Automatic procedure in GIS environment for vulnerability estimation and assessment of expected damage to buildings in flood-prone areas

Supervisors:

Prof. Giorgio Boni

Prof. Silvia De Angeli

Prof. Bianca Federici

Candidate:
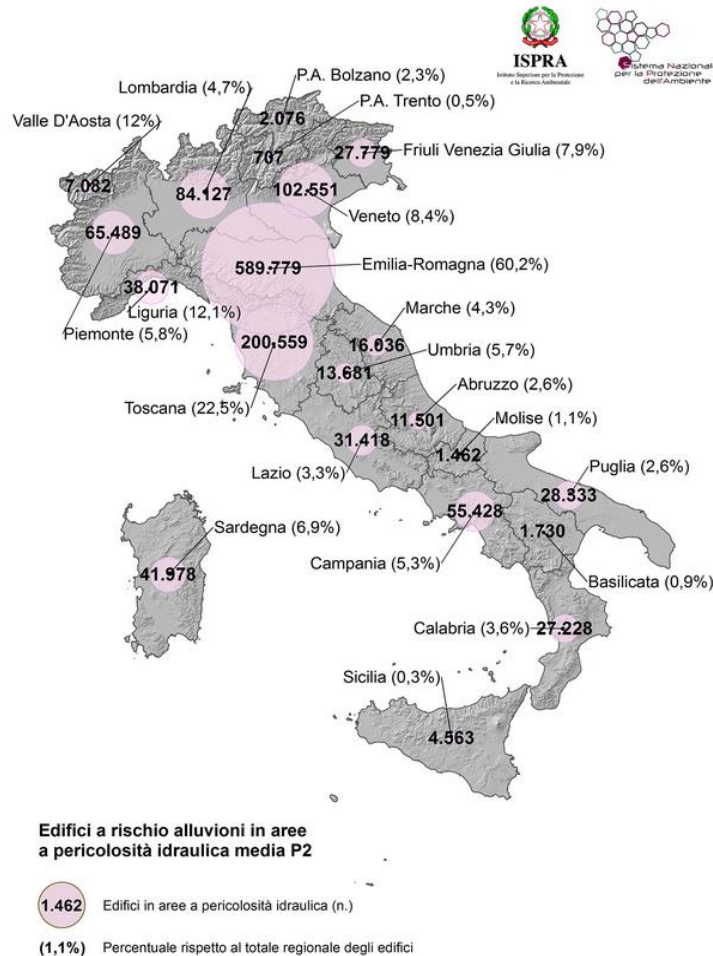
Giulia Mazzaccaro

Introduction

A neighborhood in Jackson, Kentucky, is overwhelmed by flash flooding after heavy rains caused the Kentucky River to overflow in July 2022.

Copyright © 1996-2015 National Geographic Society

Photograph by LEANDRO LOZADA / AFP via Getty Images

Purpose

Automatic GIS-based method to estimate the damage caused by floods to buildings in an urban environment

Edifici a rischio alluvioni in aree a pericolosità idraulica media P2

1.462 Edifici in aree a pericolosità idraulica (n.)

(1,1%) Percentuale rispetto al totale regionale degli edifici

- Plugin implemented in QGIS: detailed and rapid estimation of the **percentage** and the **economic damage** to buildings of a **specific urban area**

- Allow the creation of a **grading map** showing the impact of the damage

- Exploit available **official data** of the **exposed** assets and **official vulnerability models**

Methodology

Automatic GIS-based method to estimate the damage caused by floods to buildings in an urban environment
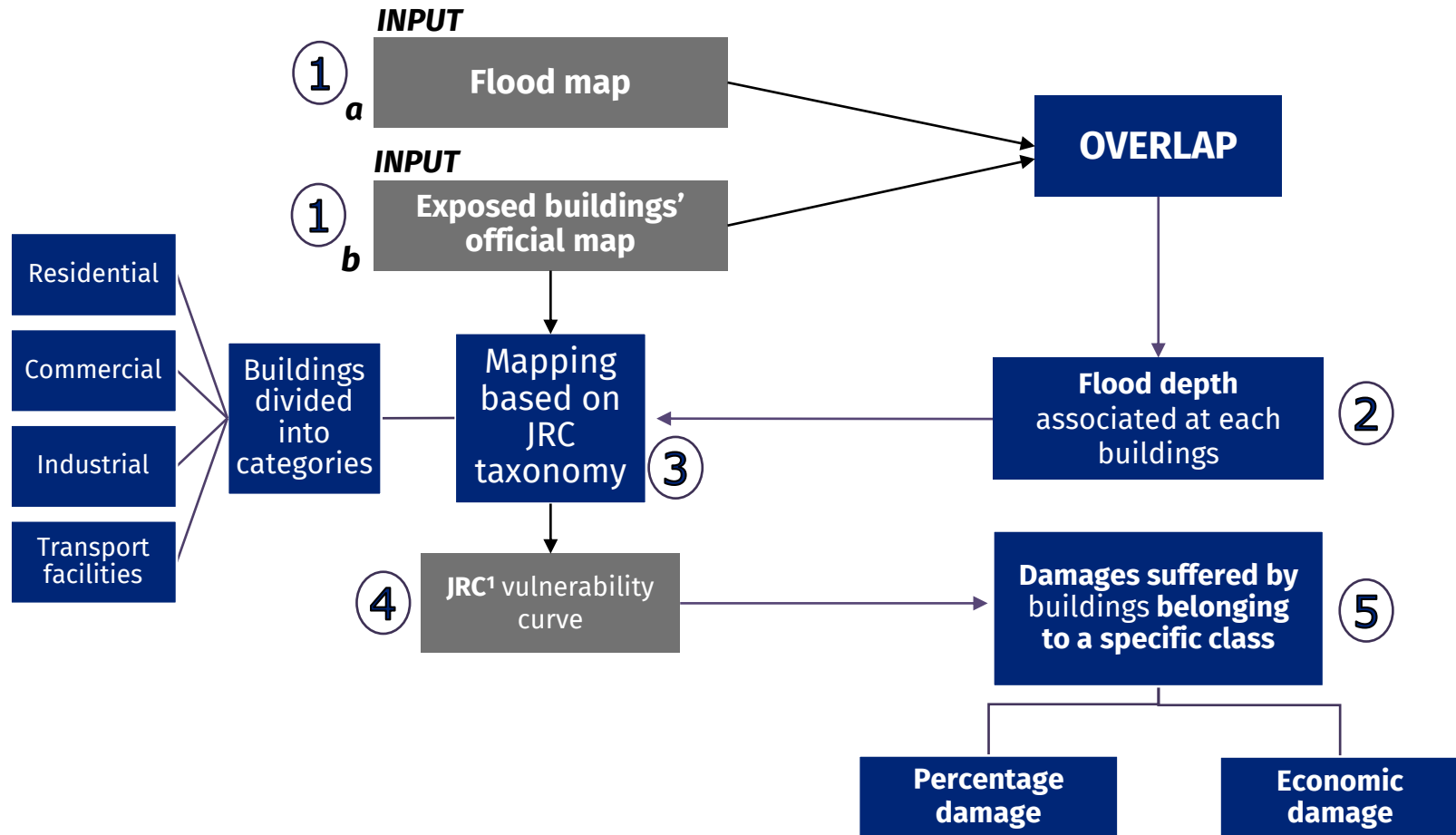
¹JOINT RESEARCH CENTRE of the European Commission

Methodology

1 **Input files necessary to perform the flood damage assessment in GIS environment**

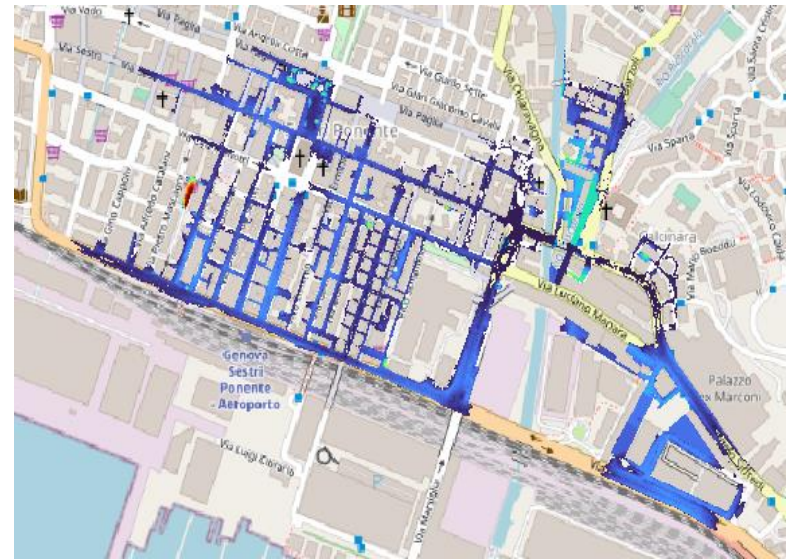## Italian context, Liguria Region - CTR (Carta Tecnica Regionale)

– Mapping all the **exposed** buildings
– Buildings must be composed by **polygons**

Map of the flood hazard scenario

– **Event's extent** and **water depth** in correspondence of the building and the surrounding area

Methodology

(2) **Procedures to estimate the flood depth reaching each building – in GIS environment**

I *"Space filling" flood map*

II *Flood map taking into account buildings*

- Hydraulic simulation's result that **cover** the **footprints** of the buildings

- Hydraulic simulations that show the **water flux around the buildings**, taking into account their presence
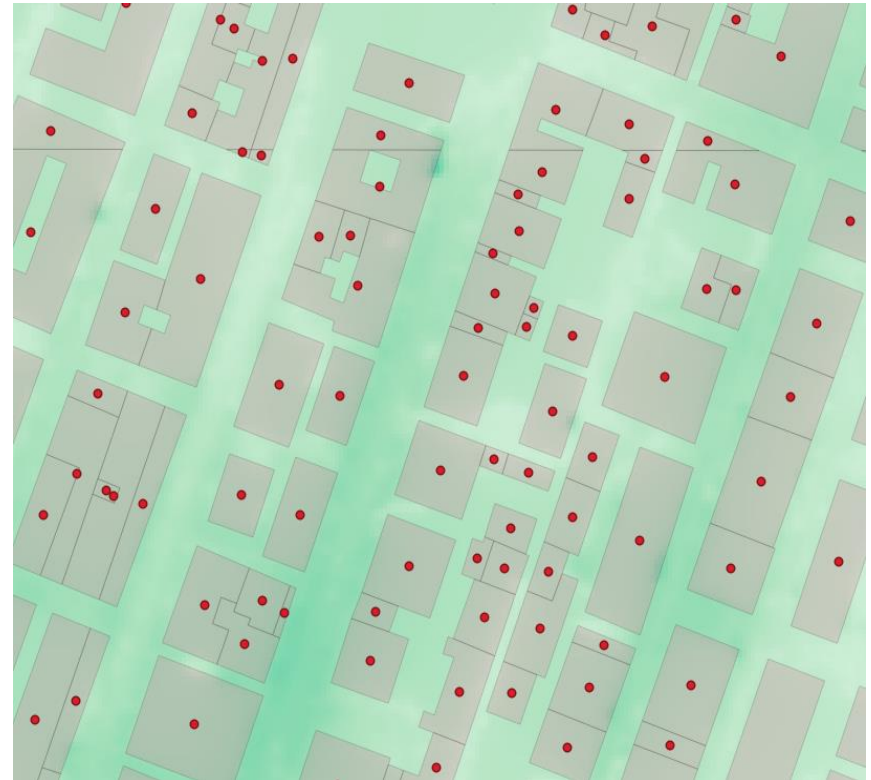
Methodology

2   **Different methodology to associate flood depth at each buildings**

Method 1

Input flood map: «space filling»

Simulation of the water flux that also cover the footprint of the buildings

- Associate to the **CENTROID** of each building a water depth value contained in that point in the pixel of the flood map
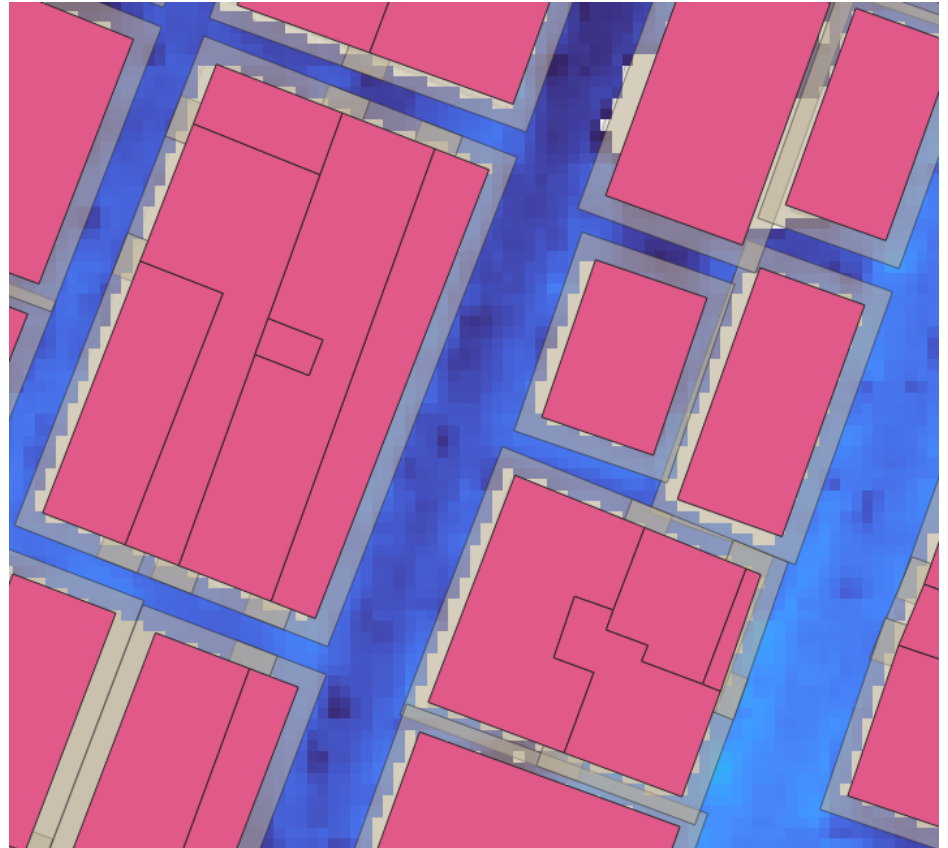
Methodology

Method 2

Input flood map: simulation of the water flux around the buildings

- Water **depth** associated to each building through a **buffer** around each building and an **average** of the values of all the pixels of the flood map inside the **buffer**
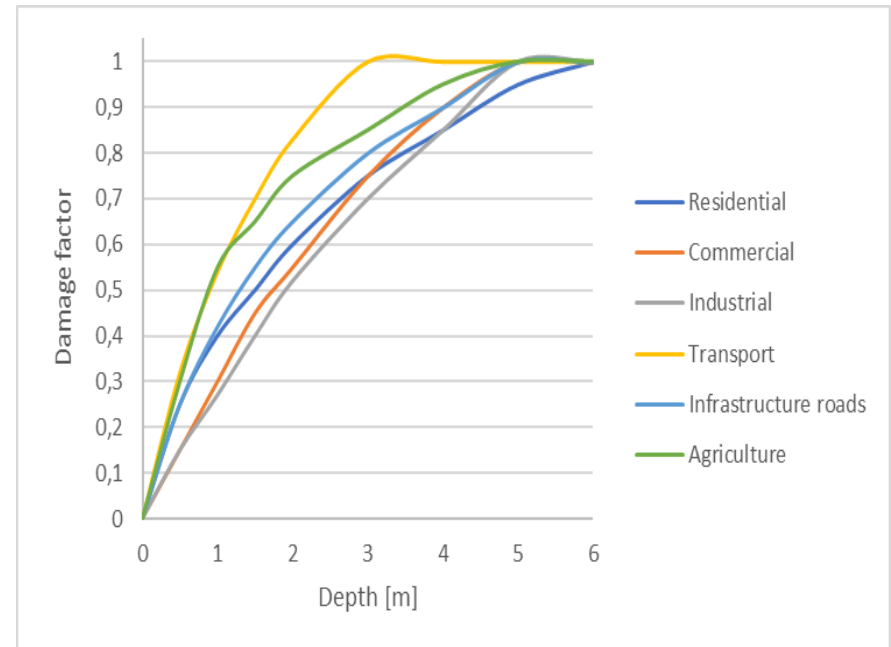

UniGe | DICCA

Methodology

JRC global flood depth–damage functions

- Maximum direct tangible physical damage values for 6 impact categories, as a function of water depth, in **percentage** and **economic** terms

- Representative of average European buildings behaviour

UniGe | DICCA

Methodology

4 **Taxonomy**

Mapping based on the JRC taxonomy

- Italian context, Liguria Region - **CTR (Carta Tecnica Regionale)** - geotopographic database of the Liguria Region provides a **layer** called **«EDIFICATO»**

RESIDENTIAL	COMMERCIAL				INDUSTRIAL	TRANSPORT
	Religious	Generic commercial	Government	Education		
Residenziale	Luogo di culto	Commerciale	Servizio pubblico-sede di polizia	Servizio pubblico-sede di scuola, università, laboratorio di ricerca	Industriale-impianto di produzione energia-centrale elettrica	Servizi di trasporto aereo
Residenziale-Abitativa	battistero	Commerciale-mercato	Servizio pubblico-sede di tribunale		Industriale-impianto di produzione energia-centrale termoelettrica	Servizi di trasporto aereo - Aerostazione
Rudere	campanile	Commerciale-sede di albergo, locanda	Servizio pubblico-sede di vigili del fuoco		Industriale-impianto di produzione energia-stazione/sottostazione elettrica	Servizi di trasporto aereo - Stazione eliporto
Palazzo a torre, grattacielo	Minareto, moschea	Commerciale-sede di centro commerciale	Struttura scolastica		Industriale-stabilimento industriale	Servizi di trasporto stradale
Edificio monumentale	Tempio	Commerciale-sede di banca	Amministrativo		Industriale-impianto di produzione energia-centrale idroelettrica	Servizi di trasporto ferroviario
Villa	chiesa, basilica	Commerciale-sede di supermercato, ipermercato	Amministrativo-municipio		Industriale-impianto di produzione energia-centrale nucleare	Servizi di trasporto ferroviario- stazione passeggeri ferrovia
Villetta a schiera		Commerciale-sede di albergo, locanda	Amministrativo-sede provincia		Industriale-impianto di produzione energia-stazione di trasformazione	Servizi di trasporto-altri impianti
Rifugio montano		Commerciale-ostello della gioventù	Amministrativo-sede regione		Industriale-impianto di produzione energia-centrale eolica	Servizi di trasporto ferroviario-casello ferroviario
		Ricreativo-sede di attività culturali	Amministrativo-sede ambasciata		Industriale-stazione di telecomunicazioni	Servizi di trasporto ferroviario-deposito ferroviario per vagoni, rimessa locomotive
		Ricreativo-sede di attività culturali-biblioteca	Servizio pubblico-casello forestale		Industriale-impianto tecnologico	Servizi di trasporto ferroviario-fermata ferroviaria
		Ricreativo-sede di attività culturali-teatro, auditorium	Militare		Industriale-depuratore	Servizi di trasporto ferroviario-scalo merci
		Ricreativo-sede di attività culturali-pinacoteca	Militare-Caserma		Industriale-inceneritore	Servizi di trasporto stradale - Stazione autolinee

Methodology

5 **Percentage of damage associated at each building**

Depth [m]	Damage factor			
	Residential	Commercial	Industrial	Transport
0	0	0	0	0
0,5	0,25	0,15	0,15	0,32
1	0,4	0,3	0,27	0,54
1,5	0,5	0,45	0,4	0,7
2	0,6	0,55	0,52	0,83
3	0,75	0,75	0,7	1
4	0,85	0,9	0,85	1
5	0,95	1	1	1
6	1	1	1	1

JRC vulnerability curves

Least squares polynomial regression

Determination coefficient $R^2 \cong 1$

	JRC curve functions
Residential	$y = 0{,}0006x^5 - 0{,}0103x^4 + 0{,}0722x^3 - 0{,}2528x^2 + 0{,}5873x + 0{,}0031$
Commercial	$y = -0{,}0004x^5 + 0{,}0054x^4 - 0{,}0247x^3 + 0{,}0184x^2 + 0{,}3051x - 0{,}0013$
Industrial	$y = -0{,}0007x^5 + 0{,}0097x^4 - 0{,}0431x^3 + 0{,}0537x^2 + 0{,}255x + 0{,}0033$
Transport	$y = -0{,}0007x^6 + 0{,}0125x^5 - 0{,}0833x^4 + 0{,}265x^3 - 0{,}4939x^2 + 0{,}8364x - 0{,}0012$

X = depth reached by the **water**
Y = percentage of **damage**

Colour	Values (%)	Legend
(grey)	0	No damage
(green)	0,0001 – 0,1	Very low
(light green)	0,1 – 0,2	Low
(yellow)	0,2 – 0,4	Medium
(orange)	0,4 – 0,6	High
(red)	0,6 - 1	Very high

Methodology

5 **Economic damage associated at each building**

Average maximum damage economic values – provided by JRC

- **Sum** of the damage to the **contents** and the **structure**

  - based on **construction cost surveys** from multinational construction companies (2010 price levels)

  - statistical regressions with **socio-economic World Development Indicators**

Area of the buildings multiplied by the average maximum damage value calculated for the Italian country

	Average maximum damage value (Italy) [€/m2]
Residential	739
Commercial	1028
Industrial	838
Transport	625

Final result of the methodologies

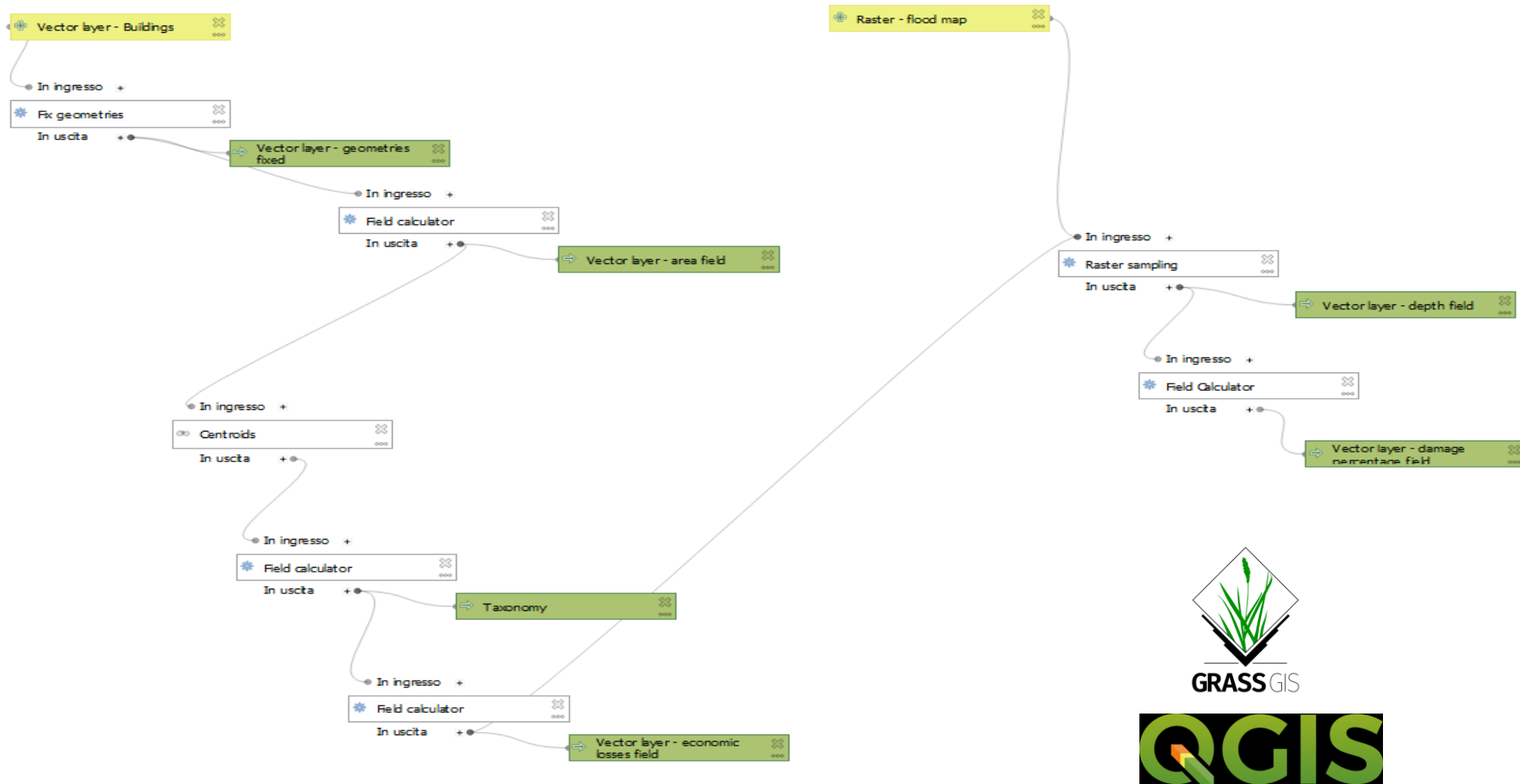| id	cat_uso	def_cat_us	WaterDepth_mean ▼	Building_typology	Area	Max_ec_dam	Perc_damage
213154_0201021018	020102020101	Residenziale-Abitativa	1,8434956701512033	1	371,216	274328,8111	0,573
213153_020102889	020102020101	Residenziale-Abitativa	1,2828875513126452	1	32,644	24123,8456	0,467
213154_0201022766	020102020801	Industriale-stabilimento industriale	1,1312668493815832	3	104,028	87175,1923	0,313
213153_020102154	020102020101	Residenziale-Abitativa	1,1138776499581964	1	145,206	107307,4427	0,429
213153_0201021059	020102020303	Servizio pubblico-sede di scuola, università, laboratorio di ricerca	1,0589701142804375	2	189,902	195219,5776	0,319
213154_0201022765	020102020801	Industriale-stabilimento industriale	1,034236412556445	3	247,583	207474,5620	0,287
213153_020102158	020102020101	Residenziale-Abitativa	1,033378231279347	1	196,221	145007,4360	0,409
213153_0201021057	020102020303	Servizio pubblico-sede di scuola, università, laboratorio di ricerca	1,0296750664710999	2	257,822	265040,7277	0,311
213153_020102157	020102020101	Residenziale-Abitativa	1,0157688679173589	1	146,194	108037,6951	0,404
213153_020102159	020102020101	Residenziale-Abitativa	0,9609385553288133	1	126,175	93243,3966	0,39

Methodology

Processing plugin

Automate the procedure for determining the damage caused by floods to buildings

- Creating a **processing plugin**, implementable in QGIS
- Allows to associate the JRC vulnerability curves and the flood depth to the buildings as automatically as possible
  - Suitable for the **CTR** (Carta Tecnica Regionale) **official map's** layer **"EDIFICATO"** - geotopographic database of the **Liguria Region**
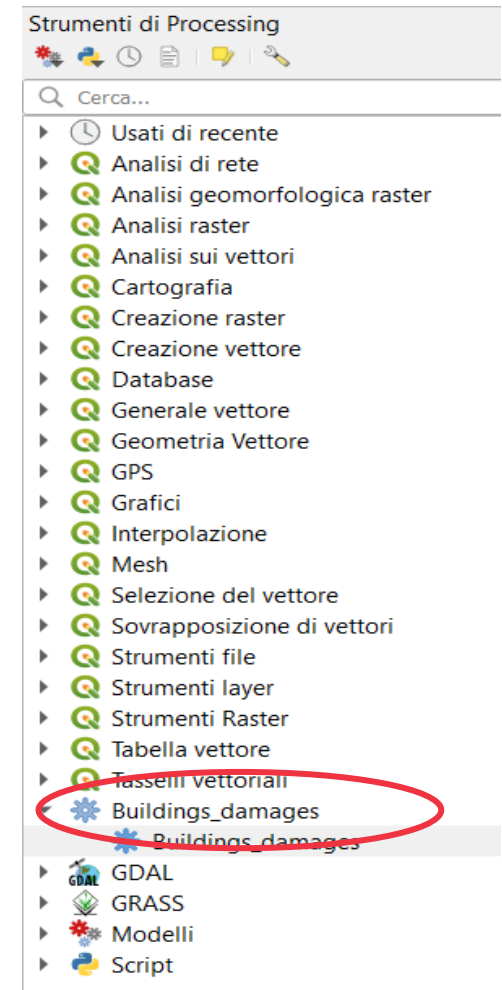
Methodology

Processing plugin - flowchart

Methodology

Processing plugin interface

Results

Application to a case of study

Flooding of the

Chiaravagna stream
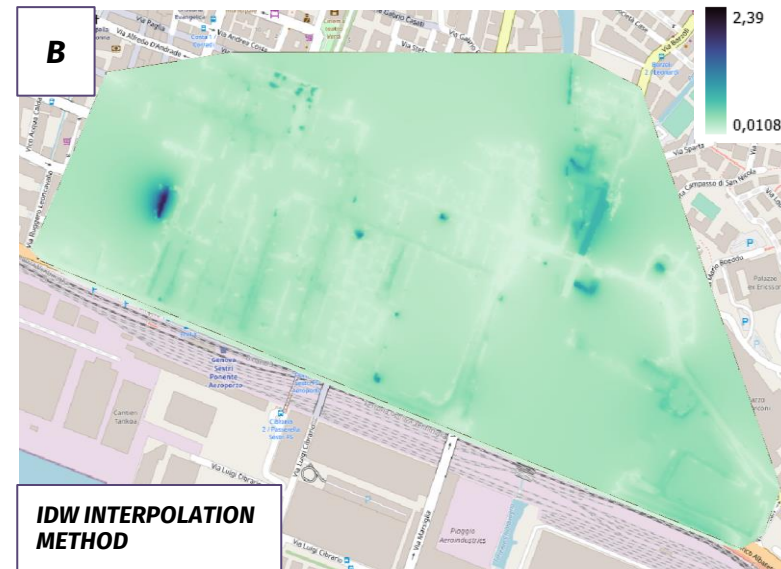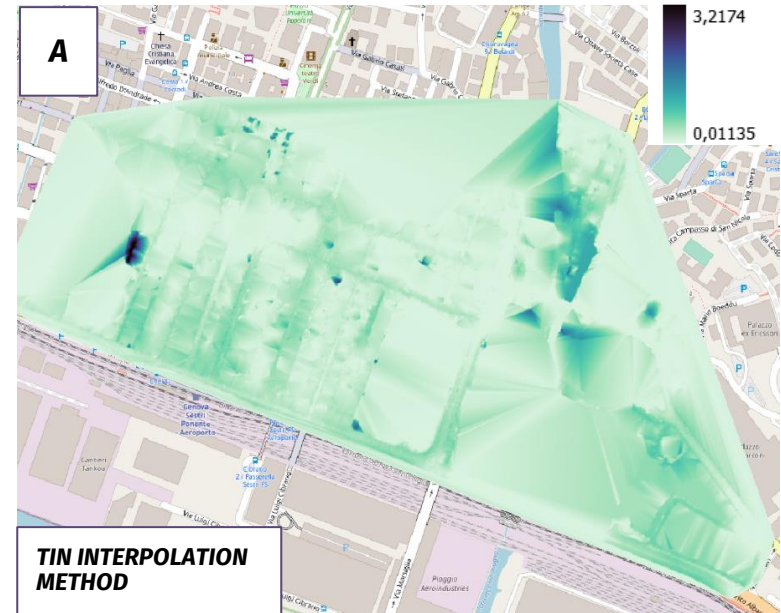
(Genova) – 4 October 2010

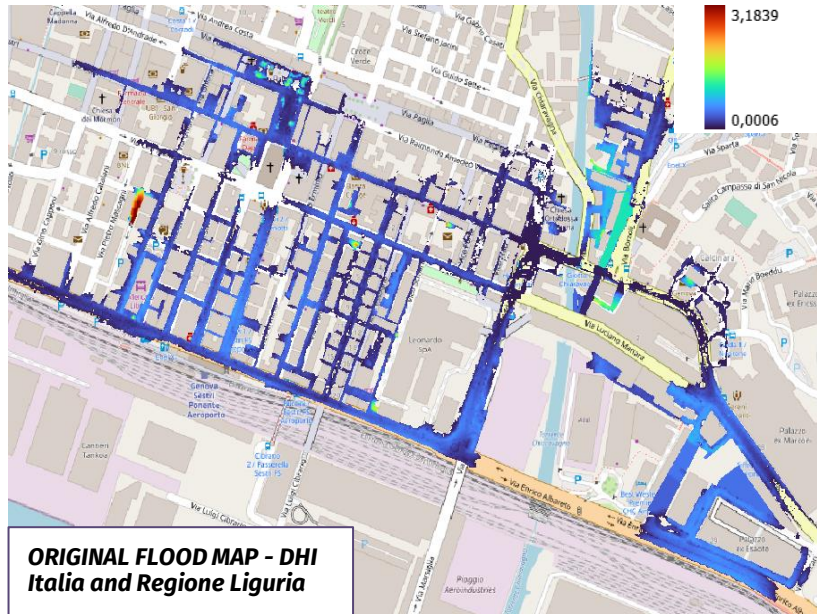- Caused by rains of
  extraordinary intensities,
  involving **buildings**, **roads**
  and people

Results

Application to a case of study
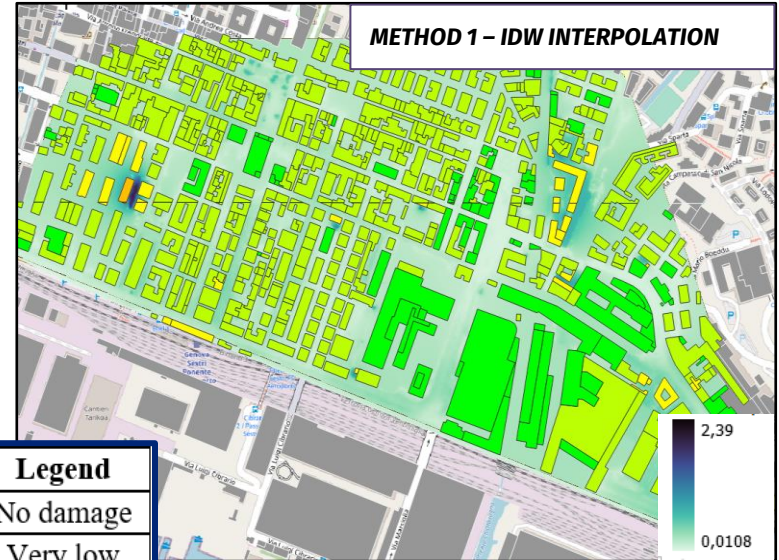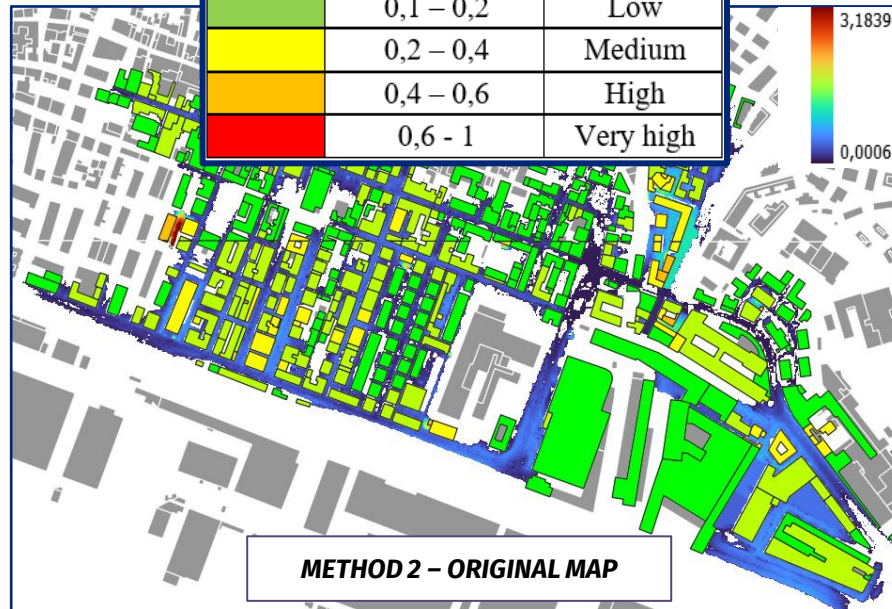
Plugin's test - available flood map

ORIGINAL FLOOD MAP – DHI
Italia and Regione Liguria

A

TIN INTERPOLATION
METHOD

B

IDW INTERPOLATION
METHOD

UniGe | DICCA

Results

METHOD 1 – TIN INTERPOLATION

3,2174

0,01135
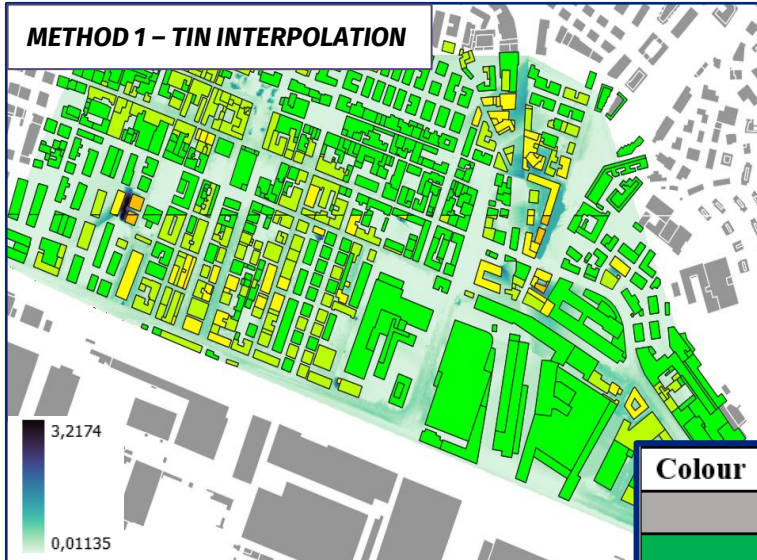
METHOD 1 – IDW INTERPOLATION

2,39

0,0108

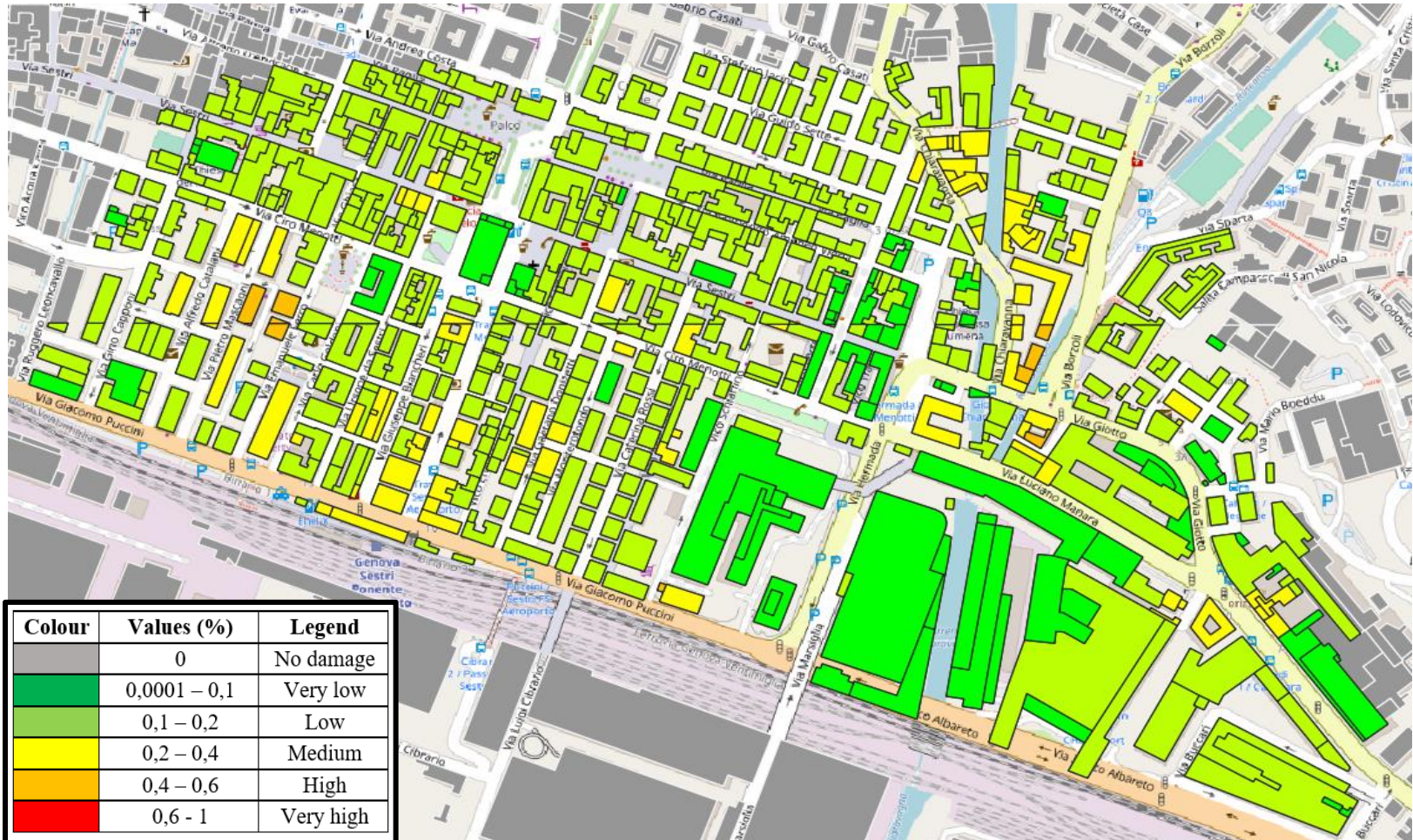| Colour	Values (%)	Legend
	0	No damage
	0,0001 – 0,1	Very low
	0,1 – 0,2	Low
	0,2 – 0,4	Medium
	0,4 – 0,6	High
	0,6 - 1	Very high

3,1839

0,0006

METHOD 2 – ORIGINAL MAP

Results

Application to a case of study

Maximum expected buildings' damage of the different test's output

Colour	Values (%)	Legend
	0	No damage
	0,0001 – 0,1	Very low
	0,1 – 0,2	Low
	0,2 – 0,4	Medium
	0,4 – 0,6	High
	0,6 - 1	Very high

UniGe | DICCA

Results

Application to a case of study

Confidence of the **results** with respect the choice of methodology

☐	Standard deviation interval (0-0,5)
🟧	Standard deviation interval (0,5-1)
🟥	Standard deviation ≈1
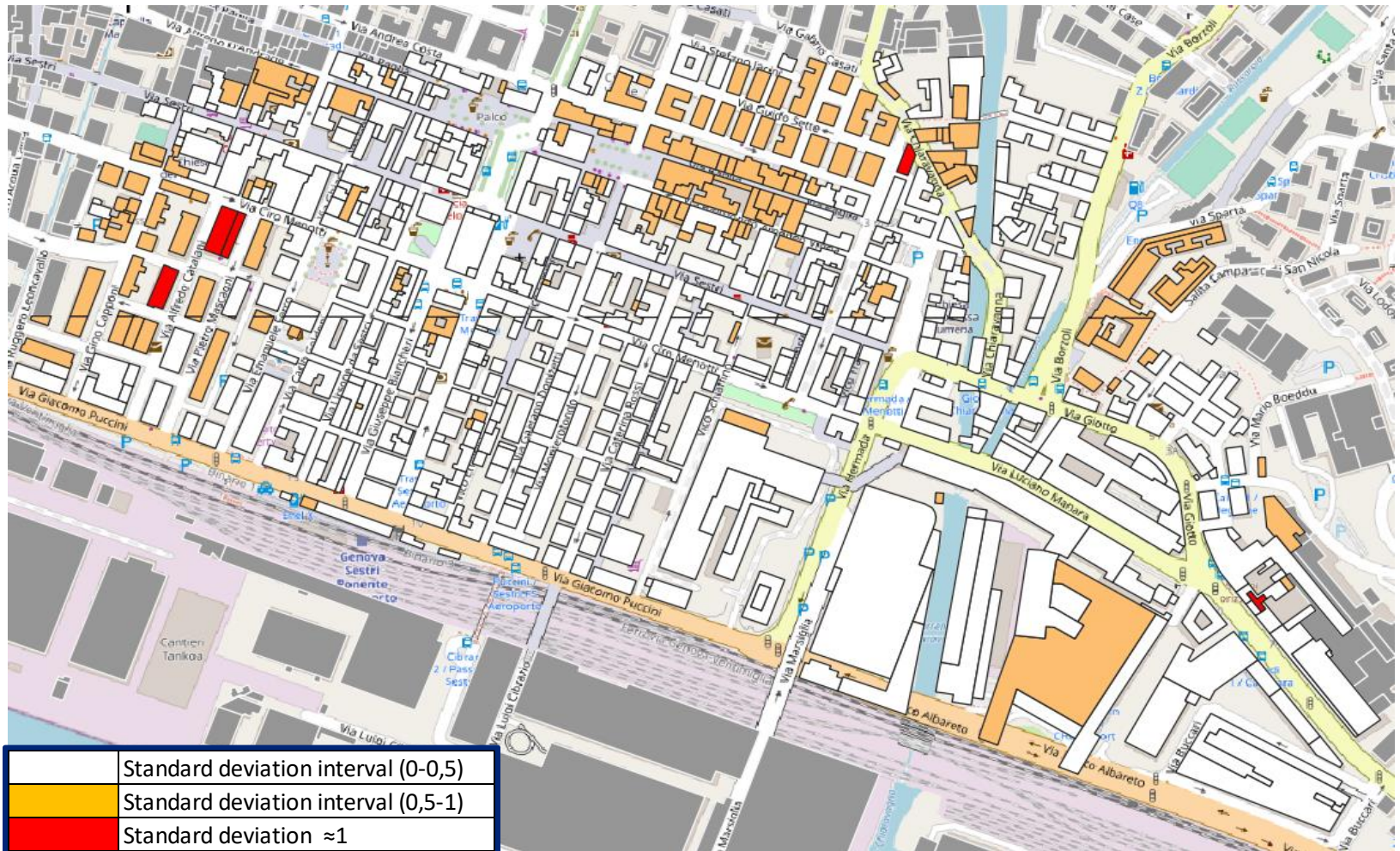
Results

Application to a case of study – buildings' maximum economic damage [€]

Legend:
- 0
- >0 – 500'000 €
- 500'000 € – 2'000'000 €
- 2'000'000 € – 6'000'000 €
- 6'000'000 €– 15'000'000 €
- 15'000'000 € – 70'000'000 €
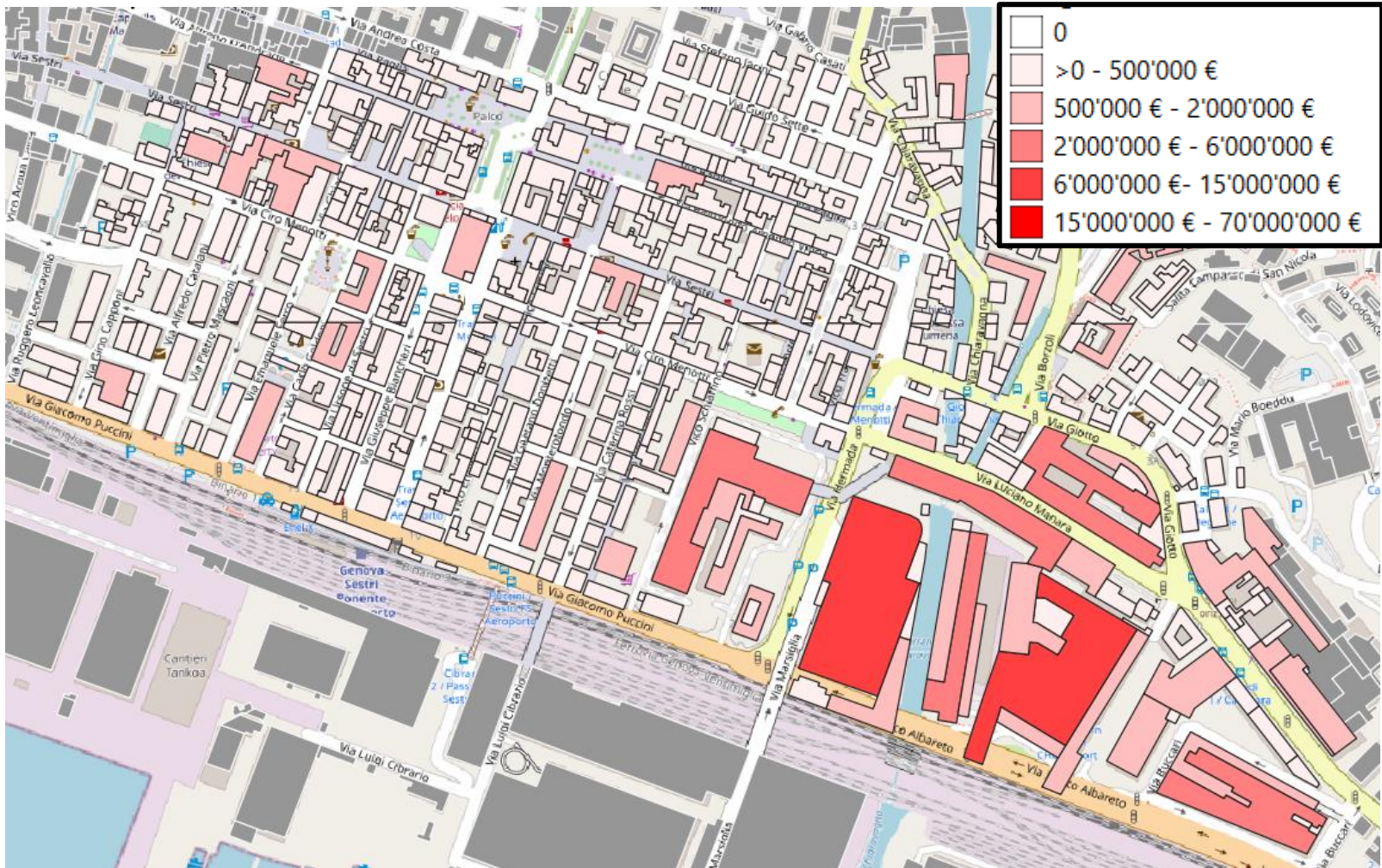
Conclusions

1 **Results**

2 *Application of a vulnerability model*

3 *The developed plugins...*

- Buildings flood damage estimation methods

  - Processing **plugin** implemented in **QGIS**

    - Exploit:

1. **official cartography** that contains information of the **buildings' intended use**

2. Standard **flood map**

- **Global flood depth-damage functions**, by the JRC, associated in **automatic** way to each buildings allowing to obtain a **grading damage map**

- **Maximum direct tangible physical damage** for the categories of buildings

- **Average values** of the maximum damage (€/m²) at **Italy level**

..allows to **utilize** every **simulations of flood map** with an indication of the **depth**:

1. **"Space filling"** flood map : cover the footprints of the buildings

2. Flood map that **take into account** the presence of the **buildings**

Conclusions

Possible further development…

..of the procedure in order that:

1. Take into account **number of people impacted** for each building;
2. Be **generalized** to use:
   - **different taxonomy tables**
   - **other vulnerability assessment methods** that take into account the number of floors, presence of basements, etc.

- Future developer can **adapt** the plugin to be used for **various applications** and a wider range of input data

- **Open Source procedure** available in the **GitHub** page of the **Geomatic Lab – DICCA** – University of Genova

UniGe | DICCA