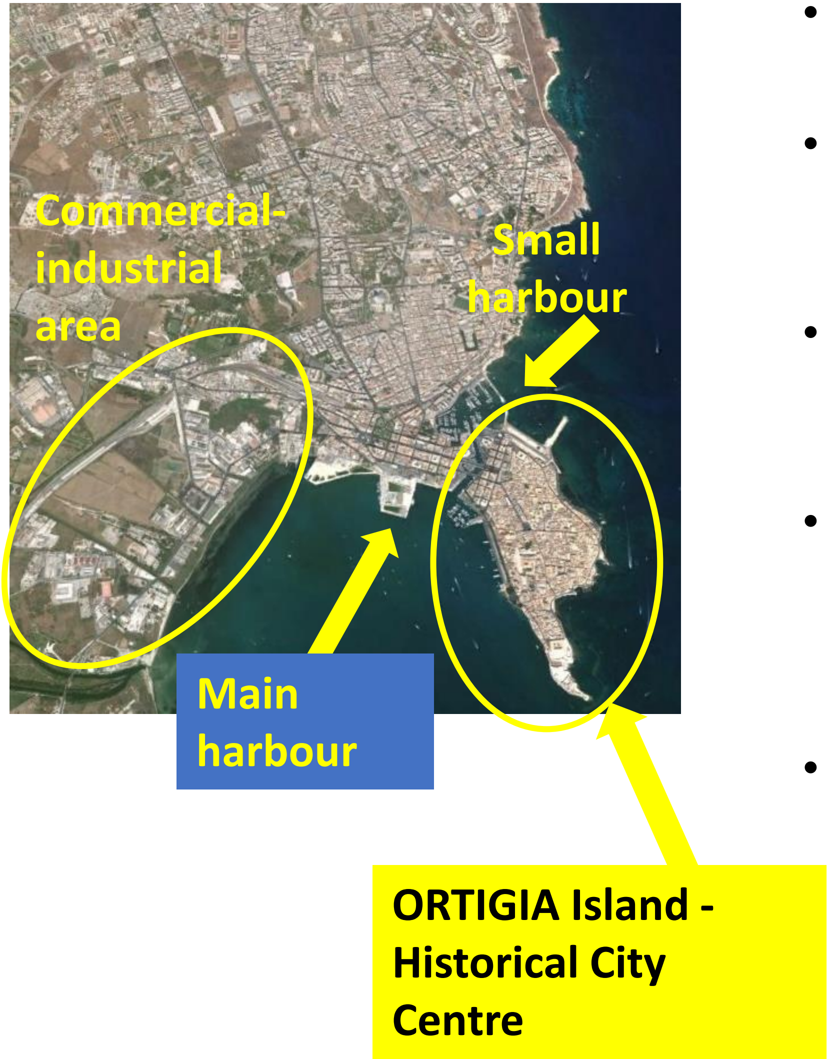
Risk assessment for tsunami events in the city of Siracusa, Italy

Gianluca Pagnoni, Alberto Armigliato, Stefano Tinti and Filippo Zaniboni

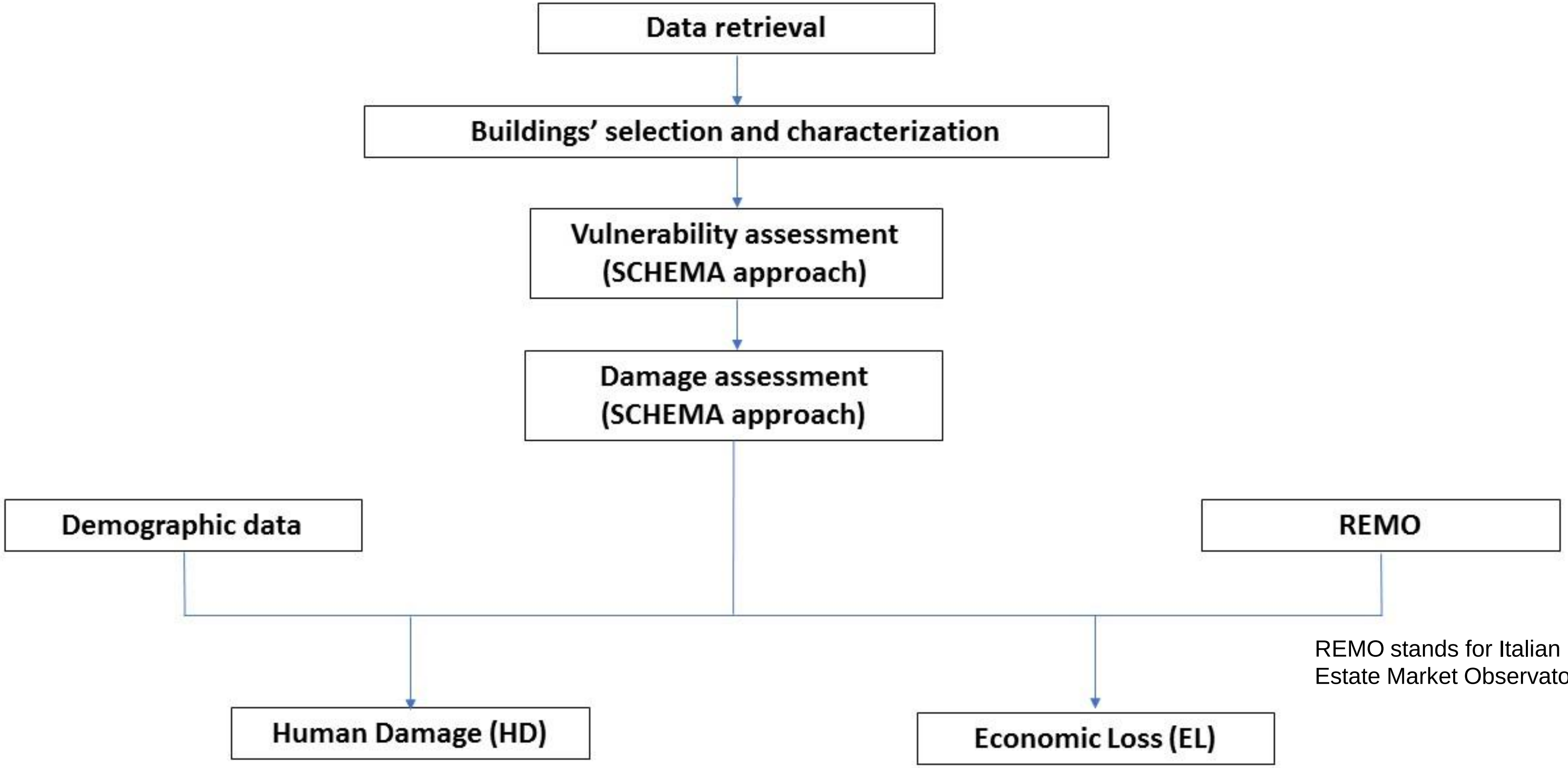
University of Bologna, Department of Physics and Astronomy, Sector of Geophysics, Bologna, Italy (gianluca.pagnoni3@unibo.it)

SIRACUSA



- It is a city of **123,000** inhabitants
- In summer season the population grows by a factor of 3
- It hosts a **commercial** (main) and a **touristic** (small) harbour
- It was founded 2,700 yrs ago by Greeks and is very rich of **history and architectural treasures**
- In 2005 it was listed as a **World Heritage Site by UNESCO**

Schematic flow chart of the tsunami risk assessment

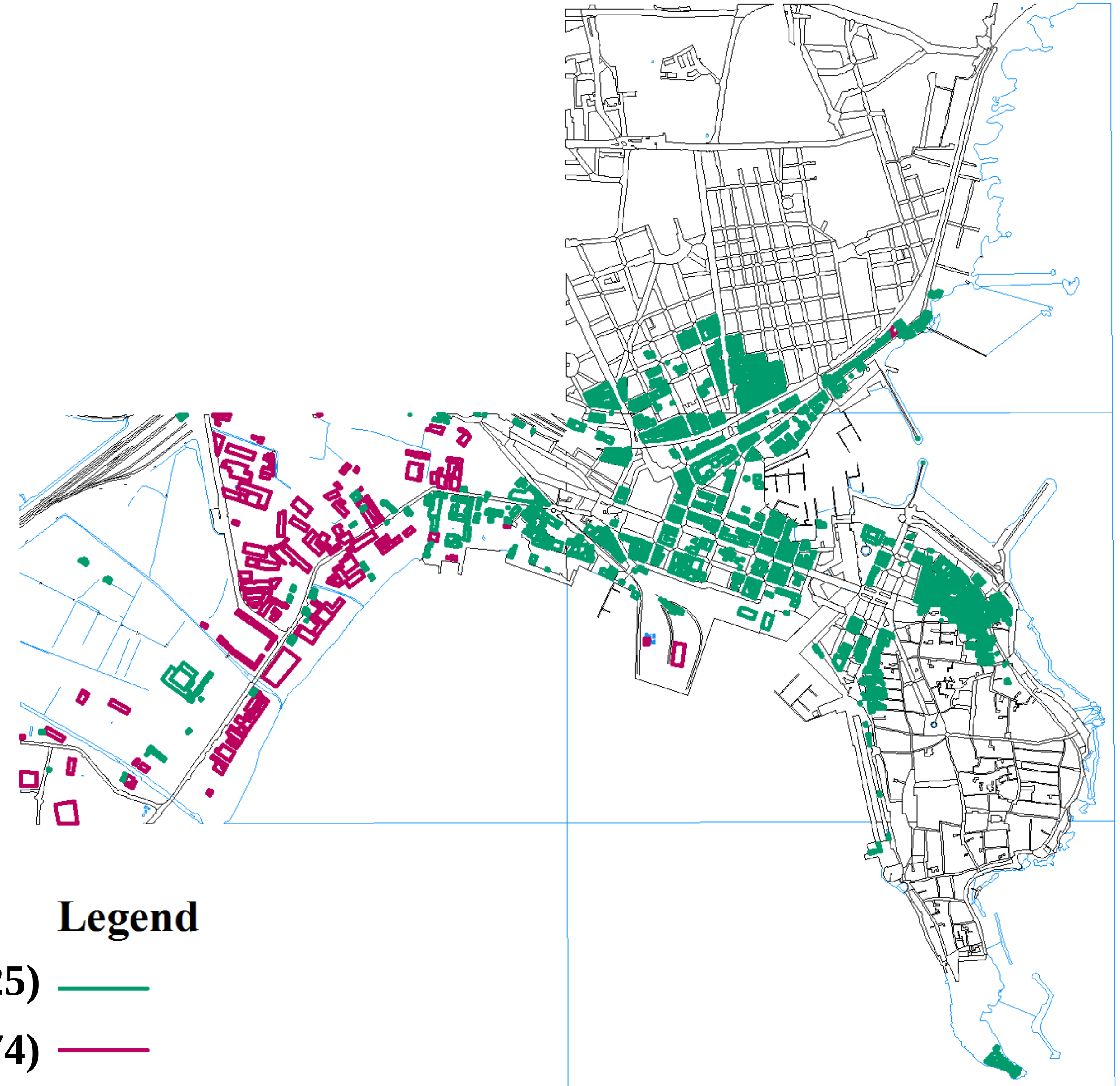


REMO stands for Italian Real Estate Market Observatory

Pagnoni G., Armigliato A., Tinti S.: *Estimation of human damage and economic loss of buildings related to tsunami inundation in the city of Augusta, Italy*. Geological Society, London, Special Publications, 501, 2020, https://doi.org/10.1144/SP501-2019-134

Map of the buildings exposed to inundation

- The exposed buildings in the map on the right are identified using the topographic altitude of the ground floor. Pagnoni and Tinti (2015) suggest a maximum inundation height of 5 m for Siracusa also on the basis of historical evidence. Buildings located above this height are not considered.
- For the human damage (HD) assessment we take in account only the people in residential buildings.
- To estimate the economic loss (EL) we consider two categories of constructions: residential (green) and industrial/commercial buildings (violet).



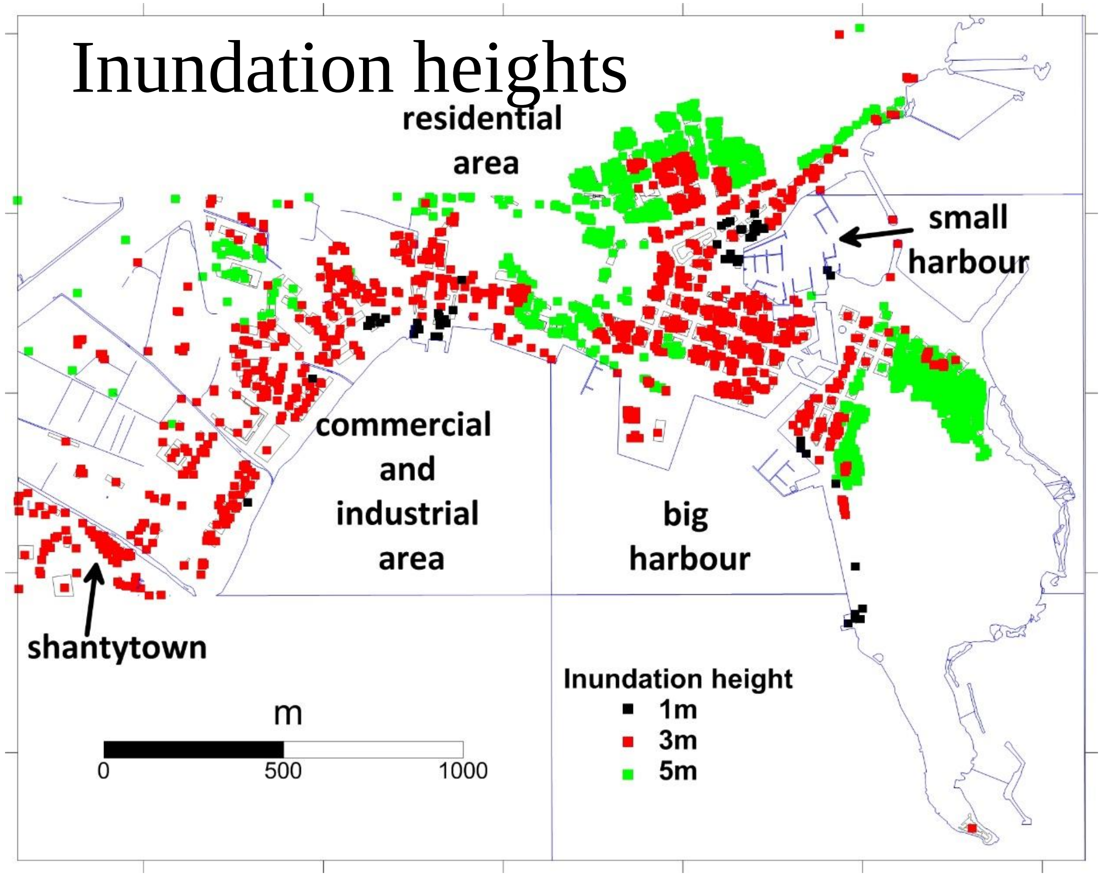
Legend

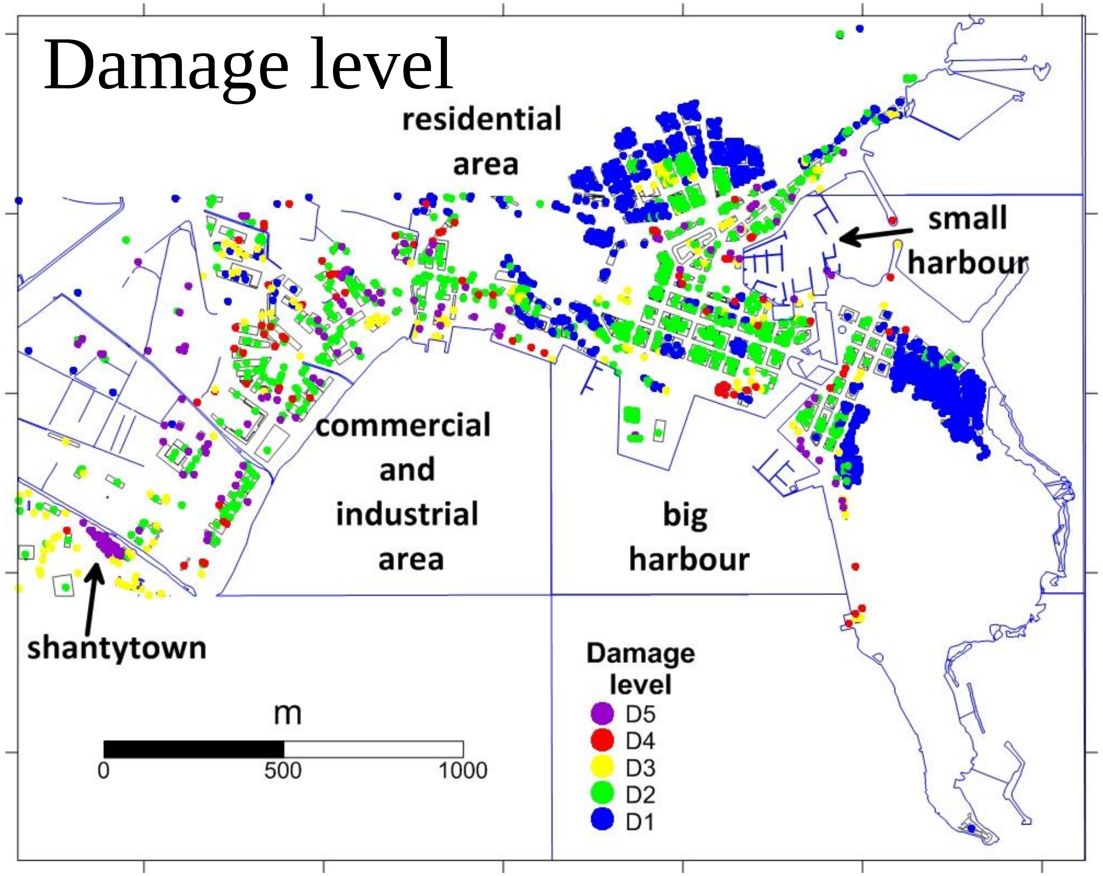
Residential buildings (1825)

Industrial and commercial buildings (174)

Pagnoni G. and Tinti S.: *Application and Comparison of Tsunami Vulnerability and Damage Models for the Town of Siracusa, Sicily, Italy*, PAGEOPH, doi:10.1007/s00024-016-1261-82016.

Damage level of the exposed buildings





The only physical tsunami data used in the analysis is the flow depth (FD), computed as the difference between the inundation height (IH) and the local topography. In this study we explore the effect of 5 tsunami cases and assume uniform IH. We vary IH from 1m to 5m at 1m step. On the left, the map shows the buildings inundated when the IH is 1m, 3m and 5m. On the right, we provide the damage on buildings for FDs, obtained by using IH = 5m. Damage is coded in levels from D1 (minimum) to D5 (maximum) computed according to a variant of the scheme adopted in the European project SCHEMA.

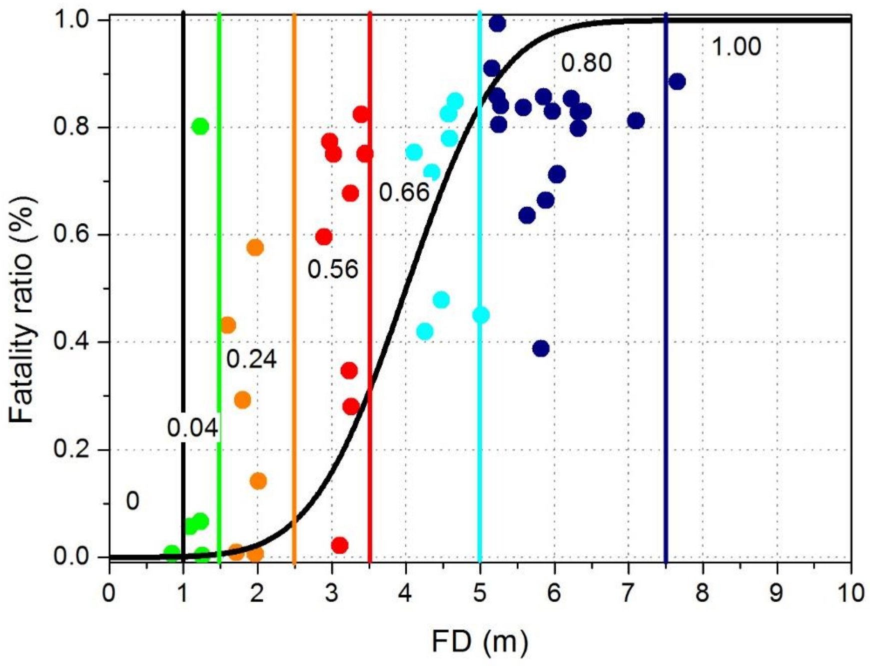
People exposure

FD (m)		Exposure	Description
Ground floor (n=0)	Upper floors (n>0)		
0 ÷ 1	nX ÷ (1+nX)	E1	Flooded floor, people are not dragged away
1 ÷ 1.5	(1+nX) ÷ (1.5+nX)	E2	Difficulty to run away
> 1.5	> nX+1.5	E3	People dragged away or trapped

In this analysis the height X of each floor is supposed to be equal to 2.5 m

Three-degree scale of human exposure. Exposure levels (En) depend on the floor where the people are caught by the tsunami. The algorithm including the ground floor and the upper floors was proposed by Pagnoni et al. (2020). In the formula X denotes the standard height (in meters) of a single floor.

Method to estimate fatalities

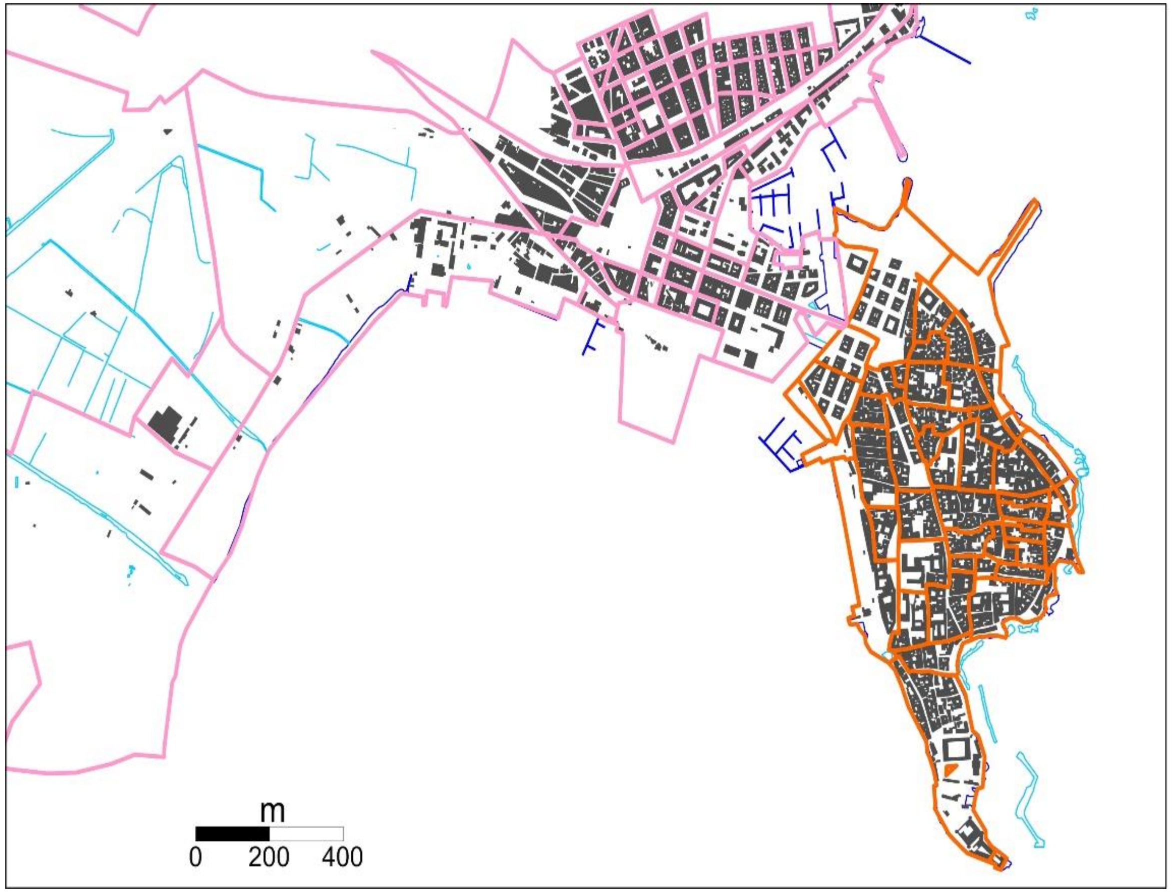


Experimental data on correlation between local tsunami flow depth and fatalities by Koshimura *et al.* (2009)

	Flow Depth (m)	Exposure	Estimated Fatality ratio (%)
Ground floor (n=0) and upper floors (n) (X= height of floor in m)	nX ÷ (nX+1.0)	E1	0
	(nX+1.0) ÷ (nX+1.5)	E2	4
	(nX+1.5) ÷ (nX+2.5)	E3	24
	(nX+2.5) ÷ (nX+3.5)	E3	56
	(nX+3.5) ÷ (nX+5.0)	E3	66
	(nX+5.0) ÷ (nX+7.5)	E3	78
	(nX+7.5) ÷ (nX+10.0)	E3	100
Partially or totally collapsed buildings	0.0 ÷ 2.5	E3	24
	2.5 ÷ 3.5	E3	56
	3.5 ÷ 5.0	E3	66
	5.0 ÷ 7.5	E3	80
	7.5 ÷ 10.0	E3	100

Fatality Ratio Table. Expected fatality ratio (given as a percentage) based on the flow depth experienced by people living on the n-th floor. Ratios are established from the experimental data shown in the left figure.

Residential people



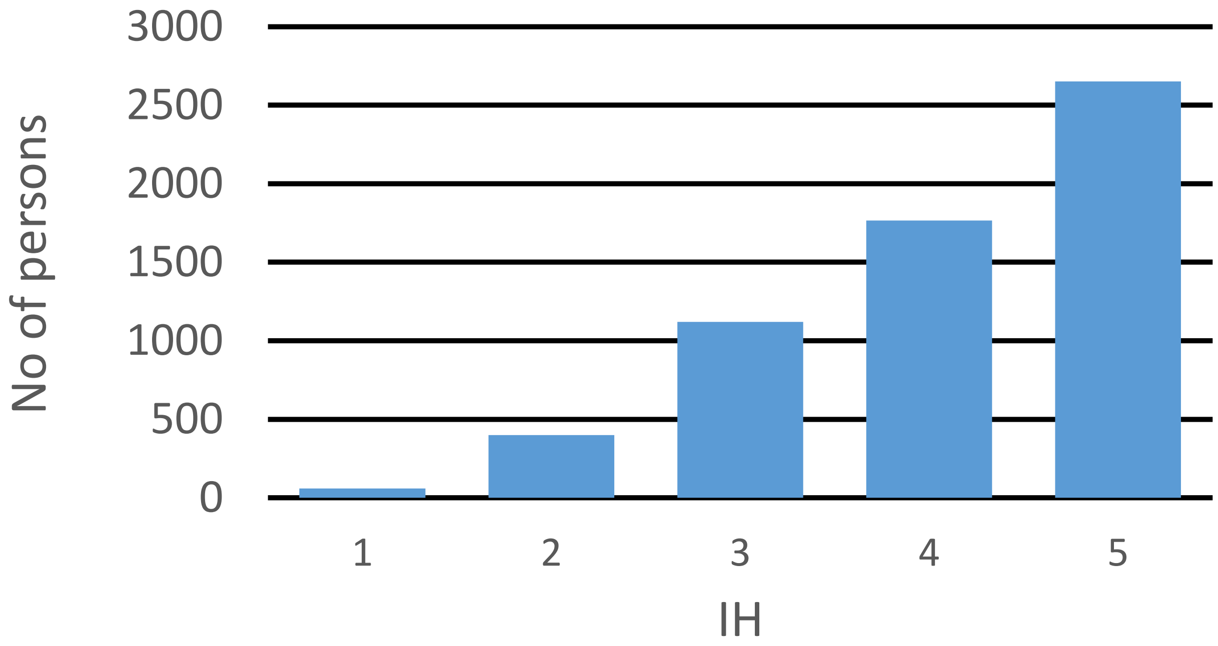
Map of buildings in Siracusa used to calculate the density of population. Orange and pink lines show the boundaries of the ISTAT sections (basic territorial units) respectively in Ortigia and in the rest of the town.

The number of people resident in each building affected by the tsunami is computed by using censor data provided by the Italian Institute of Statistics (ISTAT) through some additional processing. Indeed, the ISTAT database makes use of territorial units (called sections) that include very many buildings. By using this data, we have deduced the local density σ of residents in the inundated area. On average, the density results to be: $\sigma = 0.007$ persons/m^2 in Ortigia and $\sigma = 0.010$ persons/m^2 in the other part of Siracusa.

The area exposed to inundation for the 5 tsunami scenarios embraces part of Ortigia and part of the mainland. It is included in a more extended area covered 49 ISTAT sections (orange) as regards Ortigia where residents are 4269, and by 74 ISTAT sections (pink), as regards the mainland, where residents are 4950.

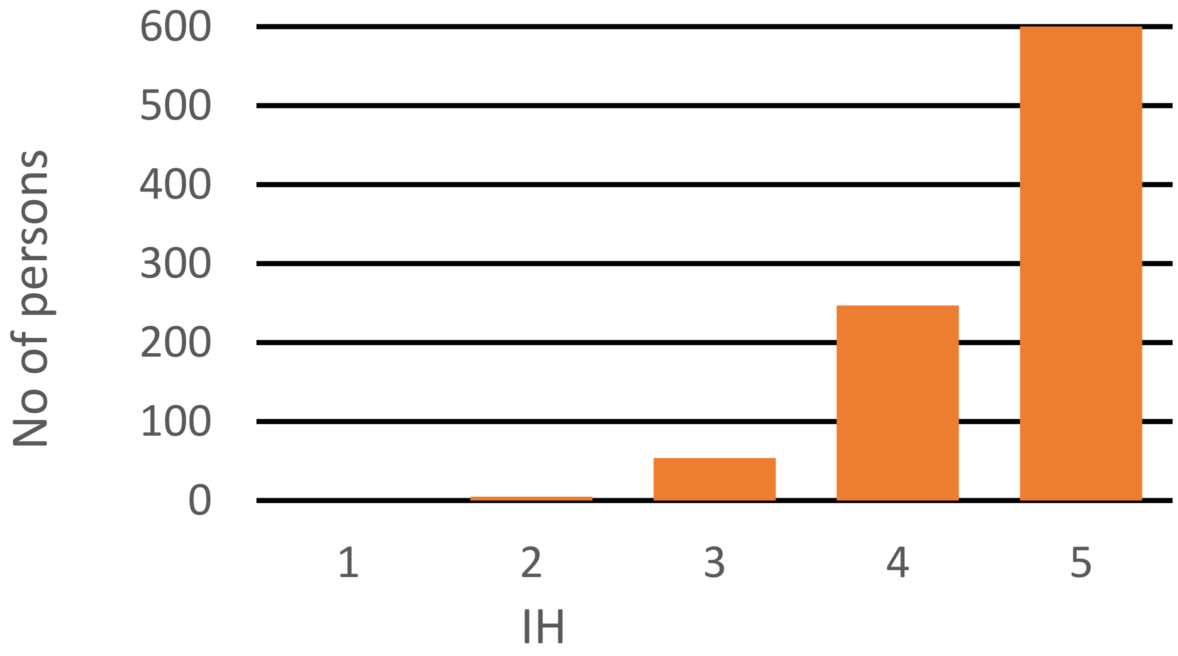
Human damage (HD) for the 5 tsunami scenarios

Affected people



Estimated number of people resident in the buildings affected by the tsunami vs. the tsunami inundation height.

Expected fatalities



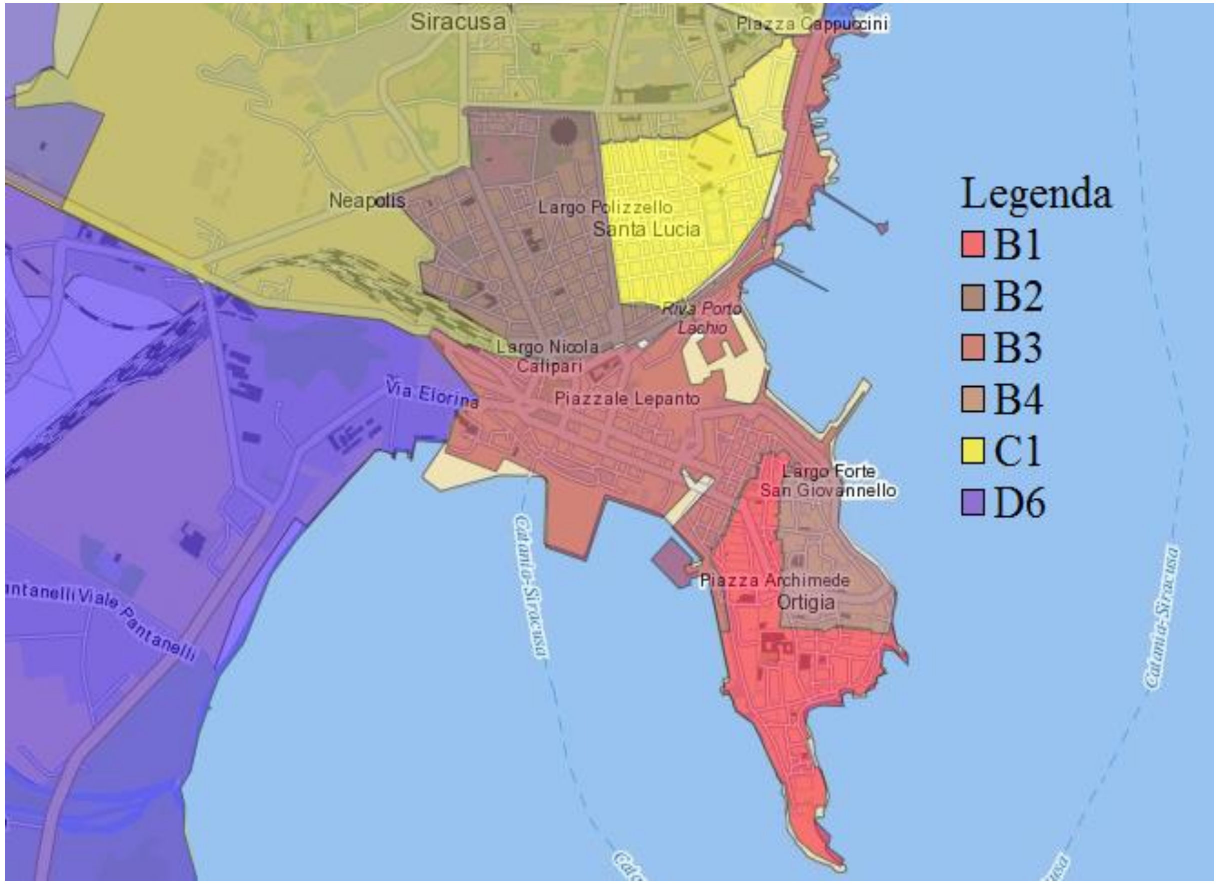
Number of expected deaths vs. the tsunami inundation height. Figures are computed through the Expected Fatality Ratio Table.

Economic loss table

Not collapsed buildings	Flow Depth (m)	Loss (% of the floor value)
Ground floor	$0 \div 0.1$	0
	$0.1 \div 1$	40
	$1 \div X$	100
Upper floors	$nX \div (0.1+nX)$	0
	$(0.1+ nX) \div (1+ nX)$	40
	$(1+ nX) \div X(n+1)$	100
Partially or totally collapsed buildings		Loss (% of the building value)
		100

Percentage of economic loss for each floor of buildings affected by the tsunami as a function of the flow depth. X denotes the standard height of a floor. In this study we choose X=2.5 m

Real estate market observatory (REMO)

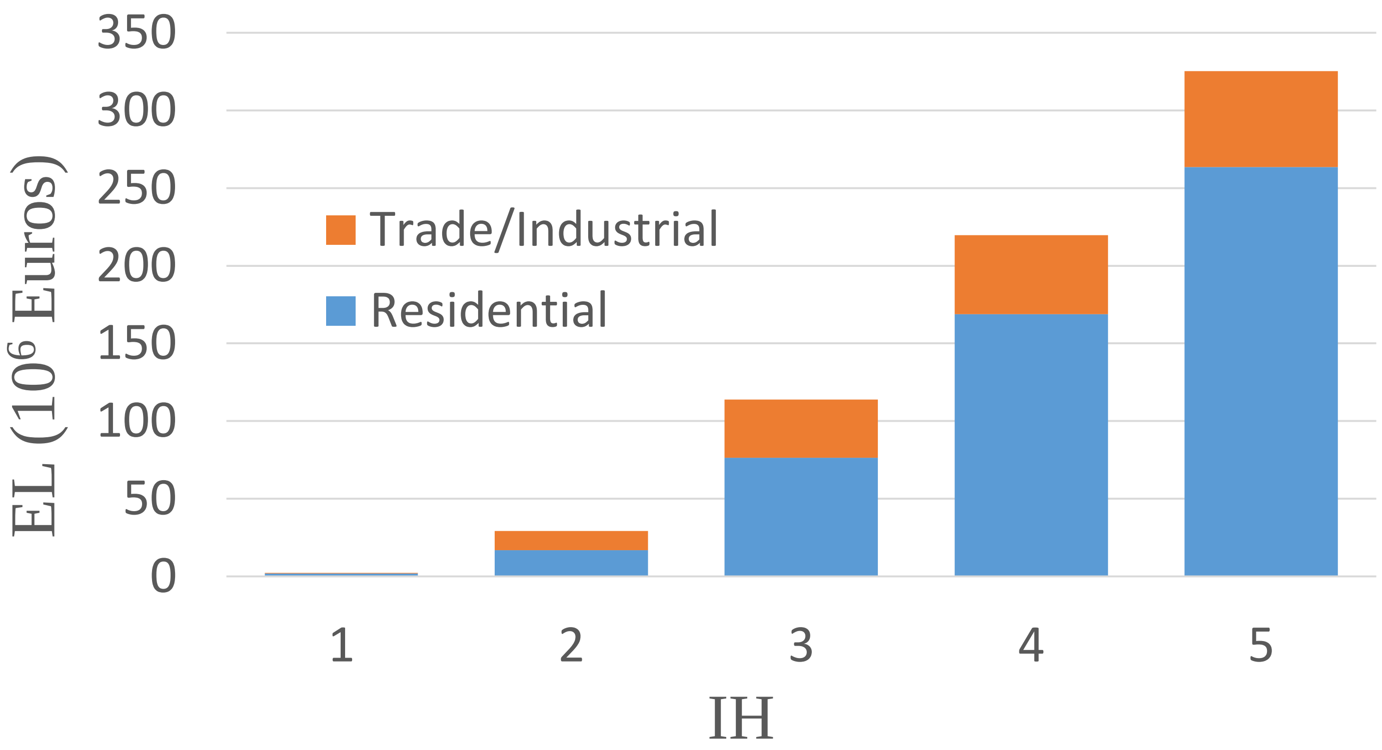


REMO (real estate market) zones for Siracusa

Zone	Type			
	Residential		Trade / Industrial	
	Minimum	Maximum	Minimum	Maximum
B1	650	920	650	900
C2	720	960	550	750
D1	740	1100	430	570

Economic value of buildings (Euro/m^2) in the 3 Siracusa REMO zones covering the area exposed to the tsunamis for the 5 study cases (see map on the left).

Economic Loss (EL)



Estimated Economic Loss in millions of Euros vs. the tsunami IH. We use the maximum market value of the constructions for the three REMO zones

Conclusions

- We have explored the effect of 5 tsunami scenarios for the town of Siracusa assuming a uniform IH. Tsunamis vary from 1m to 5m that is taken as the highest possible tsunami height for the town, based on historical data and hazard analysis.

- In the case of the highest IH (5 m), more than 2500 people resident in the inundated buildings results to be exposed to the tsunami attack and about 600 are expected to loose their life.

- Interestingly, the number of people involved increases linearly with the IH, while the number of fatalities increases following a quasi-quadratic law.

- The Economic Loss for the highest tsunami exceeds 300 Million Euros, that is equivalent to the 4% of the Gross Domestic Product of the Siracusa district.