Identification of urban critical context using multi-risk composite-index

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MOTIVATION

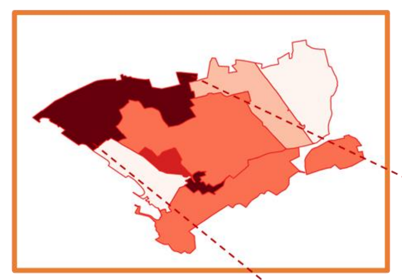
Given the complexity of the urban environment and the intricate social fabric within cities the multi-risk assessment in urban settlements is a particularly challenging task. The nature of urban risk is inherently multi-dimensional, encompassing physical, social, economic, institutional, and environmental factors. Each element of the systems constituting the urban settlement is characterized by different exposure and vulnerability to natural hazards. Moreover, the key features of the exposed elements can vary spatially and temporally, leading to an even more complex estimation of potential across an urban area. Additionally, the interrelated nature of various hazards adds another dimension of complexity to traditional risk frameworks.

The prioritization of urban areas exposed to natural hazard risks provides several advantages for effective risk management and mitigation strategies. Concentrating efforts on high-risk areas is often more cost-effective, as it minimizes the need for widespread interventions and allows for the efficient allocation of limited resources.

RESEARCH OBJECTIVES

This study presents a framework for integrating multiple dimensions in risk analysis aimed to **CRITICAL URBAN CONTEXT and URBAN HOTSPOT identification**

CRITICAL URBAN CONTEXTS



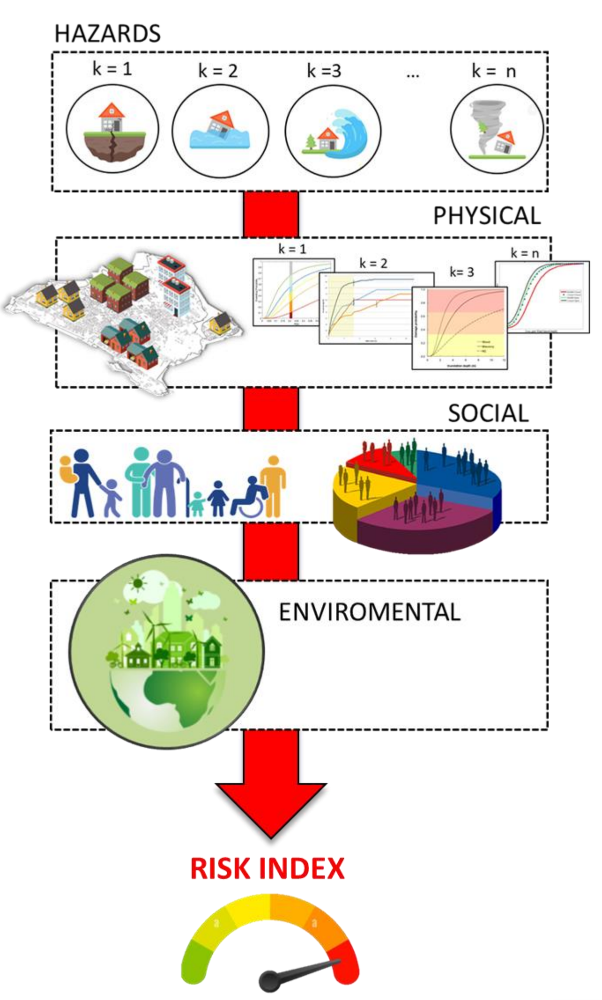
They represent **a part of an urban settlement** in which certain interconnected hazards and effects (compound events and/or cascading effects) act on specific vulnerability and exposure concerning resources, assets and people.

Urban Hotspot are built-up areas in which risks are higher.

More details for the area **urban hot-spot**

METHODOLOGY

A straightforward **risk index** that combines multiple hazards and physical, social, and environmental exposure and vulnerability information is proposed. The index is obtained by combining single indicators representative of the aforementioned dimensions, resulting in a more holistic representation of risk.

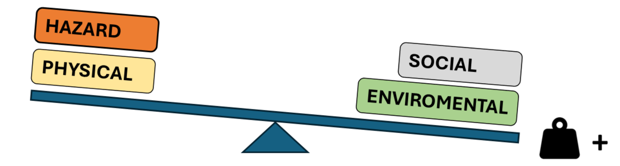


A composite index is a mathematical combination of a set of individual sub-indicators that represent different dimensions of a concept and have no common unit of measurement

Building the proposed multi-risk index

SELECTION: Indicators representative of the dimensions considered

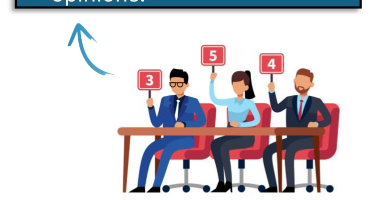
HAZARD
PHYSICAL
SOCIAL
ENVIROMENTAL



NORMALIZATION: Normalization is required to transform indicators that have different measurement units into pure, dimensionless, numbers.

WEIGHTING: Weights assigned to single indicators should reflect their importance in expressing the considered phenomenon.

The choice of the weights can be based on ***participatory methods*** that allow to incorporate various stakeholders' opinions.



AGGREGATION: Mathematical operators used to aggregate indicators

Partially compensatory

The aggregation is geometric, where, compared to a linear aggregation, a high value of one risk index does not compensate as much as for a low value of another type of risk index.

The proposed integrated multi-risk index for the jth sub-area (e.g. an urban district or census tract) of the urban settlement within a broader area of interest and considering Nh hazards is calculated according to:

$$R_J = \prod_{k=1}^{N_h} [(I^k_{PH,j})^{w_{ph}} \cdot (I^k_{SO,j})^{w_{so}} \cdot (I^k_{EN,j})^{w_{en}}]^{w_k}$$

Physical risk index with respect to hazard k and sub-area j

Social risk index with respect to hazard k and sub-area j

Environmental risk index with respect to hazard k and sub-area j

These **indices** define the integrated risk of the physical, social and environmental systems, considering the number of exposed assets to a given hazard (e.g., percentage of buildings located in hazard-prone area) taking into account also their vulnerability features influencing their response to hazards (e.g., the ratio between buildings with the poorest characteristics and the total number of buildings in the urban context) and the hazard intensity level which they are exposed to.

w_{ph}, w_{so} and w_{en} are the **weights** adopted for each dimension of the index, representing the relative importance of individual dimensions in characterizing the risk, while w_k represents the weight associated to hazard k in the multi-risk framework. As discussed before, such weights could be defined by stakeholders based on their objectives and priorities.

Single risk indices are obtained by aggregating normalized values of variables involved, thus they range between 0 and 1. Weights also vary between 0 and 1 and sum to 1. The final multi-risk index ranges from 0 and 1, with larger values indicating sub-regions that are prone to hazards of higher intensity, with exposure characterized by highest vulnerability.

HAZARD

Establish the set of indicators allowing the characterization of the hazard and its intensity level

- Which hazards should be considered?
- Which is the multi-hazard scenario of interest?

OBJECTIVES

Establish the risk/impact with respect to which the Critical Urban Context has to be defined

- Which is the main aim of the analysis?
  - *Reduce mortality/affected population*
  - *Reduce economic losses*
  - *Reduce damage to critical infrastructures & disruption of basic services*

ASSETS

1. Establish the exposed assets of the urban system that contribute to the risk/impact
2. For each exposed asset select the set of indicators allowing the characterization of integrated exposure

- Which exposed elements of the urban system play a crucial role?

INDEX

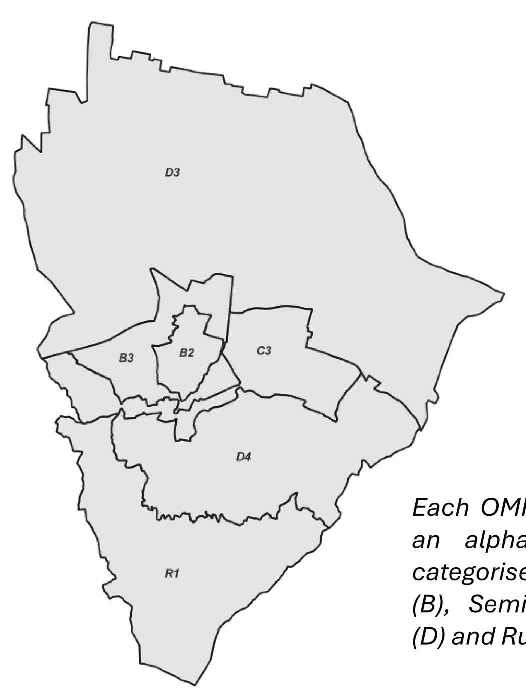
For each urban context (i.e., district or census tract):

1. For each considered hazard evaluate the risk/impact with suitable combination of hazard and integrated exposure
2. Suitably combine the risk/impact evaluated for each hazard to obtain an integrated multi-risk index that is representative for the chosen impact metric

CRITICAL URBAN CONTEXT

APPLICATION AND RESULTS

Case study:
Somma Vesuviana, a municipality in the southern Italy



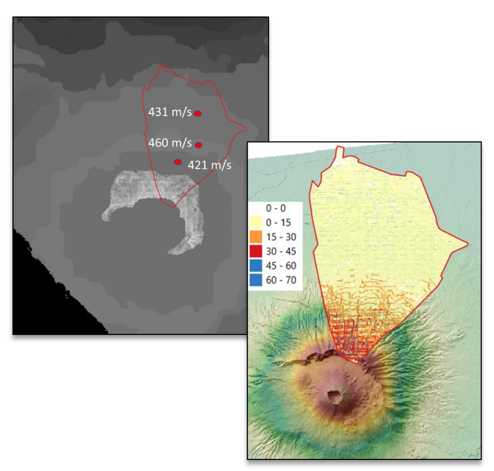
Each OMI zone is identified by an alphanumeric code that categorises the zone as Central (B), Semi-central (C), Suburb (D) and Rural (R).

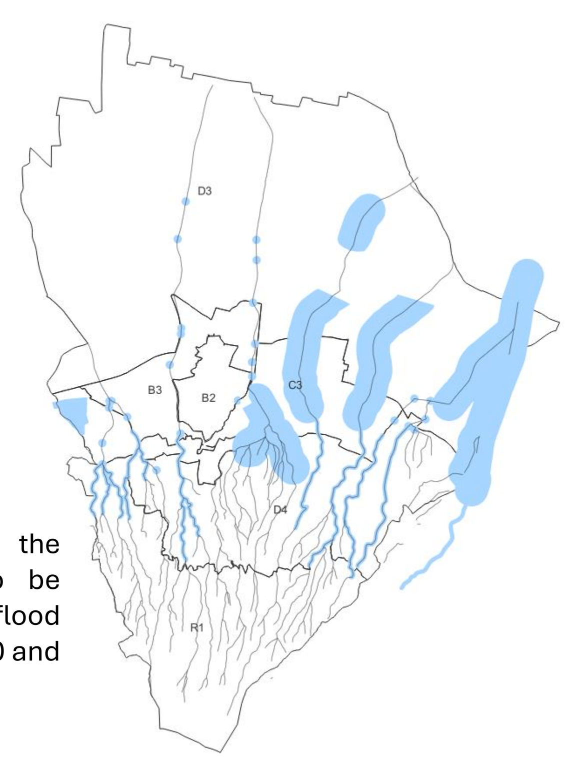
OMI zones are defined as **URBAN DISTRICTS**

The real estate observatory (Osservatorio del Mercato Immobiliare – OMI – in Italian), for which open source data and maps are available, identifies homogeneous municipal areas based on maximum/minimum market and lease real estate values, expressed in euro per surface unit (square meters), type of property and state of conservation. Also, such maps usually identify areas representing the historical center of the municipality, accounting for the historical evolution of the urban settlements as well.

1. The hazardous events considered are **earthquakes** and riverine **floods**

2. The **seismic hazard indicator** is derived from a measure of earthquake-induced ground shaking (PGA value for 475-year return period) at the district level, which is quantified according to MPS04 (Stucchi et al., 2011). PGA value at municipal centroid is assumed as hazard input for all zones. Soil amplification effects are also considered.





The adopted **flood hazard indicator** is the percentage of OMI zone area expected to be inundated according to the medium probability flood scenario (with a mean return period between 100 and 200 years) by ISPRA.

3. The **risk metric** with respect to which the Critical Urban Context has to be defined is the direct economic loss due to structural/non-structural damages of residential buildings and their contents.

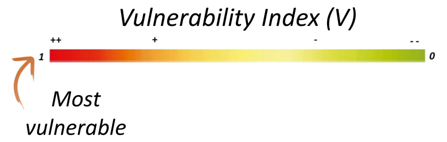
4. As exposed asset for this application only **residential buildings** are considered.

5. To characterize the integrated exposure (assessment of exposure taking into account the vulnerability) the vulnerability indicators of physical assets (in this case of the buildings), expressing the susceptibility of buildings to be damaged by the considered *k* hazardous events, have to be determined.

Seismic integrated exposure indicator - $I^{k_1}_{PH,j}$

Risk-UE (Lagomarsino & Giovinazzi, 2006)

Vulnerability Index (V)



1. Initial value of V:
   - Construction material
   - Structural system
   - Type of design

$V_{in} + \Delta V = V_{fin}$

2. Other informations on typological factors are considered through an appropriate variation ΔV
   - Storey number
   - Slab type
   - Tie rods

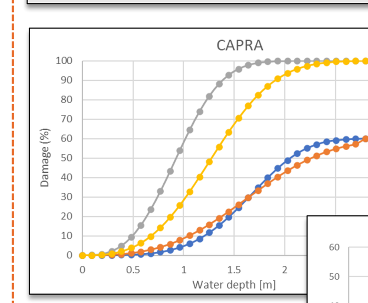
It is first evaluated at the **building class level**, *adopting* ***census data*** *and* ***suitable exposure/vulnerability model.***

Then, the final municipal-level indicator is obtained as a weighted average based on building class presence in the municipality.

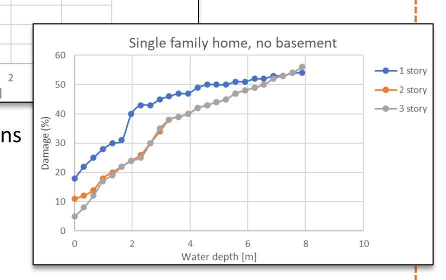
Physical exposure

Flood integrated exposure indicator - $I^{k_2}_{PH,j}$

The percentage of buildings with 1 story at OMI zone level



CAPRA depth-loss functions (Cardona et al., 2012).



HAZUS depth-loss functions (FEMA, 2022)

The only buildings feature expected to significantly affect their flood performance is the height

6. Having determined the hazard and integrated exposure indicators, the risk index for each considered hazard can be determined.

$$I^k_{PH,j} = \frac{(H^k_j + VE^k_{PH,j})}{2}$$

Where:
- *PH* denotes the physical asset (in this application only residential buildings are considered as physical asset exposed)
- H^k_j is the normalized value of the hazard intensity level in the *j-th* district for the *k-th* hazard
- $VE^k_{PH,j}$ is the normalized value of the integrated exposure indicator in the *j-th* district for the *k-th* hazard

Note that risk indices are calculated adopting the linear aggregation, i.e., a **compensatory approach** (*Nardo et al., 2008*), assuming that hazard and integrated exposure information have the same importance (i.e., without weighting single indicators). This means that a low value of the integrated exposure can be totally compensated by a high value of the hazard and vice-versa.

The **min-max transformation** is adopted as normalization method. Each variable value is converted to a normalized value by subtracting the minimum value and dividing by the range of the indicator values, according to following equation:

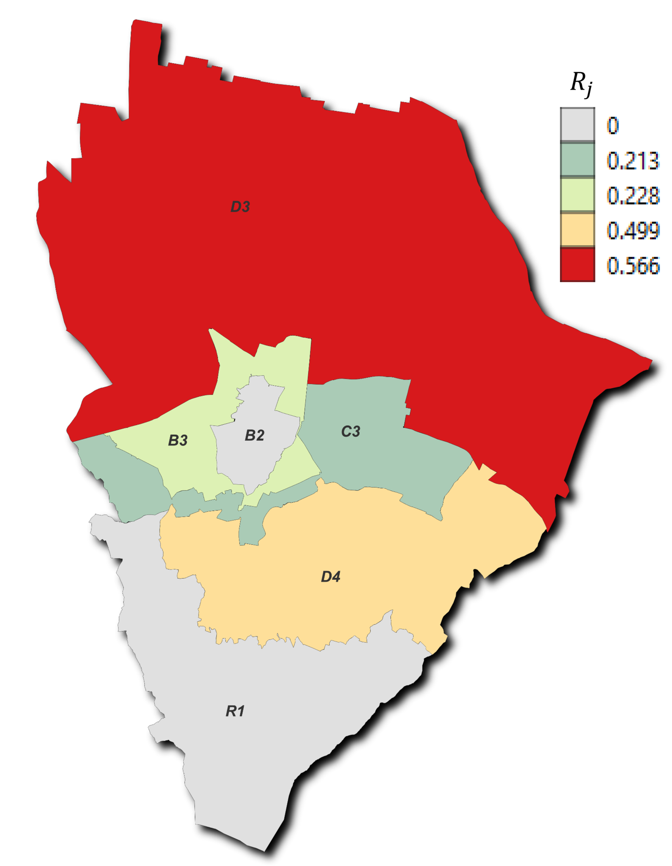
$$NV_j = \frac{V_j - min_j}{max_j - min_j}$$

Where V_j is the value of the variable for *j-th* district, min_j and max_j are the correspondent minimum and maximum values over all districts within the municipality, respectively, and NV_j the normalized value of the variable. In this way, each variable is expressed in a standard scale, where 0 indicates the lowest value within the whole sample and 1 the highest one.

7. Finally, the integrated multi-risk index is obtained combing seismic and flood risk indices as follows:

$$R_j = {I^{k_1}_{PH,j}}^{w_{k1}} \cdot {I^{k_2}_{PH,j}}^{w_{k2}}.$$

Where w_{k1} and w_{k2} are weights assigned to seismic and flood risk respectively. For this application same weights are adopted for the two risks, i.e., it is assumed that the two risks have the same importance.



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