# FRAGILITY IN ITALIAN MUNICIPAL TERRITORIES: A SPATIAL ANALYSIS BASED ON OFFICIAL STATISTICS[1]

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**Abstract.** This study analyses social fragility in Italian municipalities, aiming to provide a structural and spatial interpretation of vulnerability at the local level. Fragility is assessed through the Municipal Fragility Index (IFC), developed by Istat, a multidimensional and non-compensatory tool that integrates twelve elementary indicators related to demographic, social, economic, environmental, and territorial dimensions. Fragility is conceptualized as a lack of territorial resilience, shaped by weak human capital, limited service infrastructure, and environmental exposure. The methodological approach combines spatial analysis using Local Indicators of Spatial Association (LISA), based on Local Moran's I statistics, with unsupervised learning (k-median clustering), allowing for the identification of five distinct profiles for each dimension and a synthetic classification of municipalities into four types (T1–T4) based on cumulative fragility patterns. The study supports policy design aimed at reducing spatial inequalities.

## 1. Introduction and Conceptual Framework

Territorial fragility is a significant dimension for understanding inequalities in Italy. The country is indeed marked by strong spatial disparities that manifest at various levels: socio-economic, demographic, environmental, and infrastructural. These imbalances are not only historically rooted but also tend to intensify in times of crisis—be they economic, health-related, or environmental—revealing the differing capacities of territories to absorb shocks and respond to change (Benassi *et al.*, 2022; Frigerio and De Amicis, 2016; Frigerio *et al.*, 2018).

The notion of territorial fragility represents an important conceptual perspective, as it allows us to grasp the multidimensionality of vulnerabilities at the local level. Here, it is understood as a structural condition that expresses the exposure of a municipality to natural and anthropogenic risks, in combination with socio-demographic weaknesses and economic vulnerabilities. This condition can

[1] The work is the joint responsibility of the authors. Paragraph 1 and 2 is attributed to Alberto Vitalini, paragraphs 3 and 4 are attributed to Simona Ballabio.

undermine the territory's ability to ensure well-being, resilience, and sustainable development for the resident population (Istat, 2024).

Territorial fragility can be distinguished from related concepts such as resilience, marginality, and deprivation, although it shares some analytical dimensions with them. Unlike resilience, which refers to a territory's capacity to react and adapt to shocks and changes (Mentges *et al*., 2023), fragility highlights the structural conditions that hinder such adaptation (OECD, 2022). It includes, but is not limited to, elements of marginality, such as isolation and limited accessibility to essential services. However, while marginality often denotes a peripheral condition, either spatial or relational (UVAL, 2014), fragility adopts a systemic perspective, integrating demographic, social, economic, and environmental factors. Similarly, in contrast to deprivation, which primarily concerns a lack of resources at the individual or household level, fragility operates at the collective and territorial scale, offering a useful framework for designing integrated cohesion and development policies.

Within the theoretical framework outlined above, this study aims to offer a spatial reading of municipal territorial fragility in Italy, using an index produced within the framework of official statistics that adopts an integrated methodological approach (Istat, 2024). In particular, the use of a spatial approach—through tools of geographic autocorrelation (LISA)—makes it possible to highlight relationships between neighboring municipalities and to capture phenomena of systemic fragility. The study then focuses on the most fragile municipalities in the country, in order to construct an internal typology of this subgroup and distinguish between different forms and degrees of fragility.

The reflection proposed here fits within the broader framework of analyses on territorial cohesion and inequalities, providing useful evidence for guiding intervention strategies that are capable of responding to the complexity and diversity of local situations.

## 2. Methodology

The analysis is based on the use of the Municipal Fragility Index (IFC), developed by Istat, which provides a synthetic measure of the structural vulnerability of Italian municipalities (Istat, 2024). The index is designed to identify territories most exposed to risks and criticalities and to support analyses that are comparable across space and time. Its structure is multidimensional and is based on twelve elementary indicators divided into two main domains: territorial-environmental and socio-economic.

### *2.1 Information Sources and Territorial Scope*

The data underlying the index used come from official Istat sources, including: the demographic balance of the resident population; the permanent census of population and housing; territorial, environmental, and economic indicators available at the municipal level[2].

The unit of analysis is the Italian municipality, with a reference year of 2021, the most recent available at the time of the analysis. In an initial exploratory phase, a LISA spatial analysis was conducted on all Italian municipalities, aimed at identifying spatial clusters of fragility.

Subsequently, the analysis was restricted to the municipalities falling within the last three deciles (8th, 9th, and 10th) of the IFC distribution, representing the most fragile territories at the national level, totalling 2,019 municipalities.

### *2.2 Municipal Fragility Index (IFC)*

The IFC is a non-compensatory composite index, calculated using the Adjusted Mazziotta-Pareto Index (AMPI+), which corrects the average effect of the arithmetic mean through a penalty linked to indicator variability. It assumes that the dimensions of fragility are not (or only partially) substitutable, meaning a disadvantage in one cannot be offset by an advantage in another (Mazziotta & Pareto, 2024).

All indicators are normalized with respect to the 2018 national value, set equal to 100, using a linear transformation based on specific goalposts. The final value of the index, calculated for each municipality, reflects both the average level of fragility and the internal consistency among the dimensions considered.

The two thematic areas of the index include:

- Territorial and environmental indicators:
  - Landslide hazard (percentage of municipal area at risk)
  - Incidence of protected natural areas (protected surface as a percentage of total municipal area)
  - Land consumption (percentage of urbanized land)
  - Accessibility to essential services (average travel time to services)
  - High-emission motorization (Euro 0–3 vehicles per 100 inhabitants)
  - Non-recyclable waste collection (kg per inhabitant)
- Economic and social indicators:
  - Workers in low-productivity units (percentage share in industry and services)

[2] Available at https://esploradati.istat.it/databrowser/#/it/dw/categories/IT1,Z0930TER,1.0/CFI_MUN

- Density of local production units (units per 1,000 inhabitants)
- Employment rate (age 20–64, employed over working-age population)
- Population growth rate (net migration balance)
- Adjusted demographic dependency ratio (youth + elderly relative to population aged 20–64)
- Population with low educational attainment (aged 25–64 with at most lower secondary education)

### *2.3 Clustering Analysis*

To deepen the understanding of the different dimensions of fragility, an unsupervised classification of the most fragile municipalities was carried out through two separate clustering exercises: one focused on the territorial and environmental domain, and the other on the economic and social domain. The goal is to identify homogeneous groups of municipalities that share similar structural characteristics within each set of variables.

In both cases, the k-median clustering algorithm was used (which selects as the centroid of each cluster an actual data point: the median). This method is particularly robust in the presence of skewed distributions and outliers. It proved well-suited to the heterogeneous and highly variable nature of municipal-level territorial data.

The distance metric used to calculate similarity between municipalities was the Manhattan distance (also known as city block distance), which is more appropriate than Euclidean distance for standardized and multidimensional data. Prior to applying the algorithm, all variables were standardized to eliminate the influence of measurement scales and to ensure equal weight among the indicators.

The number of clusters was fixed in advance at 5 for each domain, based on empirical considerations, result stability, and interpretability from a policy perspective. This choice also ensured symmetry between the two readings and facilitated the subsequent construction of an integrated fragility typology.

### *2.4 Construction of a Fragility Typology*

The interpretative and operational aim of the study required the development of a synthesis capable of integrating two distinct analytical perspectives—socio-economic and territorial-environmental—into a single typological variable. To this end, after conducting the two independent clustering analyses on the socio-economic variables (CL_soc) and the territorial-environmental variables (CL_terr), a combined four-class typology was constructed. This step was not carried out through an additional automated statistical procedure, but rather as a logical-interpretive

operation based on the cross-referencing of the clusters obtained in the two domains, without assuming any implicit hierarchical order.

The intersection of the two classifications initially generated an attribute space structured as a 5x5 matrix, resulting in 25 theoretical combinations. These combinations were then aggregated into a synthetic typology, based on reduction criteria that considered the overlap or divergence of fragility dimensions, the intensity of the phenomenon, and operational clarity for policy-making purposes. This allowed a transition from the attribute space (based on the original variables to the space of interdimensional configurations (CL_terr × CL_soc), constructing an explanatory typological variable.

The resulting typology makes it possible to go beyond the separate analysis of individual domains, offering a synthetic yet informed interpretation of vulnerability combinations. This is useful for setting intervention priorities and differentiating territorial policies. The results have been assigned to each municipality and serve as the basis for the typological and territorial analysis presented in the following section of the paper.

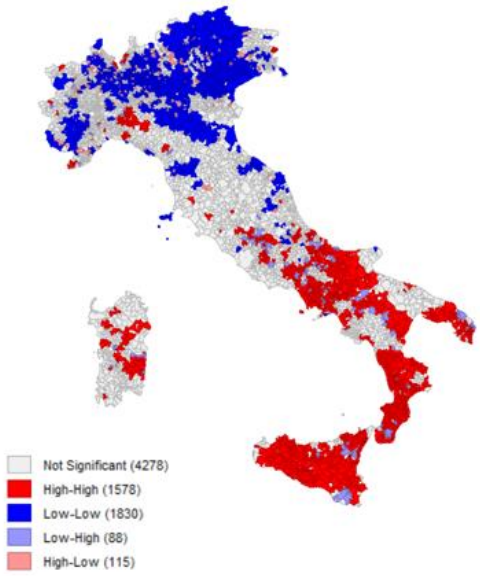
## 3. Results

### *3.1 Spatial Distribution of Fragility: LISA Analysis*

The exploratory analysis carried out using the Local Indicators of Spatial Association (LISA) made it possible to identify significant patterns of homogeneous fragility among neighboring municipalities. Clusters of the High-High type emerged—groups of municipalities with high levels of fragility surrounded by others with similarly high fragility—as well as Low-Low clusters, representing "islands of resilience" within structurally robust areas (Figure 1).
The LISA cluster map highlights a well-known and marked territorial polarization:

- Northern Italy: A predominance of Low-Low clusters, particularly in urban and flat areas of the North-West and North-East, confirming the stronger structural and infrastructural capacity of these regions.
- Central Italy: A mix of areas, with High-High clusters mainly located in the inland Apennine regions (Abruzzo, Molise, Lazio) and Low-Low clusters in metropolitan cities and along the Tyrrhenian coast.
- Southern Italy and the Islands: A widespread concentration of High-High clusters, especially in Calabria, Sicilia, Campania, Basilicata, and inland Sardegna. These areas exhibit systemic fragility, evenly distributed across large portions of the territory.

**Figure 1 –** *Italian municipalities by IFC. LISA values, year 2021.*




### *3.2 Environmental and Territorial Typologies (Clusters A1–A5)*

As mentioned in the previous section, the clustering analyses and the subsequent construction of the typology were limited to municipalities falling within the last three deciles (8th, 9th, and 10th) of the IFC distribution. These deciles identify municipalities characterized by high, very high, and extreme levels of fragility, representing the most structurally vulnerable territories at the national level.

The analysis of the physical and infrastructural characteristics of municipalities, conducted through clustering techniques, made it possible to identify five environmental and territorial profiles. Each cluster reflects a distinct configuration of vulnerability, resulting from the combination of variables related to accessibility, environmental protection, and anthropogenic pressure. This classification provides a clearer representation of the geography of environmental and infrastructural fragility, highlighting the heterogeneity of conditions in more peripheral and marginal contexts (Figure 3).

*Cluster A1 – Accessible municipalities with low environmental protection*. This represents the least critical configuration. It mainly includes flat and urban areas in the North and Centre of Italy, characterized by good infrastructure but limited coverage of protected natural areas. In this case, fragility is linked to potential risks from land consumption and a reduced presence of ecological buffers.

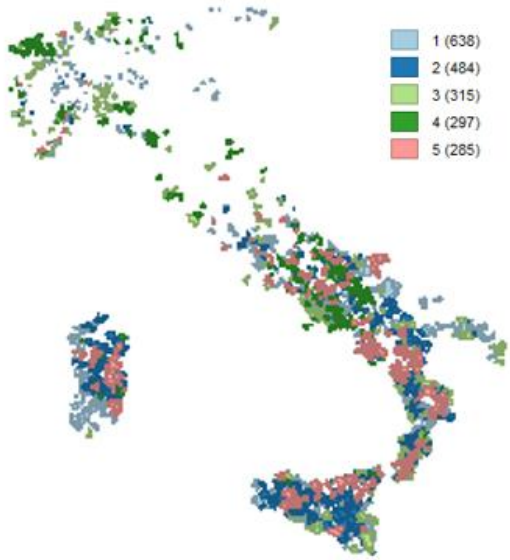
*Cluster A2 – Peripheral areas under high anthropogenic pressure*. Primarily concentrated in the South and the Islands, these areas suffer from poor accessibility to essential services and a highly polluting vehicle fleet. Infrastructural marginality combines with high environmental pressure, outlining a multidimensional vulnerability scenario.

*Cluster A3 – Municipalities with multiple environmental issues*. Mainly located in mountainous and hilly areas, these municipalities are marked by high exposure to hydrogeological risks (landslides, instability) combined with inefficiencies in waste management systems. These are internal and marginal territories, often penalized by persistent infrastructural weaknesses.

*Cluster A4 – Areas with partial environmental protection and difficult access*. Typical of Alpine and Apennine systems, these areas have some presence of protected zones but suffer from poor accessibility and vulnerability to natural hazards. Partial environmental protection is not enough to offset territorial isolation.

*Cluster A5 – Isolated natural areas with high emission levels*. These are sparsely populated areas with significant natural features but burdened by a high incidence of polluting vehicles. This configuration is common in Sardinia and some inland areas of Sicilia, where isolation coexists with latent vulnerabilities.

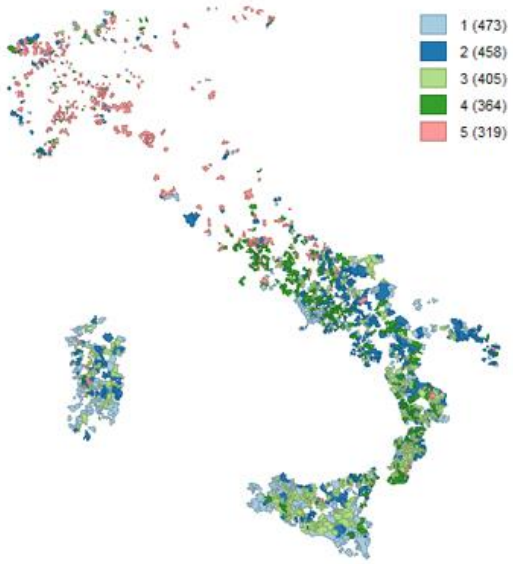
**Figure 3 –** *Choropleth map of municipal fragility typology – environmental and territorial dimension (Cluster A), year 2021*



### *3.3 Socio-Economic Typologies (Clusters S1–S5)*

The analysis of social and economic dimensions led to the identification of five municipal profiles, resulting from a classification based on human capital composition, demographic dynamics, social cohesion, and productive structure. The resulting taxonomy captures differences in levels of social fragility across territories, with particular attention to the quality of human resources and the resilience of local communities. The first three clusters represent the most vulnerable configurations, while the last two reflect relatively more favorable conditions, especially from a social standpoint (Figure 4).

**Figure 4 –** *Choropleth map of municipal fragility typology – social and economic dimension (Cluster S), year 2021*




*Cluster S1 – Socially vulnerable municipalities with partial economic stability*. Includes territories with negative demographic trends, low education levels, and fragile social structures. It is widespread in various inland areas of the South and the Islands, as well as in some marginal zones of Central Italy.

*Cluster S2 – Productive areas with marked social fragilities*. These municipalities show a relatively dense productive fabric, accompanied by weak social conditions: low educational attainment, high demographic dependency, and low employment. Found primarily in Southern Italy and Sardegna, but also in some peri-urban areas of the Centre.

*Cluster S3 – Marginal territories with structural social deprivation*. This is the most critical configuration in social terms. It is marked by low employment rates, demographic unattractiveness, a depleted human capital base, and significant social vulnerability. It is widely present in the South, the Apennine hinterlands, and much of Sicilia, outlining a geography of marginality that aligns with the country's historical divides.

*Cluster S4 – Municipalities with relatively strong human capital but economic vulnerabilities*. Represents an intermediate profile, where the presence of social resources—such as higher educational levels or a more balanced demographic structure—partially offsets economic difficulties. These territories are distributed unevenly, with notable concentrations in Central Italy (Tuscan-Umbrian-Marchigian Apennines), parts of Sardegna, and the North-East.

*Cluster S5 – Socially resilient contexts with strong cohesion*. This is the most solid typology. It includes municipalities with good education levels, positive migration balances, demographic attractiveness, and a more balanced social structure. It is largely prevalent in Northern Italy (particularly in Lombardia, Emilia-Romagna, Veneto, and Trentino-Alto Adige), with smaller clusters also found in urban centers of the Centre.

### *3.4 Types of Combined Fragility (T1–T4) and Territorial Analysis by Macro-Area*

The integration of the environmental-territorial and socio-economic classifications led to the definition of a four-class synthetic typology, aimed at representing the main interdimensional configurations of fragility among the selected municipalities (Tab. 1). The resulting profiles reflect significant differences in the intensity and nature of vulnerabilities and offer a useful basis for guiding differentiated intervention policies.

*T1 – High combined fragility*. Represents the most exposed municipalities, where socio-economic and environmental -infrastructural vulnerabilities overlap. These areas face marginality, poor service access, low human capital and employment, and high physical risks.

*T2 – Predominantly social fragility*. Includes municipalities with mainly social vulnerabilities, marked by low education, employment challenges, demographic dependency, and weak cohesion, while environmental conditions are less critical.

*T3 – Predominantly environmental fragility*. Comprises territories with infrastructural shortcomings, physical isolation, or exposure to environmental risks, yet with relatively solid social conditions.

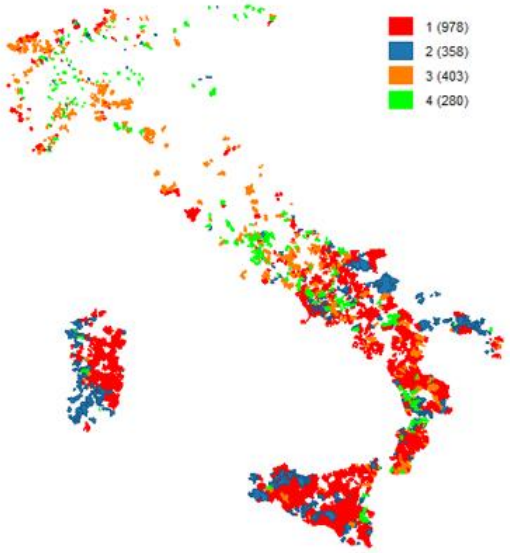
*T4 – Relatively lower fragility*. It includes municipalities with more limited levels of vulnerability across both dimensions, characterized by a relatively favorable

balance between social and environmental resources.

**Table 1. -** *Mapping between environmental and socio-economic cluster combinations and synthetic fragility typologies (T1–T4).*

| | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|
| A1 | T2 | T2 | T2 | T4 | T4 |
| A2 | T1 | T1 | T1 | T3 | T3 |
| A3 | T1 | T1 | T1 | T3 | T3 |
| A4 | T1 | T1 | T1 | T3 | T3 |
| A5 | T1 | T1 | T1 | T3 | T3 |

**Figure 5 –** *Choropleth map of total municipal fragility typology (T), year 2021*.




The territorial distribution of the typologies reveals clear regional differences. Northern Italy is dominated by T4 and T3 typologies, indicating more selective or moderate fragility, particularly in environmental terms. Central Italy presents a heterogeneous picture, with all typologies present, but a higher incidence of T2 and T3 in inland and mountainous areas. Southern Italy and the Islands show the highest concentration of T1 and T2, reflecting widespread and multidimensional fragility, with pronounced social vulnerabilities even in areas with relatively favorable physical conditions (Figure 5).

## 4. Discussion, Policy Implications and Conclusions

The analysis reveals a geography of territorial fragility in Italy characterized by marked spatial and structural discontinuities. Persistent North–South divides coexist with more nuanced forms of internal marginality, particularly in mountainous and Apennine areas of the Centre and North, while more resilient dynamics emerge in major metropolitan zones.

The clustering and resulting typology (T1–T4) provide a nuanced understanding of fragility, distinguishing not only its intensity but also its nature—offering concrete implications for targeted and differentiated policy design:

*T1 – Combined fragility (environmental + social): r*equires integrated actions across infrastructure, environment, and human capital. Isolated measures would be insufficient in these highly disadvantaged contexts.

*T2 – Predominantly social fragility:* found in municipalities with good environmental conditions but social and demographic weaknesses. Interventions should focus on education, services, and strengthening territorial attractiveness.

*T3 – Predominantly environmental fragility*: calls for environmental planning, risk mitigation, and adaptive strategies to preserve physical resilience.

*T4 – More resilient contexts*: represent models to protect and reinforce through sustainability, prevention, and territorial cohesion strategies.

Methodologically, the study combines an institutional fragility index (IFC), clustering, and spatial analysis (LISA), enabling a systemic and localized reading of territorial fragility.

Looking ahead, this framework can evolve through time-series analysis and additional data sources, offering valuable support for territorial planning in an era of environmental, demographic, and digital transitions. Understanding differentiated forms of fragility is essential for effective, equitable, and sustainable public action.

## 5. Temporal limitations and sensitivity of the socio-economic component

It is important to emphasize that the analysis is based on data from the year 2021, the most recent available at the time of the study. This temporal constraint implies that the results provide a snapshot of territorial fragility in the immediate post-pandemic period. Although the Municipal Fragility Index (IFC) is designed to capture structural vulnerabilities, some dimensions—particularly those related to socio-economic conditions—may be subject to short- and medium-term variations.

In order to assess the sensitivity of the index to the pandemic phase, preliminary analyses were conducted using data from different reference years (pre- and post-pandemic). These explorations did not reveal significant changes in the overall levels

of fragility, suggesting a relative stability of the IFC during the period considered. This does not exclude, however, the possibility that delayed structural effects may emerge over time, especially in relation to demographic shifts, employment conditions, or access to services. In this regard, the analysis may be appropriately updated as soon as more recent data become available, with the aim of capturing any transformations that may have occurred across territories.

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