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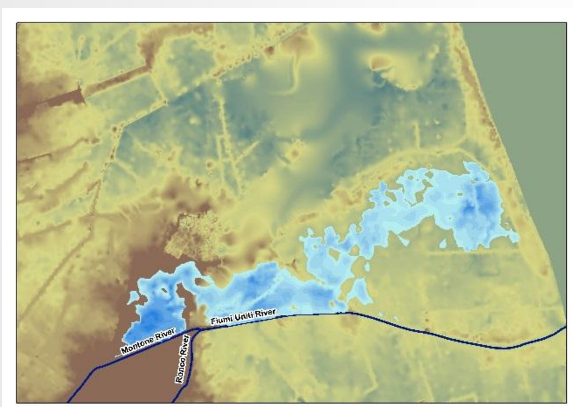
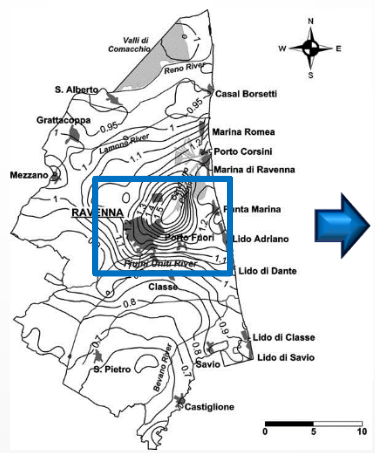
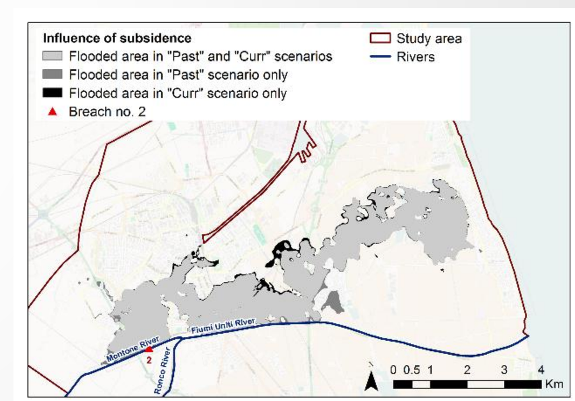
Is anthropogenic land-subsidence a possible driver of riverine flood-risk dynamics? A case study in Ravenna, Italy.







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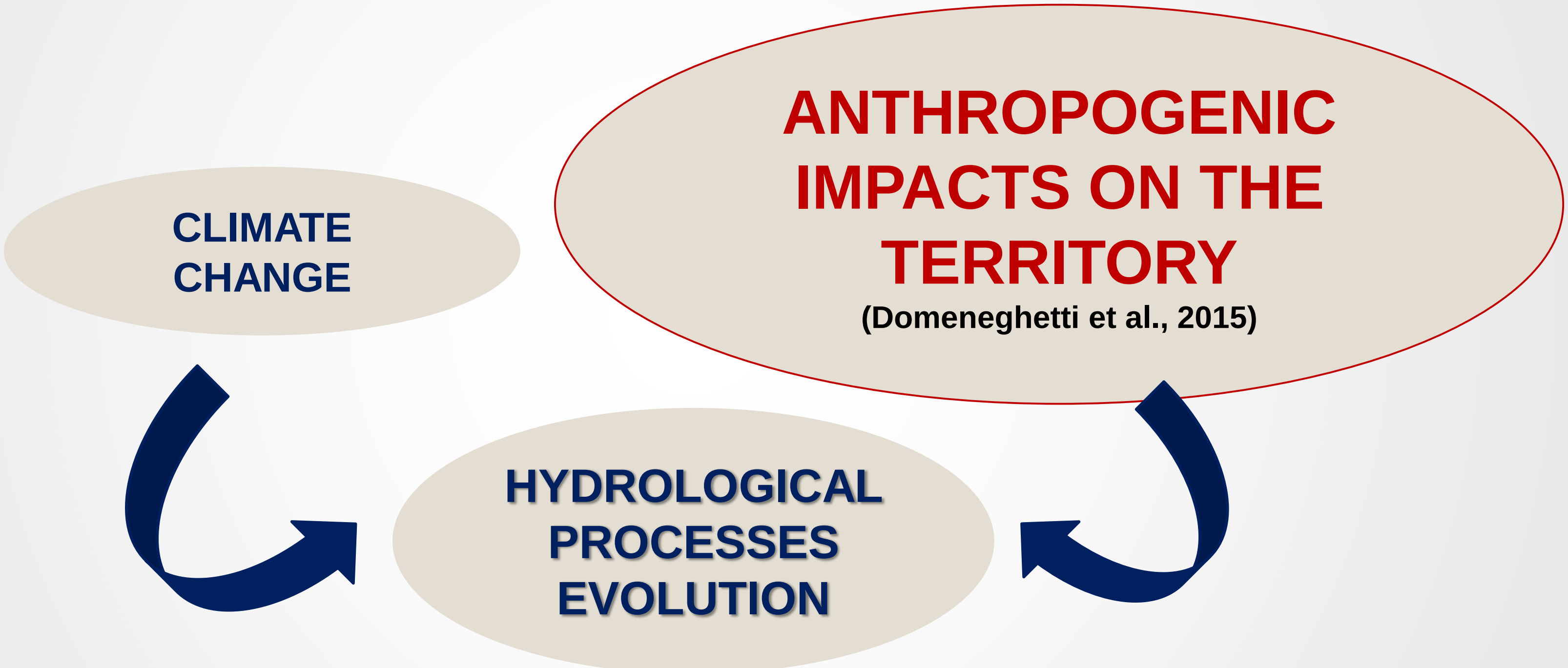
Introduction and study aim



- **Flood-risk** evolution
- Increasing of potential **damages** during extreme flood events

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Introduction and study aim

Human-induced land-subsidence due to the pumping of underground fluids in densely populated areas in the last half of the XX century

Japan
(Daito and Galloway, 2015)

Thailand
(Phien-wej et al., 2005)

Mexico
(Ortega-Guerrero et al., 1999)

Bangladesh
(Brown and Nicholls, 2015; Howladar and Hasan, 2014)

- Rich literature on the effects of land-subsidence in coastal areas (salt-water intrusion, decrease of the coastal floods return period)
- Poor literature on the dynamics of hydraulic risk in rivers flood-prone areas

AIM OF THE STUDY:
if and to which extent the human-induced, or human-accelerated, land-subsidence can change the riverine flood hazard

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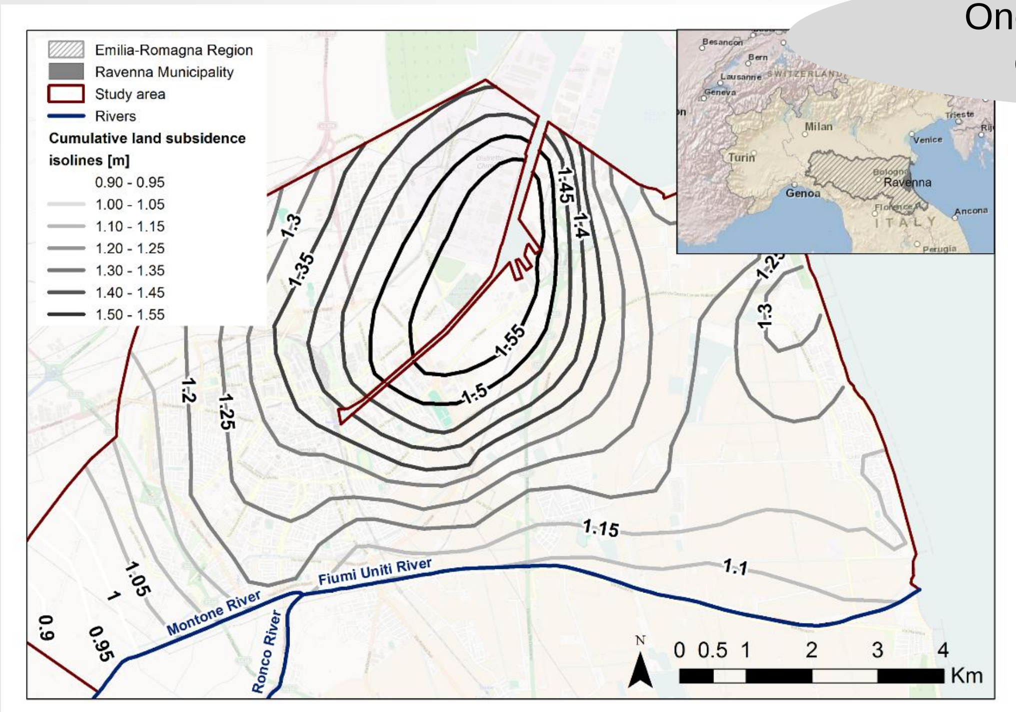
Study area: 77-km^2 area around the city of Ravenna, Italy

One of the Italian most prominent cases of anthropogenic land-subsidence



- Municipal area: 653 km^2
- Population: 160 000 inhabitants with high population density
- Complex network of road infrastructures
- Long and rich cultural history
- Montone River + natural streams with artificial embankment systems
  → higher damages in case of extreme events or levee failure

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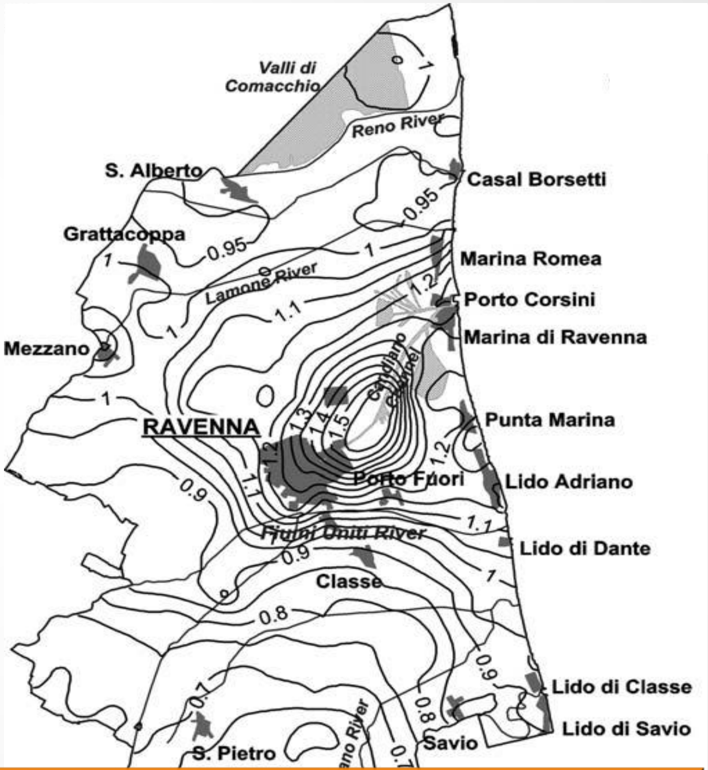
- Land-subsidence rate: naturally in the order of a few mm/year
- Sudden land-subsidence acceleration after World War II due to an intense water and gas extraction from underground (Gambolati et al., 1991; Carminati and Martinelli, 2002)
- Peaks > 1,5 m over an area of 10 km^2 between the historical center and the coastline (Teatini et al., 2005)
- Subsidence gradients reach 0.3 m/km



Problem:

Can differential LAND-SUBSIDENCE significantly alter the river flooding dynamics and thus flood-risk in flood-prone areas?

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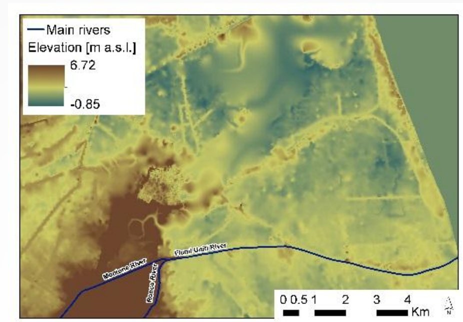
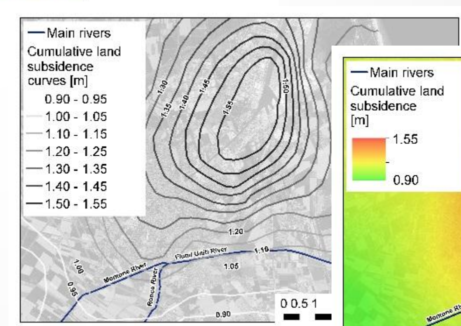
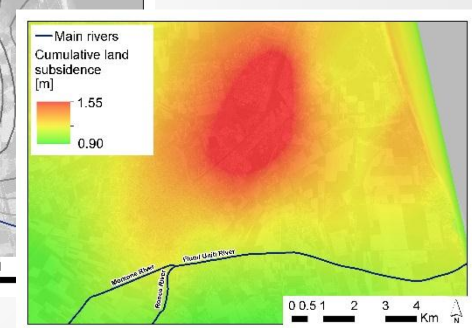
Topography of the study area: current and reconstructed conditions

Current topography:
5m Digital Elevation Model (DEM)

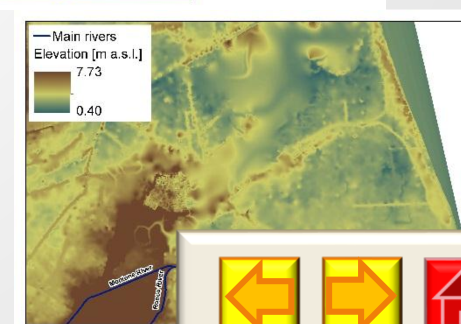


Land-subsidence curves;
Land-subsidence 5m DEM





Back-warped DEM:
5m historical DEM describing ground elevations in 1897



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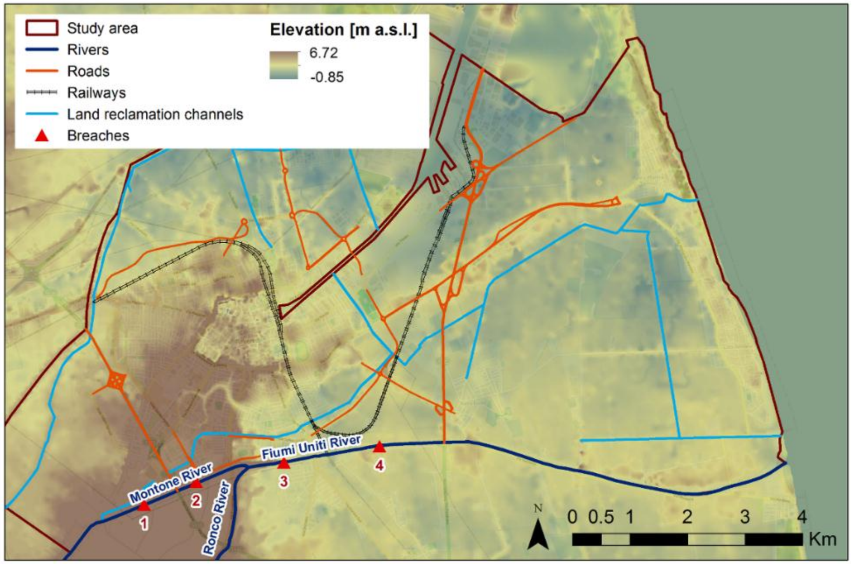
Topography of the study area: influence of main infrastructures

Modification of the major discontinuities elevation according to the real topography:

- + 1 m for the main railways
- - 1.5 m for the greater channels



➡ ***4 scenarios***

- **Scenario "Curr"**: current morphology without infrastructures
- **Scenario "Curr_Infr"**: current morphology with main infrastructures
- **Scenario "Past"**: 1897 reconstructed morphology without infrastructures
- **Scenario "Past_Infr"**: 1897 reconstructed morphology with main infrastructures

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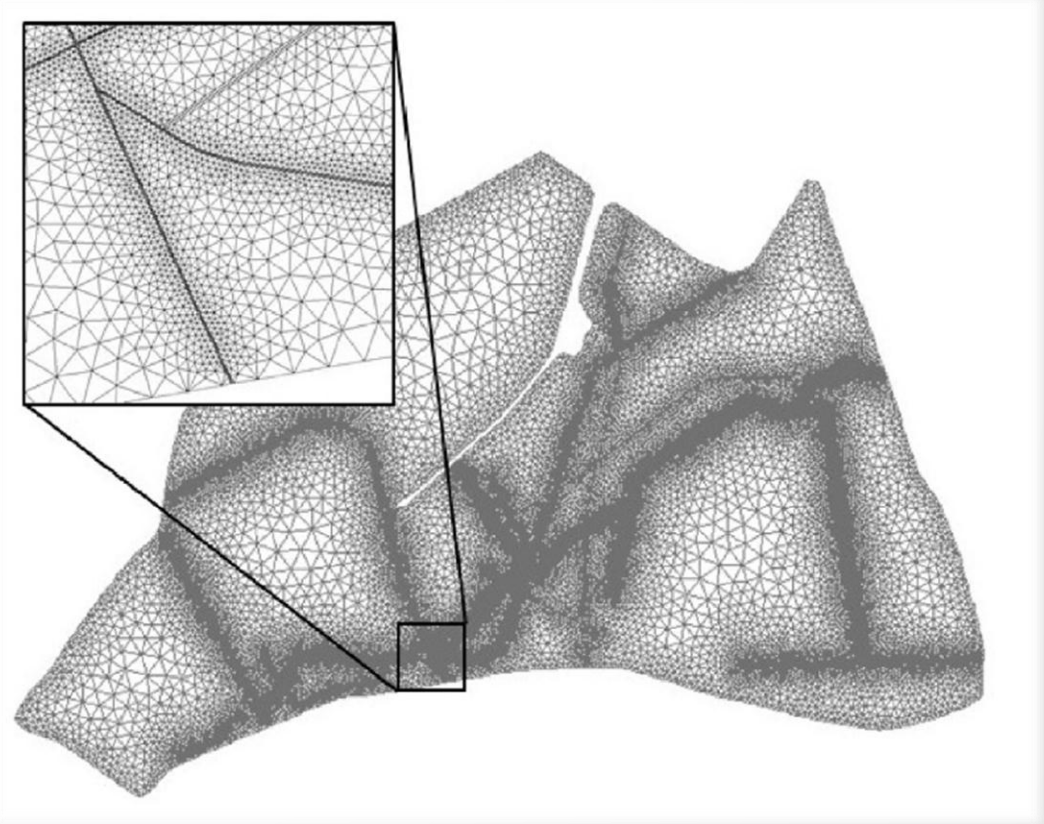
2D numerical model

Fully-2D hydrodynamic model TELEMAC-2D:

- Non-structured computational mesh of triangular elements, which vary from 350 to 0.5 m size, moving from flatter zones to major discontinuities
- Accurate reproduction of the real flooding dynamics, considering the main topographic discontinuities
- Roughness coefficient: function of land-use characteristics retrieved from CORINE 2012 data set



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2D numerical model

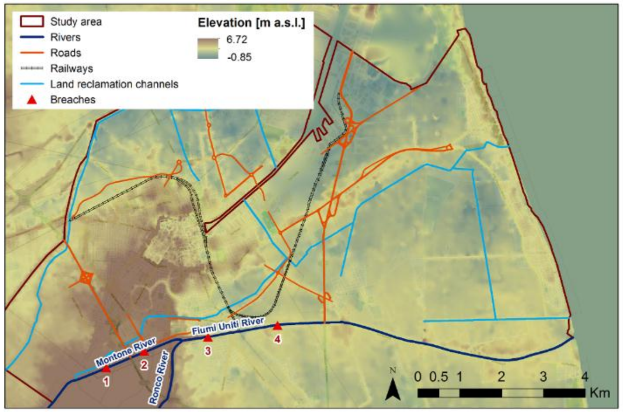
Input function:

Overflowing discharge calculated by referring to a quasi-2D model of the Montone-Ronco River system

Downstream boundary condition:

Constant water surface elevation at river's outlet into the Adriatic Sea

4 different levee-breaching scenarios along the left Montone-Ronco embankment



Modifications due to adjustments that the structures have suffered over the decades, as well as historical land-use changes, have been neglected, thus enabling a direct comparison of flooding scenarios and better understanding the impacts of anthropogenic land-subsidence on flood hazard dynamics, regardless of any other factor.

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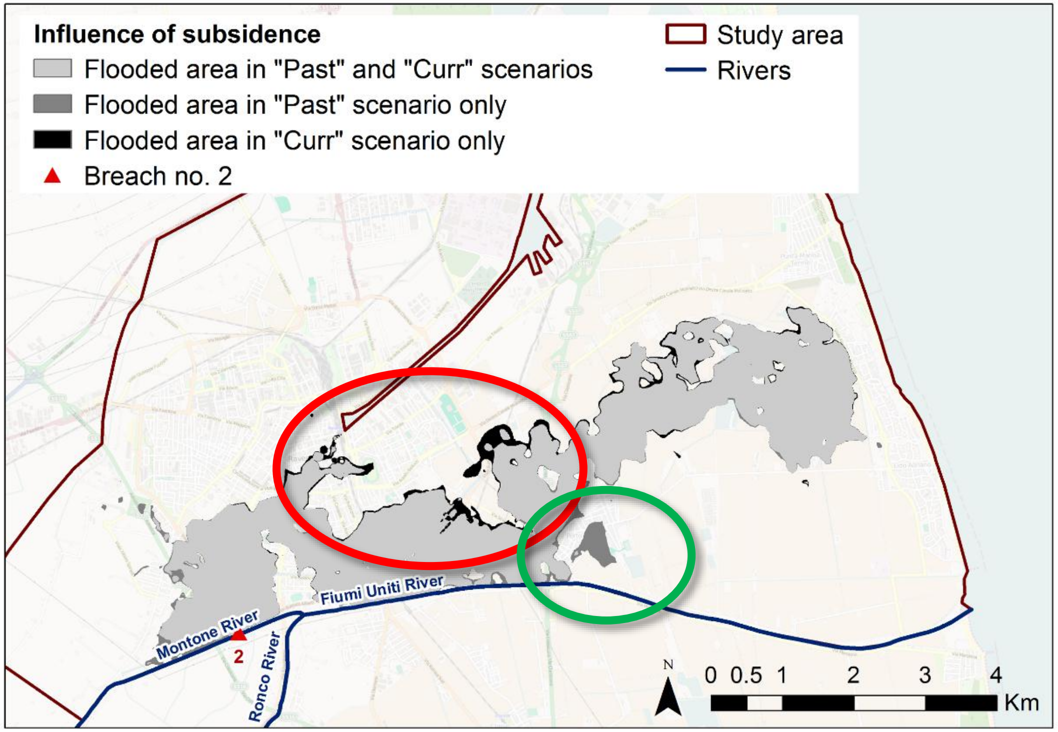
Results/1: can anthropogenic land-subsidence alter riverine flood hazard in a given flood-prone area?



The majority of inundated areas was flooded in both terrain configurations

Present scenario: urban area is mainly affected by flood-risk

1897: rural areas in the Eastern side are mostly impacted by inundation

Similar results for the remaining 3 breaches

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Results/2: can anthropogenic land-subsidence significantly modify the inundation dynamics (e.g. extent and distribution of flooded areas; distribution of water depth, *h*, current velocity, *v* and/or intensity, h·v, etc.)?

According to literature (Kreibich et al., 2009), we consider as significantly flooded (more than slight structural damages and more than moderate non-structural damages) areas with:

Water depth (*h*) > 50 cm; Water velocity (*v*) > 0.25 m/s;
Water intensity ($i = h \cdot v$) > 0.1 m^2/s

COMPARISON OF RESULTS: *FAI*

	FAI (h)	FAI (v)	FAI (i)
Curr vs. *Past* (Effect of subsidence neglecting linear infrastructures)	0.88	0.81	0.83
Curr_Infr vs. *Past_Infr* (Effect of subsidence considering linear infrastructures)	0.93	0.77	0.87

What is ***FAI*** ?

Again, modifications due to anthropogenic land subsidence appear to be limited (high values of *FAI*)

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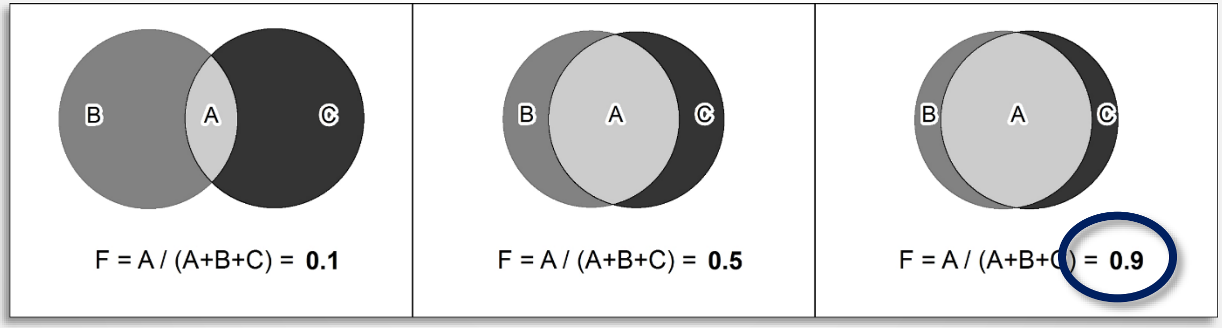
FAI (Flood Area Index, see Falter et al., 2013; Schumann et al., 2009) quantifies the agreement between flooded areas in different scenarios

$$FAI = \frac{A}{A+B+C}$$



A = extent of the areas simulated as flooded in both scenarios
B = extent of the area that results flooded only in Scenario 1
C = opposite of B, i.e. areas flooded only in Scenario 2

**THE CLOSER TO ONE THE *FAI* COEFFICIENT,
THE HIGHER THE SIMILARITY BETWEEN THE FLOODED AREAS ACCORDING TO THE TWO SCENARIOS**

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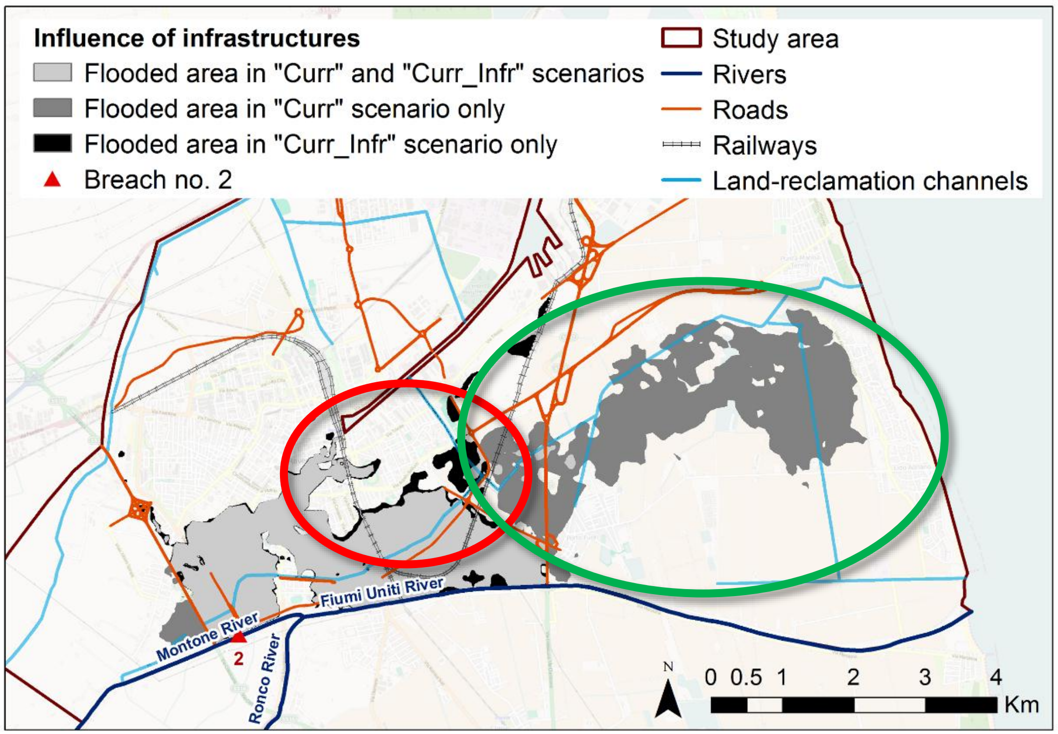
Results/3: are human-induced land-subsidence's effects on flooding dynamics more intense than those resulting from the construction of roads, railways and artificial channels?



	FAI (h)	FAI (v)	FAI (i)
Curr* vs. *Past (Effect of subsidence neglecting linear infrastructures)	0.88	0.81	0.83
Curr_Infr* vs. *Past_Infr (Effect of subsidence considering linear infrastructures)	0.93	0.77	0.87
Curr* vs. *Curr_Infr (Effect of linear infrastructures on current topography)	0.50	0.47	0.58
Past* vs. *Past_Infr (Effect of linear infrastructures on past topography)	0.51	0.49	0.58
Past* vs. *Curr_Infr (Effect of both subsidence and linear infrastructures)	0.50	0.49	0.58

The presence of linear infrastructures strongly affects the flooding extent

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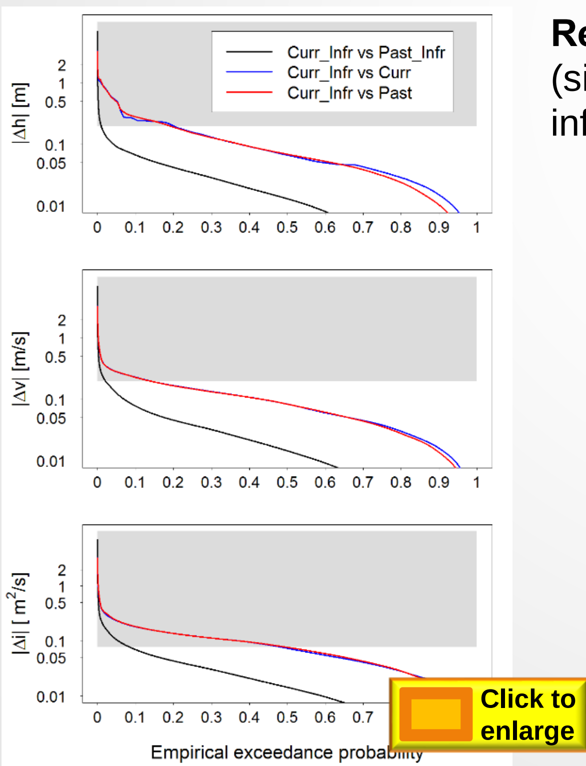
Results/3: are human-induced land-subsidence's effects on flooding dynamics more intense than those resulting from the construction of roads, railways and artificial channels?

Spatial distribution of relevant hydraulic indices (i.e. *h*, *v*, and *i*) for all 5 m cells of the reference area, defined as the merger of all areas significantly inundated in terms of *h* (or *v*, or *i*) at least in one of four configurations; results of all 4 breaches are grouped together



Reference scenario: Scenario "Curr_Infr"
(situation closer to reality: current DEM and schematization of major infrastructures).

	Curr_Infr vs. *Past_Infr* (Impact of subsidence)	*Curr_Infr* vs. *Curr* (Impact of infrastructures)	*Curr_Infr* vs. *Past* (Impact of subsidence and infrastructures)
$\lvert\Delta h\rvert$	0.01	0.20	0.19
$\lvert\Delta v\rvert$	0.02	0.14	0.14
$\lvert\Delta i\rvert$	0.08	0.48	0.48

Limited influence of land-subsidence on flood hazard alteration, compared to the effect of linear infrastructures

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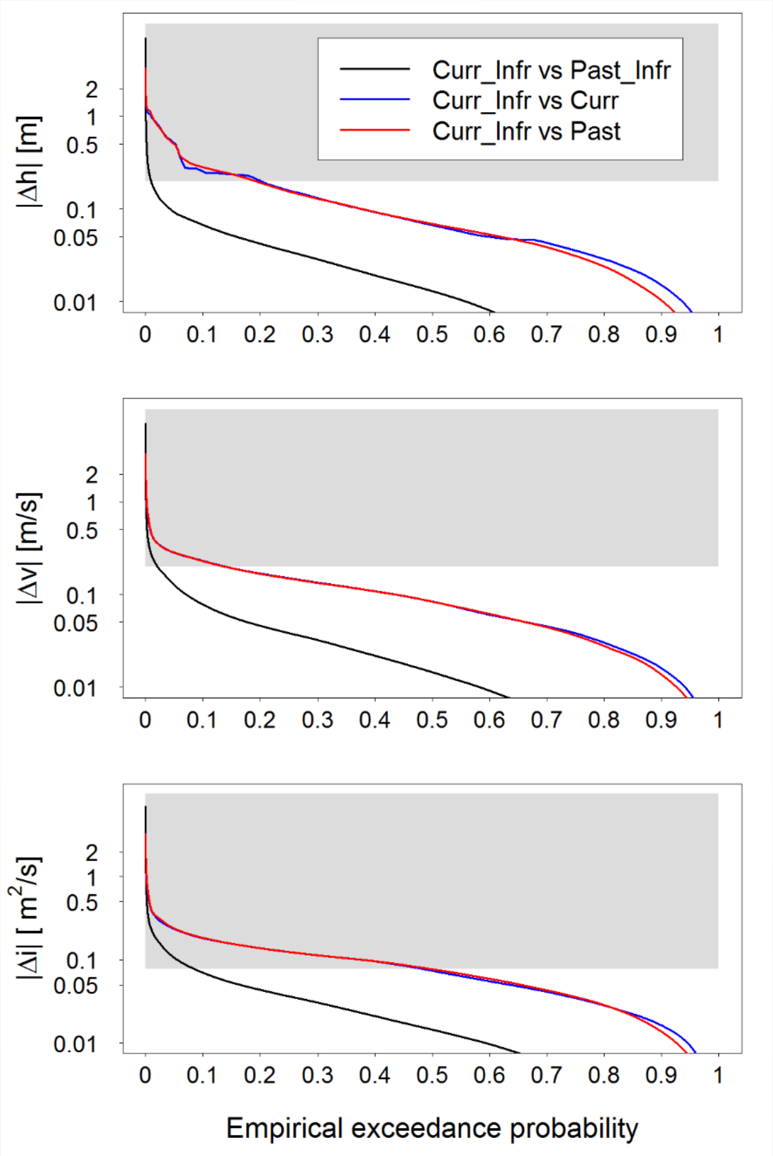

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Conclusions

- Anthropogenic land-subsidence may have a role in altering inundation extent (or more precisely, the extent of significantly inundated area), but its effects are marginal if compared with the impact of linear infrastructures in area surrounding the city of Ravenna.

Human induced, or human-accelerated, land-subsidence may be seen as the potential driver of riverine flood hazard and risk changes, but the construction of artificial canals and road embankments has a significantly stronger impact on flooding potential

- Considering or neglecting main linear discontinuities relative to anthropogenic land-subsidence observed in the study area resulted to have an overwhelming importance

The correct assessment and mapping of flood hazard and risk that rely on hydrodynamic inundation modelling cannot dispense with an accurate representation of major topographic discontinuities, such as artificial irrigation and land-reclamation channel systems, roads and railways embankments

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Thanks for your welcome interest!

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