Bounce Back or Breakdown? Assessing Territorial Vulnerability to Repeated Disasters across European NUTS-3 Regions

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1. Introduction

Climate-related disasters and their destructive impacts have been at the forefront of public attention recently. More recent examples include the severe events in the Italian region of Emilia-Romagna and Spain's Valencian Community, which have resulted in significant disruption to local communities and extensive damage to infrastructure and economic activity. According to the latest IPCC report (IPCC, 2021), human-induced climate change is intensifying the magnitude and frequency of climate-related extreme events, with growing evidence of this trend compared to previous reports (IPCC, 2013). This finding is supported by many scholars in the research community (e.g., Mechler & Bouwer, 2015; Noy et al., 2024).

Economic development and population growth have also contributed to increased vulnerability, while the implementation of mitigation efforts has not kept pace (Hallegatte et al., 2017; Dormady et al., 2021). Additionally, there is increasing evidence that human-induced climate change has increased the probability of consecutive extreme events (IPCC, 2021). Consecutive disasters are defined as *"two or more disasters that occur in succession, and whose direct impacts overlap spatially before recovery from a previous event is considered to be completed"* (De Ruiter et al., 2020, p.2). In addition, De Ruiter et al. (2020) pointed out the reasons why we can no longer ignore consecutive disasters, highlighting the raising risk of the latter due to growing exposure, the interconnectedness of human society, and the increased frequency and intensity of climate-related hazards. Consequently, there is a heightened probability of recurrent extreme events occurring in neighbouring locations, which in turn increases the risk of spatially and/or temporally related hazards impacting the socio-economic vulnerability of affected communities. Indeed, the vulnerability of populations to hazards is shaped not only by physical proximity but also by societal factors, which play a crucial role in determining it (Cutter et al., 2000). Moreover, those most vulnerable to one risk often face heightened vulnerability across multiple threats, compounding their overall susceptibility (Kelman et al., 2016).

Highly vulnerable locations should become priority sites for climate resilient development with the aim of adapting the economic and social systems to a changing climate (Birkmann et al., 2022).

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Additionally, a comprehensive analysis of the anthropogenic factors contributing to vulnerability is vital for the proactive mitigation of disaster impacts (Raju et al., 2022). While there is some research on the potential socio-economic risks related to multiple hazards (e.g. AghaKouchak et al, 2020; De Ruiter et al. 2020) and its possible links to vulnerability (e.g. Drakes et al., 2022; Kreibich et al., 2022), still no large-N empirical study has been conducted on the potentially disruptive effects of multiple hazards on socio-economic vulnerability at the local level.

We aim to fill this gap in the literature by conducting an assessment of the effects of repeated climate-related hazards on subsequent socio-economic vulnerability at the local level. In particular, we focus on European NUTS-3 regions. We do so for a number of reasons. First, the European continent is subject to a significant risk of multiple climate-related impacts. Second, the existing literature on this topic tends to focus on specific case studies (Cutter et al., 2000; Sung and Liaw, 2021; Kohler et al., 2023), or is centered on the United States (Cutter et al., 2003), developing countries (Kim and Gim, 2020; Mechler and Bouwer, 2015) or specific individual countries (Fekete, 2009; Marin et al., 2021; Nikannen et al., 2021), leaving European countries understudied from this perspective. In addition, the literature presents mixed evidence on the effects of repeated disasters. For instance, Kohler et al. (2023) found that prior flood experience positively influences adaptive behavior but has a detrimental impact on resilience. In contrast, Kreibich et al. (2022) observed that the impact of a second disaster event tends to be lower due to enhanced risk management and increased investment. However, when the second event is an unprecedented extreme occurrence, managing its effects remains a significant challenge. In this complex framework , this study aims to contribute to the existing literature by providing empirical evidence on the differentiated impacts of multiple climate-related hazards on socio-economic vulnerability across Europe. Furthermore, the analysis seeks to identify potential limitations and opportunities for strengthening adaptive capacity at the local level. Specifically, this research examines the influence of recurrent disasters on socio-economic vulnerability, the mechanisms through which these disasters exert their effects, and the vulnerability dimensions most affected by repeated exposure.

2. Literature Review

Previous literature on vulnerability demonstrates that areas exhibiting greater vulnerability are more susceptible to the adverse effects of climate-related disasters (AghaKouchak et al., 2020; Choo and Yoon, 2024; De Silva & Kawasaki, 2018; Navarro et al., 2023; Nikkanen et al., 2021). A disaster can be defined as an event that arises from the interaction of two contrasting forces: the processes that generate vulnerability, which are primarily rooted in socio-economic conditions, and the occurrence of a natural hazard event (Chaudhary & Piracha, 2021; Gizzi, 2023; Noy &

Yonson, 2018; O'Keefe et al., 1976; Raju et al., 2022; Wisner et al., 2004). The first force is not purely natural, as it often stems from human activities that contribute to the development of vulnerabilities (Quarantelli, 2005).

However, the term vulnerability has become overused (Cannon, 2008), and measuring it is a complex task due to its multidimensional and place-based nature (Adger, 2006; De Ruiter and Van Loon, 2022; Navarro et al., 2023). Indeed, if vulnerability is measured solely in terms of income, the result will only reflect relative poverty (Adger, 2006). A substantial body of research has sought to quantify socio-economic vulnerability, frequently employing composite indicators to examine specific case studies. Examples include the United States (Cutter & Finch, 2003; Cutter et al., 2012) and Italy (Marin et al., 2021).

However, to the best of our knowledge, still no research examines the effects of repeated climate-related events on subsequent socio-economic vulnerability. Hence, we aim to fill this gap by providing the first analysis of the effects of repeated events, offering valuable insights and enabling policymakers to take proactive action in disaster risk management.

3. Methodology

3.1 Data

To the best of our knowledge, only one existing sub-national indicator of socio-economic vulnerability for European countries incorporates a temporal dimension. This indicator was developed by the Joint Research Centre (JRC, 2022; Sibilia et al., 2024) and is available at the NUTS-3 level. It is constructed based on five key dimensions: economic, environmental, political, physical and social. Each sub-dimension comprises multiple variables, which are aggregated to form the overall indicator (See Table 1 for details).

[Table 1 here]

For the purpose of our analysis, we exclude the physical dimension, which captures the impact of disasters through proxies such as total fatalities and economic losses. Including this dimension could introduce spurious correlations with our independent variables. Further details on this methodological choice are provided in the empirical strategy sub-section. For what concerns data on disasters, we specifically focus on floods. Floods are one of the costliest forms of climate-related hazards (Dottori et al, 2018), accounting for approximately 40% of the total damage caused by natural hazards (Alexander, 2018). Flood data are sourced from HANZE - Historical Analysis of Natural Hazards in Europe (Paprotny et al., 2024). This database provides comprehensive information on floods at the local level for 42 countries in Europe, including data on the number of people affected and the NUTS-3 regions impacted.

3.2 Empirical Strategy

This study investigates the key determinants of sub-national socio-economic vulnerability, with a particular emphasis on assessing the impact of both single and recurrent climate-related disasters. Given that vulnerability at time *t* is influenced by its level in the preceding period (*t-1*), we incorporate the lagged variation of the vulnerability index as a control variable in our model specification. However, this inclusion introduces endogeneity, as the independent variables become correlated with the error term (ϵ). To address this issue, we apply a bias-corrected estimation approach for linear dynamic panel data models, as proposed and implemented by Breitung, Kripfganz, and Hayakawa (2022). The model specification is as follows:

$$\Delta_{vuln\,j,i,t} = \beta_0 + \beta_1 \cdot first_{i,t} + \beta_2 \cdot second_{i,t} + \beta_3 \cdot third_{i,t} + \beta_4 \cdot first_{i,t-1} + \beta_5 \cdot second_{i,t-1} + \beta_6 \cdot third_{i,t-1} + \beta_7 \cdot \Delta vul_{j,i,t-1} + \beta_c \cdot controls_{j,i,t} + \epsilon_{j,i,t}$$

where *j* represents the different vulnerability indicators (overall index, social, economic, environmental, and political), *i* denotes NUTS-3 regions, and *t* corresponds to the year. A detailed description of the variables is provided in Table 2.

[Table 2 Here]

4. Preliminary Results

Preliminary findings suggest that the first disaster event has a positive effect on socio-economic vulnerability, whereas the second event does not produce significant effects, except for the social dimension. Interestingly, the third event appears to have little to no impact and, in some cases, even a negative effect, potentially indicating an adaptation mechanism. However, this pattern does not hold for social vulnerability, which continues to increase. This highlights the importance of social factors in understanding how disasters affect populations and societies.

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List of tables

Table 1: Variables included in the composite indicator, divided by dimensions – Source Sibilia et al. (2024)

Scale	Indicator	Source
	Social	
NUTS 0	Projected population change	Eurostat
NUTS 0	Children at-risk-of-poverty	Eurostat
NUTS 0	Disabled people with need for assistance	Eurostat
NUTS 0	Long-term care (health) expenditure	Eurostat
NUTS 0	Change in Age-dependency	Eurostat
NUTS 0	Self-reported unmet need for medical care	Eurostat
NUTS 0	Perceived Good Health	Eurostat
NUTS 2	Life expectancy	Eurostat
NUTS 2	Hospital beds per 100,000 population	Eurostat
NUTS 2	Participation in Social Networks	Eurostat
NUTS 2	Internet access (once a week or more)	Eurostat
NUTS 2	People at risk of poverty or social exclusion	Eurostat
NUTS 2	Primary and lower secondary education	Eurostat
NUTS 2	People with tertiary education	Eurostat
NUTS 3	Population density	Eurostat
NUTS 3	Net migration	Eurostat
NUTS 3	Average distance to healthcare facilities	Eurostat
NUTS 3	Access to Local Services	JRC.B3
NUTS 3	Young dependency	JRC.B3/LUISA
NUTS 3	Old dependency	Eurostat
	Economic	
NUTS 0	Gross National Saving	WBG
NUTS 0	GDP per capita	Eurostat
NUTS 0	Income Inequality	Eurostat
NUTS 0	Cultural heritage	UNESCO
NUTS 2	Severe material deprivation rate	Eurostat
NUTS 2	Household income	Eurostat
NUTS 2	Motorways	Eurostat
NUTS 2	Railways	Eurostat
NUTS 2	Employment rate	Eurostat
NUTS 3	GDP per capita vs country average	Eurostat
NUTS 3	Gross Value Added per capita	Eurostat
NUTS 3	Power plants per 100,000 inhabitants	WRI
NUTS 3	Patent applications to the EPO	Eurostat
	Political	
NUTS 0	Governmental efficiency	WGI
NUTS 0	Political Stability	WGI
NUTS 0	National Adaptation Strategies	Climate-Adapt
NUTS 2	Regional Quality of Governance index	QoG
	Environmental	
NUTS 0	Environmental protection expenditure	Eurostat
NUTS 0	Environmental goods and services sector	Eurostat
NUTS 0	Common farmland bird index	Eurostat
NUTS 0	Natural areas (CLC)	CORINE
NUTS 0	Environmental Performance Index	SEDAC
NUTS 2	Proportion of artificial surfaces	CORINE
NUTS 2	Proportion of agricultural areas	CORINE
NUTS 2	Proportion of forest and seminatural areas	CORINE
NUTS 3	Green urban areas vs other artificial surfaces	CORINE
NUTS 3	Land take intensity	CORINE

Table 2: Dependent and Independent variables

Variable	Description	Source
Dependent Variables		
$\Delta vuln\_index$	Annual variation of Vulnerability Index (no physical dimension)	JRC (2022)
$\Delta vuln\_social$	Annual variation of Social Vulnerability	JRC (2022)
$\Delta vuln\_economic$	Annual variation of Economic Vulnerability	JRC (2022)
$\Delta vuln\_political$	Annual variation of Economic Vulnerability (at the NUTS-2 level)	JRC (2022)
$\Delta vuln\_environment$	Annual variation of Environmental Vulnerability	JRC (2022)
Independent Variables and Controls		
$first$	Dummy of first flooded year	HANZE (2024)
$second$	Dummy of second flooded year	HANZE (2024)
$third$	Dummy of third flooded year	HANZE (2024)
$\ln pop$	Logarithm of the population	EUROSTAT
$vuln\_index$	Vulnerability Index (no physical dimension)	JRC (2022)
$vuln\_social$	Social Vulnerability	JRC (2022)
$vuln\_economic$	Economic Vulnerability	JRC (2022)
$vuln\_political$	Political Vulnerability (At the NUTS 2 level)	JRC (2022)
$vuln\_environment$	Environmental Vulnerability	JRC (2022)