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Population at Risk: An Integrated Framework for Volcanic Risk Assessment applied to the Mt. Vesuvius Area

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Short abstract

This study presents an integrated multidimensional framework for assessing volcanic risk in the Mt. Vesuvius area, one of the most hazardous volcanic zones in Europe due to its proximity to densely populated urban centers. Building on the UNDRR definition of risk as the product of hazard, exposure, and vulnerability, the research combines Geographic Information Systems (GIS) and statistical techniques to evaluate long-term hazard from pyroclastic density currents (PDCs), population and building exposure, and social and physical vulnerability at the enumeration area (EA) level. Hazard was assessed using PDC impact parameters and standardized through factor analysis. Exposure was calculated via population and building density, while vulnerability was derived from demographic, socioeconomic, and structural building data using principal component analysis. The resulting indices were mapped and integrated to produce a volcanic risk classification ranging from very low to very high. Results show that nearly 90% of the population and over 92% of buildings in the study area are located in zones exposed to volcanic risk, with significant concentrations of high and very high risk in municipalities such as Sant'Anastasia, Portici, Ercolano, and Napoli. The framework supports cost-benefit analysis, land-use planning, and emergency preparedness, offering a replicable methodology for local-level risk assessment. The study highlights the urgent need for targeted mitigation strategies and long-term planning in multi-source volcanic regions like Campania, which also includes Campi Flegrei and Ischia Island.

Keywords: volcanic risk, Vesuvio, population and building exposure, social and physical vulnerability.

Extended abstract

Introduction

Urban areas located near active volcanoes, such as Mt. Vesuvius in the Campania Region of Southern Italy, face a wide range of direct and indirect threats from volcanic hazards—including pyroclastic density currents (PDCs), lava flows, ash fall, toxic gases, and landslides. These events can result in loss of life, damage to infrastructure, forced displacement, and economic disruption (Loughlin et al., 2015; El Hadri et al., 2021). Despite these risks, approximately 500 million people globally live in volcanic zones, drawn by fertile soils, water availability, geothermal energy, and tourism opportunities (Kelman & Mather, 2008; Erfurt-Cooper et al., 2015).

Mt. Vesuvius is considered one of the most hazardous volcanoes worldwide due to its potential for explosive eruptions and the high population density in its surroundings (Gurioli et al., 2010; Baxter et al., 2008). However, its prolonged quiescence and the area's urban and touristic development contribute to low risk perception, complicating the implementation of effective mitigation strategies (Ricciardi et al., 2024).

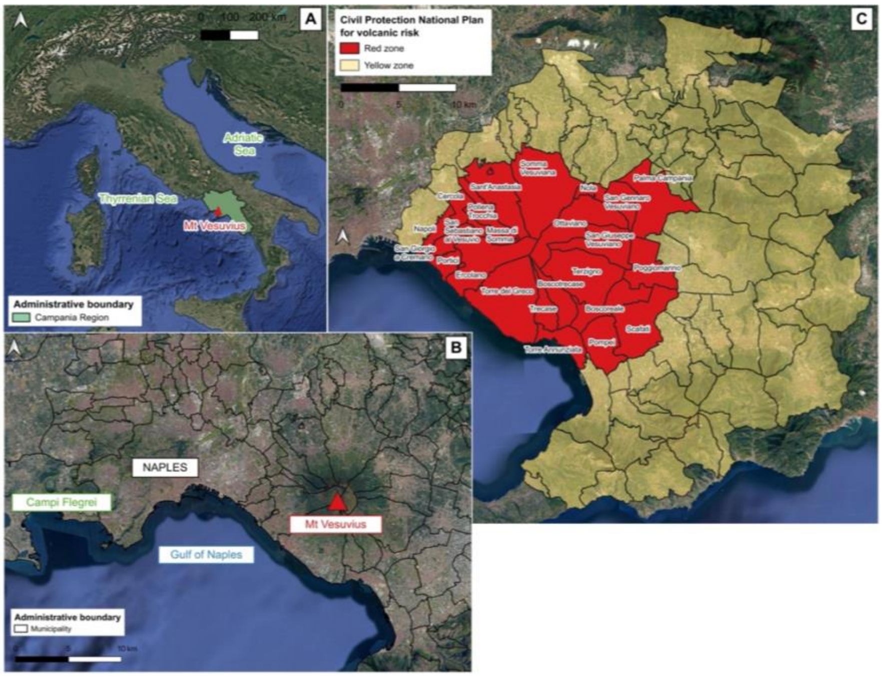
According to the United Nations Office for Disaster Risk Reduction (UNDRR, 2022), disaster risk is defined as the product of hazard, exposure, and vulnerability. In this context, the present study introduces an integrated multidimensional framework for volcanic risk assessment, combining geophysical, demographic, socioeconomic, and structural data at the enumeration area (EA) level. The aim is to support land-use planning, emergency preparedness, and cost-benefit analysis in a densely populated and complex territorial setting.

This paper focuses on the investigation and mapping of (i) volcanic hazard, (ii) exposure, (iii) vulnerability and (iv) volcanic risk in the Mt. Vesuvius area at enumeration area (EA) level in order to retrieved information about (v) inhabitants and buildings located in the different risk levels for cost-benefit analysis, land-use planning and risk mitigation. This approach, based on cartographic and statistical techniques, helps prioritize areas in need of targeted strategies to promote sustainable development, disaster preparedness, and resilience.

The Vulcanic context

Mt Vesuvius is located in the Campania region (Southern Italy) (Figure 1A) in a complex multi-source volcanic area which also include Campi Flegrei (Figure 1B) and Ischia Island. Vesuvius is considered one of the most hazardous volcanoes in the world (Giurioli et al., 2009) with 700 thousand people living on the slopes of the volcano. The National Emergency Plans for the Vesuvius area consisting of two zones (Figure 1C). The red zone, covering 25 municipalities, includes the area exposed to pyroclastic flows (Red Zone 1) and the territory at high risk of roof collapse due to the accumulation of pyroclastic deposits (Red Zone 2). The yellow zone, comprising of 63 municipalities and three districts of the City of Naples, represents the area exposed to significant fallout of volcanic ash and pyroclastic material. The red zone map does not take into account the impact that PDCs could have on buildings and people that required the distribution of the impact parameters (flow temperature, flow duration, particle concentration and flow dynamic pressure) that better represent flow intensity in terms of damage potential over the volcano's surroundings (Dellino et al., 2025).

Figure 1. Geographic setting of Mt Vesuvius within the national context (A), a zoom at the local level (B) and the municipalities included in the Civil Protection National Plan of volcanic risk (C).



Data and methods

This study applies a spatially detailed methodology to assess volcanic risk in the Mt. Vesuvius area by integrating hazard, exposure, and vulnerability indicators at the enumeration area (EA) level. The analysis relies on multiple data sources:

- **Volcanic hazard** was assessed using four key parameters of pyroclastic density currents (PDCs): flow temperature, particle concentration, flow duration, and dynamic pressure (Dellino et al., 2025). These variables were standardized and subjected to factor analysis to derive a composite **Volcanic Hazard Index**, mapped on a 250m resolution grid and rescaled from 1 (very low hazard) to 5 (very high hazard).
- **Exposure** was evaluated through population and building density. Population data were retrieved from ISTAT (2021), while building data came from the Civil Protection Department (DPC, 2021). Population exposure was calculated as the number of inhabitants per EA area, and building exposure as the number of buildings per EA area. Both were rescaled from 1 to 5 and combined into a **Total Exposure Index**.
- **Vulnerability** was divided into social and physical components. Social vulnerability was assessed using demographic and socioeconomic variables (e.g., age structure, household size, unemployment, education level) from ISTAT (2021), while physical vulnerability was based on building characteristics (e.g., construction material, age, number of floors, condition) from ISTAT (2011). Principal Component Analysis (PCA) was used to compute composite indices: **Social Vulnerability Index (SVI)** and **Physical Vulnerability Index (PVI)**, both rescaled from 1 to 5.
- **Volcanic risk** was calculated by multiplying the hazard, exposure, and vulnerability layers using GIS raster operations. The final **Volcanic Risk Index** was classified into five categories: very low, low, medium, high, and very high risk.

This integrated framework enables spatial prioritization for emergency planning, land-use regulation, and mitigation strategies.

Summarized and selected results:

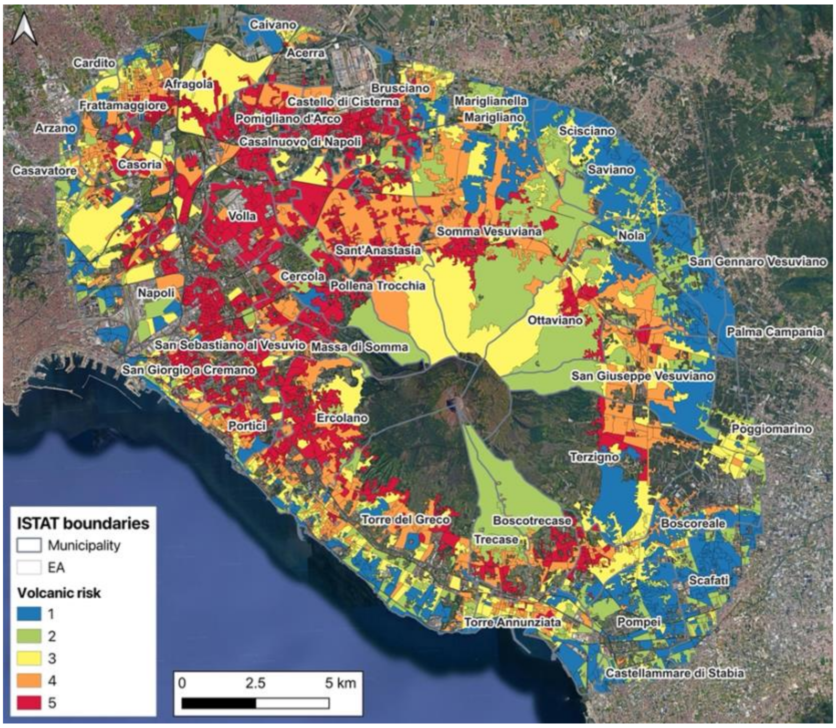
The volcanic hazard index, derived from pyroclastic density current (PDC) parameters, identifies areas with varying levels of hazard across 43 municipalities and 6,608 enumeration areas (EAs). The highest hazard levels (4 and 5) are concentrated near Mt. Vesuvius, particularly in Sant'Anastasia, Pollena Trocchia, Somma Vesuviana, Ottaviano, and Massa di Somma. Hazard intensity decreases with distance from the volcano, with outer municipalities showing lower levels (1 and 2).

Exposure analysis reveals that population and building densities are highest in coastal and urban municipalities such as Portici, San Giorgio a Cremano, Napoli, and Ercolano. Approximately 80% of municipalities show very high exposure levels (level 5). In contrast, areas closer to the volcano tend to have lower exposure due to lower population and building density.

Social and physical vulnerability indices highlight significant disparities across the study area. High vulnerability levels (4 and 5) are prevalent in western municipalities, including Volla, Portici, and Afragola, driven by demographic fragility and poor building conditions. Southeastern municipalities like Scafati, Terzigno, and Pompei exhibit lower vulnerability levels (1 and 2).

The integrated volcanic risk index, combining hazard, exposure, and vulnerability, shows that nearly 90% of the population and over 92% of buildings are located in areas exposed to volcanic risk. High and very high risk levels are concentrated in municipalities such as Sant'Anastasia, Volla, Cercola, San Sebastiano al Vesuvio, Ercolano, Portici, and Napoli. These findings underscore the urgent need for targeted mitigation and emergency planning in densely populated zones. At the scale of the entire study area, 89.24% of the population resides within EAs exposed to volcanic risk, distributed as follows: 4.63% at very low risk, 9.97% at low risk, 14.35% at medium risk, 23.23% at high risk, and 37.06% at very high risk. Regarding buildings, 92.42% are located within areas exposed to volcanic risk: 7.62% at very low risk, 11.63% at low risk, 23.23% at medium risk, 20.70% at high risk, and 29.24% at very high risk.

Figure 2. Spatial distribution of volcanic risk levels across the municipalities under investigation at enumeration area level.



References

Baxter, P. J., Aspinall, W. P., Neri, A., Zuccaro, G., Spence, R. J. S., Cioni, R., & Woo, G. (2008). Emergency planning and mitigation at Vesuvius: A new evidence-based approach. Journal of volcanology and geothermal research, 178(3), 454-473. https://doi.org/10.1016/j.jvolgeores.2008.08.015.

Dellino, P., Dioguardi, F., Sulpizio, R., & Mele, D. (2025). Long-term hazard of pyroclastic density currents at Vesuvius (Southern Italy) with maps of impact parameters. Natural Hazards and Earth System Sciences, 25(8), 2823-2844. https://doi.org/10.5194/nhess-25-2823-2025.

El Hadri H., Goujon M., Paris R. (2021) "A database of the economic impacts of historical volcanic eruptions", Études et Documents, n°14, CERDI. Available online at: https://uca.hal.science/hal-03186803v1/document.

Erfurt-Cooper, P., Sigurdsson, H., & Lopes, R. M. (2015). Volcanoes and tourism. In The encyclopedia of volcanoes (pp. 1295-1311). Academic Press. https://doi.org/10.1016/B978-0-12-385938-9.00075-4.

Gurioli, L., Sulpizio, R., Cioni, R., Sbrana, A., Santacroce, R., Luperini, W., and Andronico D.: (2010). Pyroclastic flow hazard assessment at Somma-Vesuvius based on the geological record, Bull. Volcanol., 72, 1021-1038, https://doi.org/10.1007/s00445-010-0379-2.

Kelman, I., & Mather, T. A. (2008). Living with volcanoes: the sustainable livelihoods approach for volcano-related opportunities. Journal of volcanology and geothermal research, 172(3-4), 189-198. https://doi.org/10.1016/j.jvolgeores.2007.12.007.

Loughlin, S. C., Sparks, R. S. J., Brown, S. K., Jenkins, S. F., & Vye-Brown, C. (Eds.). (2015). Global volcanic hazards and risk. Cambridge University Press. Available online at: https://www.cambridge.org/core/services/aop-cambridge-core/content/view/7653B9CA75E2F32A81CE5B7110BEF8AB/9781107111752AR.pdf/Global_Volcanic_Hazards_and_Risk.pdf?event-type=FTLA

Ricciardi, A., Scalzo, A., Cristiani, C., Fiorito, D., Durantini, M., Colombi, A., … & Spatola, P. (2024). Emergency management and risk reduction measures during the Vulcano (Aeolian Islands) unrest 2021–2023. Bulletin of Volcanology, 86(5), 42. https://doi.org/10.1007/s00445-024-01731-x.

UNDRR, Global assessment report on disaster risk reduction 2022: our world at risk: transforming governance for a resilient future, United Nations Office for Disaster Risk Reduction: Geneva, Switzerland (2022). Available at: https://www.undrr.org/gar/gar2022-our-world-risk-gar.