 5% (**a**) and 1% (**b**) (modified, after Massaro et al., 2023).

CAMPI FLEGREI

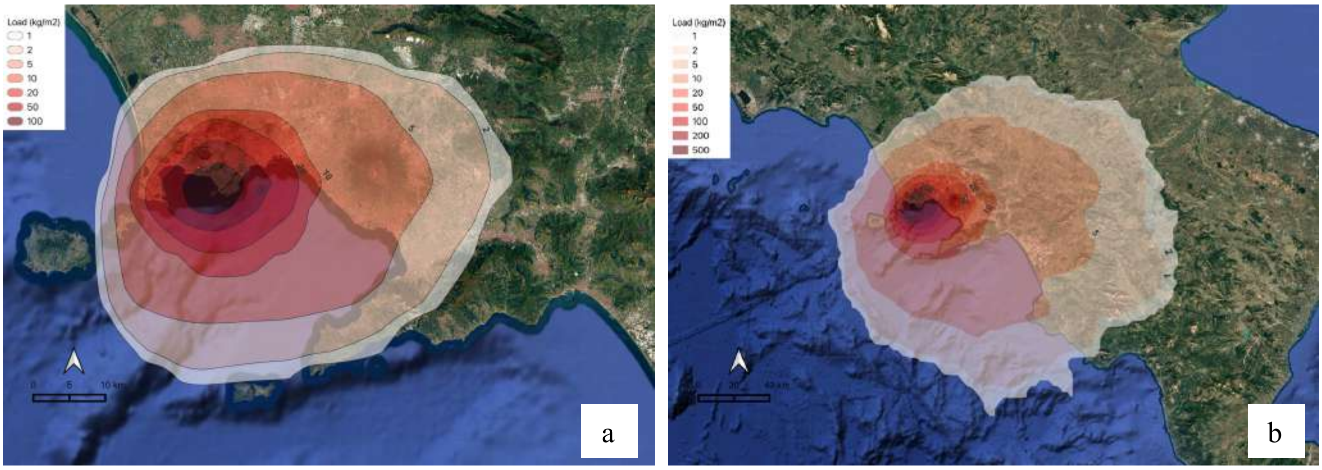


Figure 4. Long-term hazard maps at Campi Flegrei, reporting the mean hazard intensity (tephra load, kg/m^2) in 50 years with the probability of 5% (**a**) and 1% (**b**) (modified, after Massaro et al., 2023).

4.2 Multirisk maps of Campi Flegrei

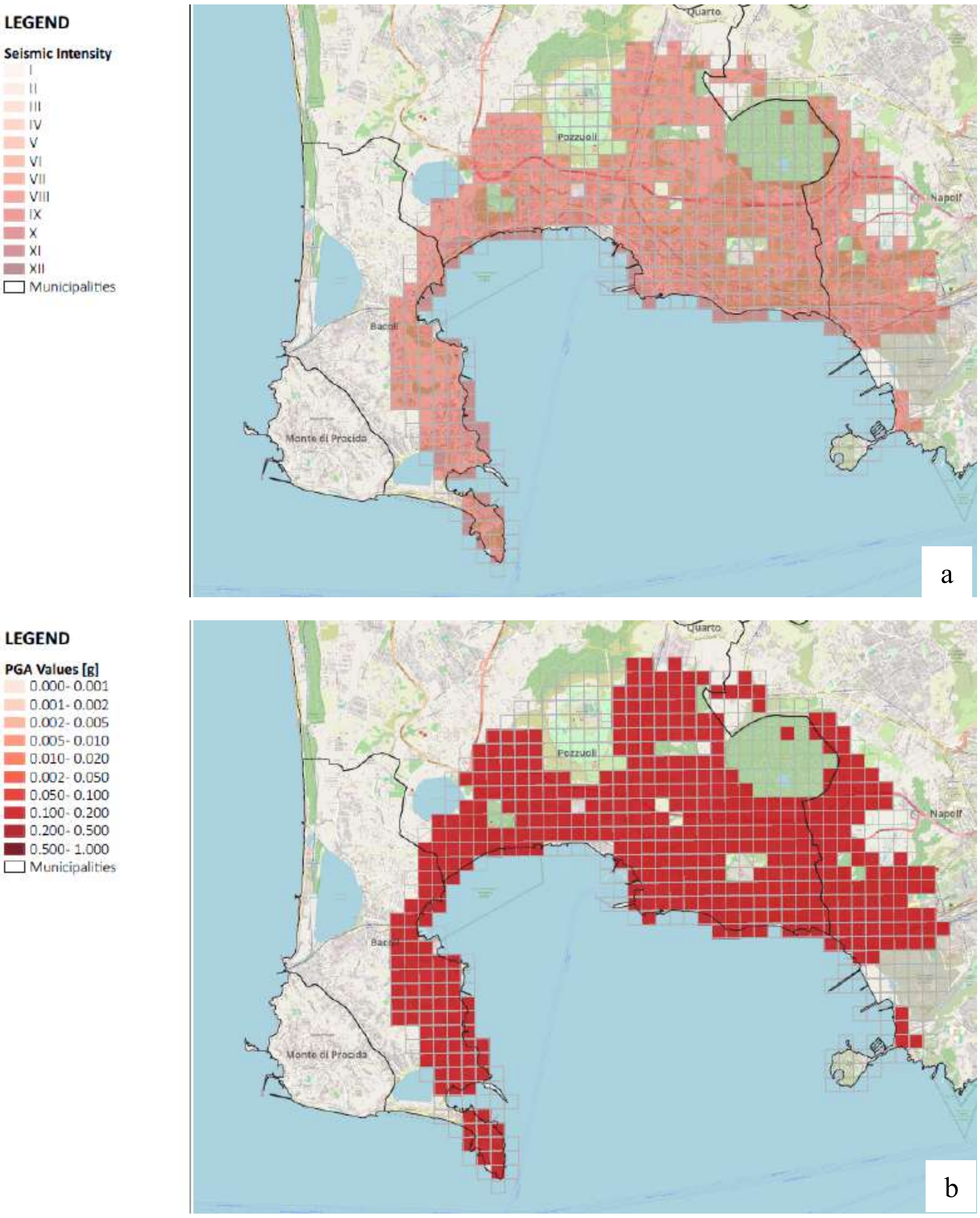


Figure 5. Hazard value for earthquake in seismic intensity (a) and PGA (b) in Campi Flegrei with the 2% probability of exceedance in 50 years

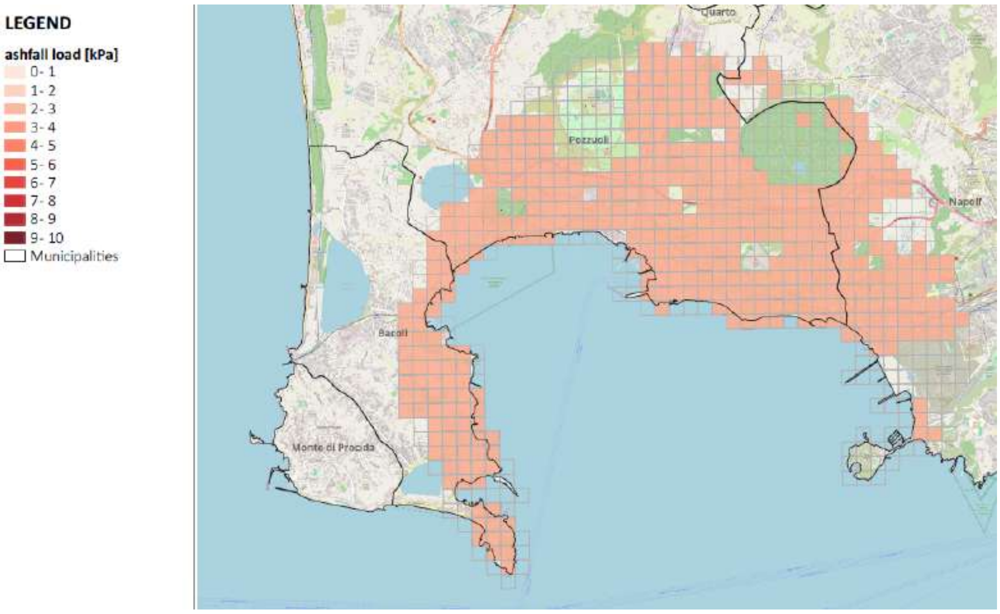


Figure 6. Hazard value for ashfall in kPa in Campi Flegrei with the 1% probability of exceedance in 50 years

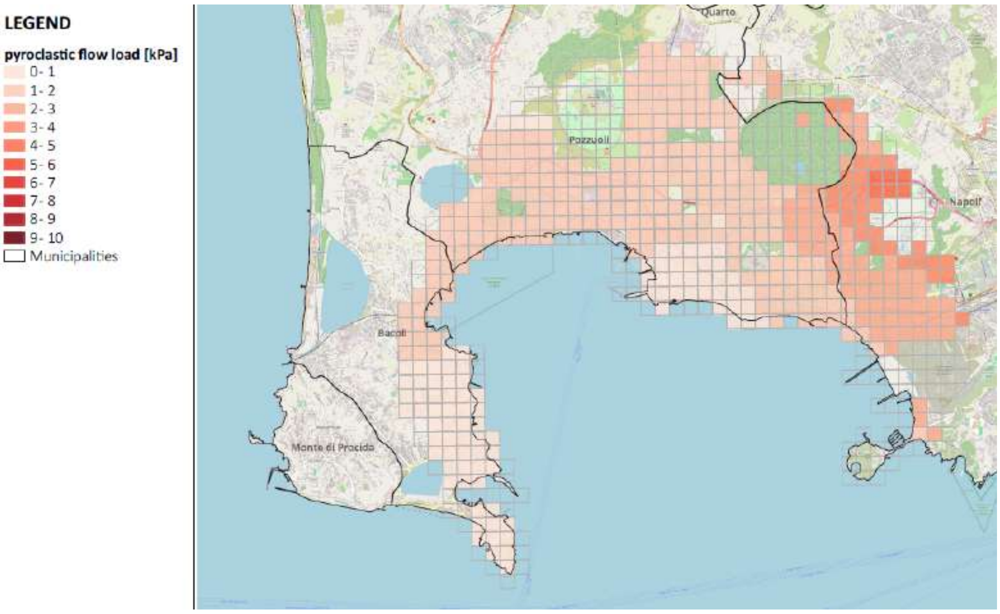
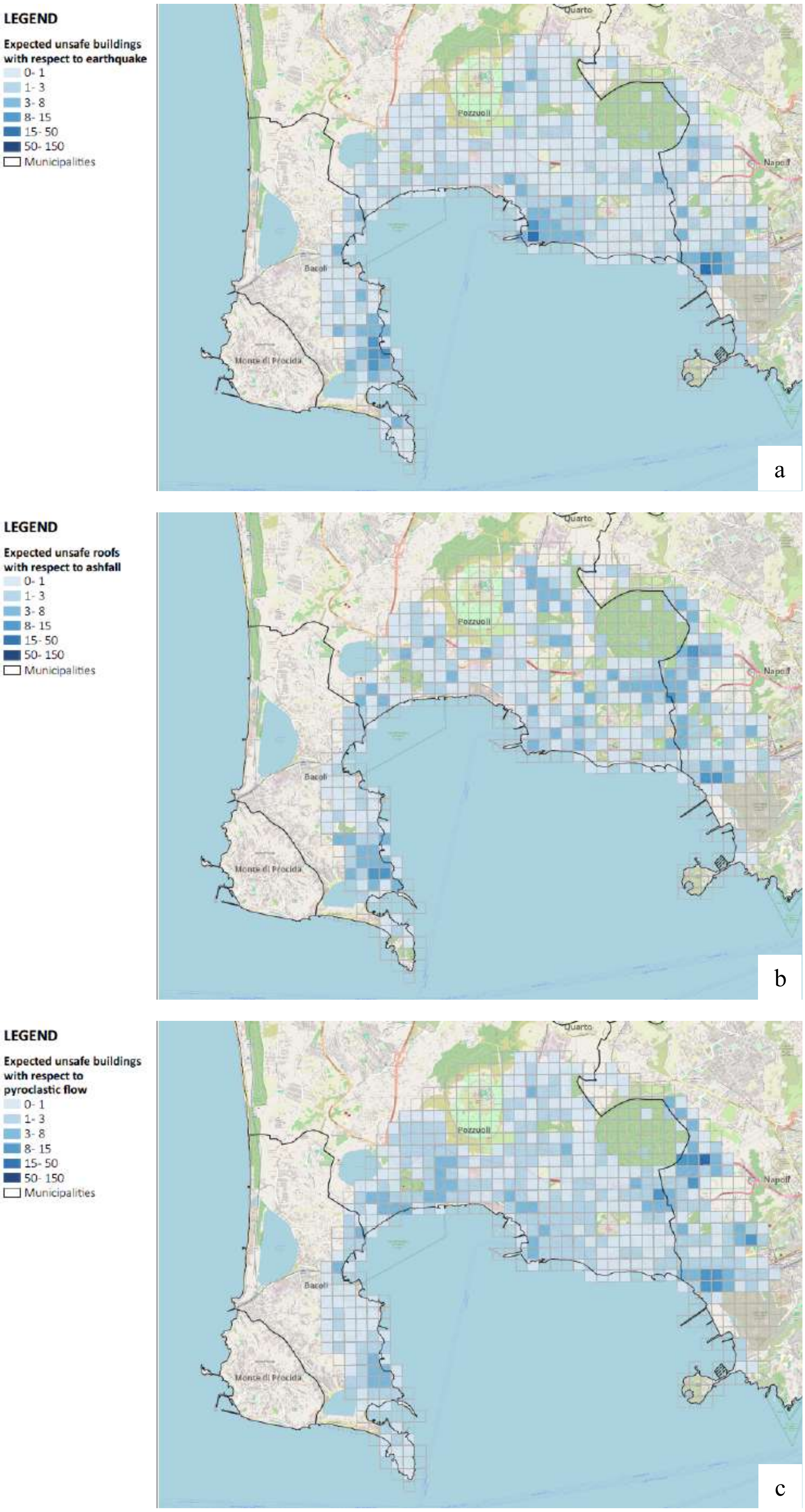


Figure 7. Hazard value for pyroclastic flow in kPa calculated at the 84th percentile (16% exceedance probability)



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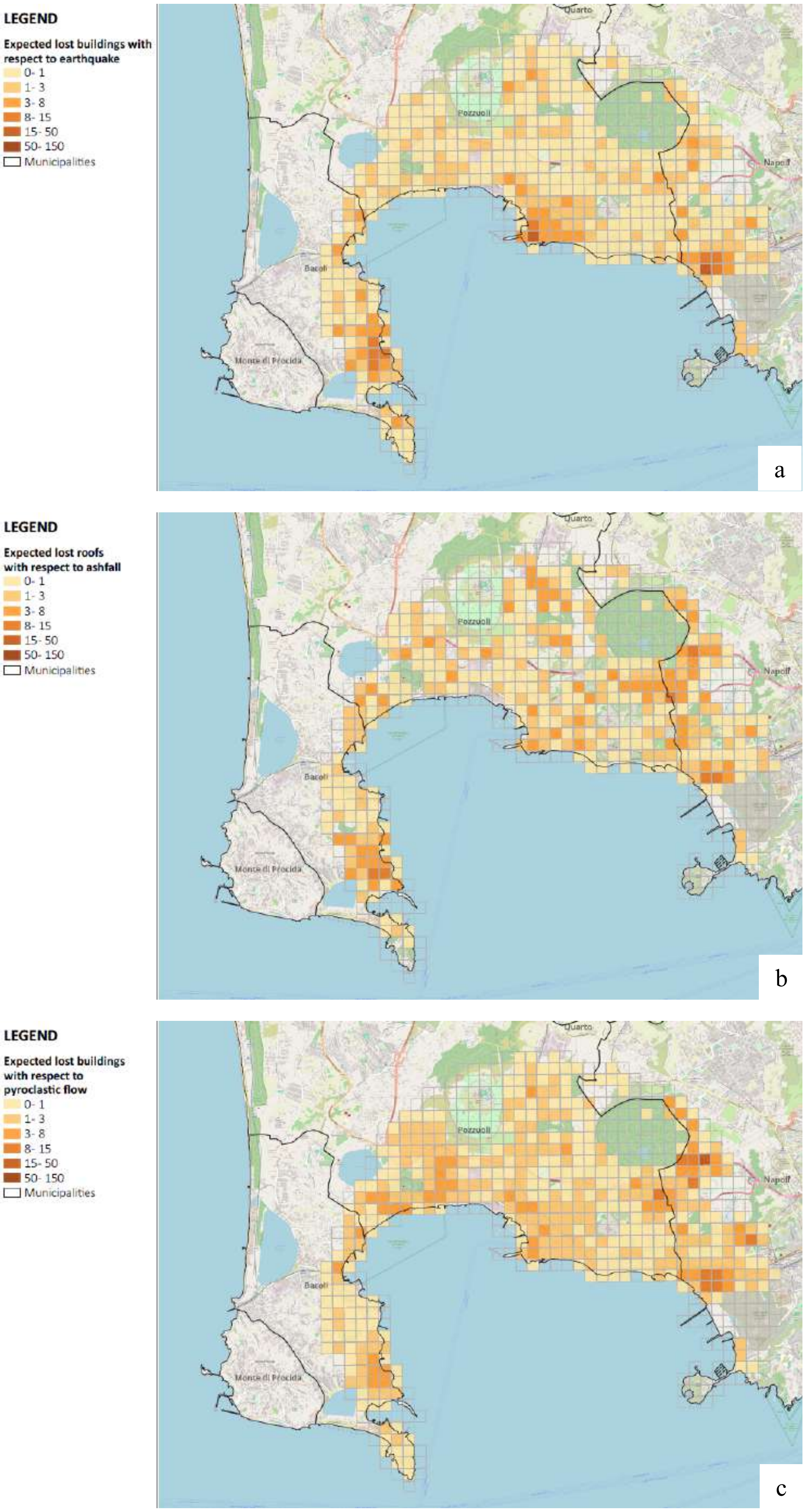

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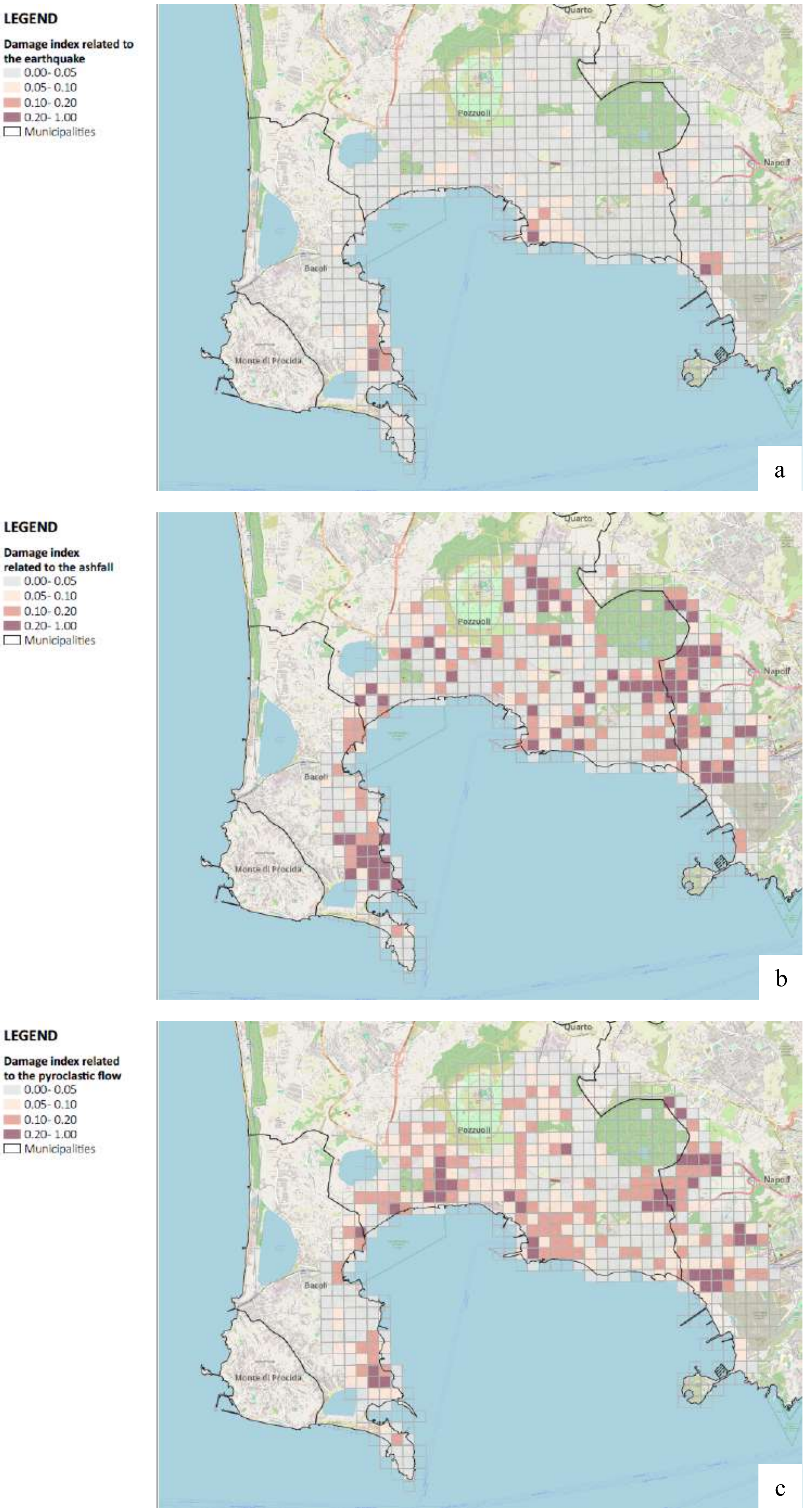

Figure 11. Damage index estimated as in DV 3.6.4 for seismic hazard (a), ashfall (b) and pyroclastic flow (c) in Figure 5, Figure 6 and Figure 7 respectively

Figure 12. Cost index estimated as in DV 3.6.4 for seismic hazard (a), ashfall (b) and pyroclastic flow (c) in Figure 5, Figure 6 and Figure 7 respectively

5. Conclusions

This deliverable presents a set of hazards and multi-risk maps developed for the volcanic areas of Vesuvius and Campi Flegrei, integrating advanced hazard modelling with territorial vulnerability and impact assessment. The results provide spatially distributed information on the intensity of key volcanic hazards, including pyroclastic density currents and ash fallout, derived from numerical simulations and probabilistic approaches. These hazard representations allow the characterization of the expected variability of impact parameters across the territory and provide a quantitative basis for comparison with the emergency planning zones defined by the Italian Civil Protection system.

The hazard maps highlight how the intensity of volcanic phenomena varies significantly as a function of distance from the eruptive source and local topographic conditions. In particular, the maps of pyroclastic density currents describe the spatial distribution of dynamic pressure, particle concentration, temperature, and flow duration, while the probabilistic tephra fallout maps provide estimates of long-term ash load under different exceedance probabilities. These datasets represent a fundamental component for the assessment of potential impacts on the built environment and infrastructure.

Building upon these hazard assessments, the Campi Flegrei test case demonstrates the application of a multirisk approach that combines hazard intensity with exposure and vulnerability indicators in order to estimate potential damage and economic losses. By integrating seismic hazard, ashfall load, and pyroclastic flow impact with vulnerability models and cost indices, the analysis provides spatially explicit estimates of unsafe buildings, lost buildings, and expected damage levels. This integrated representation allows the identification of areas where multiple hazards may interact and amplify risk conditions.

Overall, the developed maps constitute a useful tool for supporting territorial-scale risk assessment and for informing mitigation strategies and emergency planning. In particular, the multirisk framework applied to the Campi Flegrei area represents a demonstrative step toward operational decision-support tools capable of integrating different hazard sources and their potential impacts on the built environment. Such approaches are particularly relevant in the current context of renewed volcanic unrest in the area and contribute to improving preparedness and resilience of exposed communities.

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