UNIVERSITÀ DEGLI STUDI DI GENOVA

SCUOLA POLITECNICA

DICCA

Dipartimento di Ingegneria Civile, Chimica ed Ambientale

MASTER'S DEGREE IN
ENVIRONMENTAL ENGINEERING

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

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Academic Year 2021/2022

Aknowledgements

Desidero dedicare questo spazio alle persone che hanno avuto un ruolo fondamentale per il raggiungimento di questo importantissimo traguardo.

Ai miei relatori, i Professori Giorgio Boni, Silvia De Angeli e Bianca Federici, per avermi guidato e consigliato per lo svolgimento di questo lavoro. Per la loro pazienza e le gratificazioni, per avermi permesso di svolgere la tesi su argomenti per me di particolare interesse e per avermi trasmesso la passione per questo lavoro.

Alla mia famiglia, per la fiducia che ha riposto in me e per essere da sempre la mia sostenitrice. Per aver sempre appoggiato le mie scelte, aver capito i miei momenti no e per avermi permesso di seguire la mia strada. Senza di loro non avrei potuto realizzare tutto questo.

Alla mia ancora, Daniel, sempre al mio fianco. Grazie per essere la persona con cui vorrei vivere ogni singolo momento. Grazie per aver condiviso tutte le gioie e i dolori di questo percorso, per non aver mai smesso di credere in me anche quando non lo facevo io. Un grazie anche alla sua famiglia, che in questi anni mi ha fatto sempre sentire come a casa e a cui voglio un bene dell'anima.

Alle mie migliori amiche, grazie per non lasciarmi mai sola ed esserci sempre quando ho bisogno, non importa se vicine o lontane. Grazie per le risate a non finire, per aver sempre ascoltato i miei sfoghi e per essere sempre al mio fianco.

Un grazie a Monica, mia compagna di avventure, con me fin dal primo giorno. Diciamo sempre che insieme lavoriamo meglio, grazie per essere stata di appoggio nei momenti no e per aver reso più leggeri questi anni.

Ai miei compagni di corso, le persone con cui ho condiviso i momenti di gioia e le preoccupazioni, sempre pronti ad aiutare e a sostenerci a vicenda. Un grazie in particolare al “Gruppo 1”, che avrà sempre un posto nel mio cuore.

Grazie ai miei zii, per tutto il loro sostegno e, da non dimenticare, per avermi ospitato a casa per sostenere gli esami online, siete stati fondamentali.

A te nonna, un anno che non ci sei più. Il nostro rito: ogni esame sostenuto e ogni successo ero lì da te a raccontarti tutto. Ora non potrò farlo, ma sono sicura che per te ero e sarò sempre un 110 e lode.

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1. Introduction

In 2021 in Italy there are about 3 million families and almost 7 million inhabitants residing in areas at risk of flooding and landslides. Just over 1.5 million (10.7%) of buildings fall into flood-prone areas with medium hydraulic hazard and the industries and services exposed to flood, again with medium hydraulic hazard, exceed 640,000 (13.4%) [1]. Figure 1 shows the summary of buildings (left panel) and people (right panel) exposed to flood risk per region.

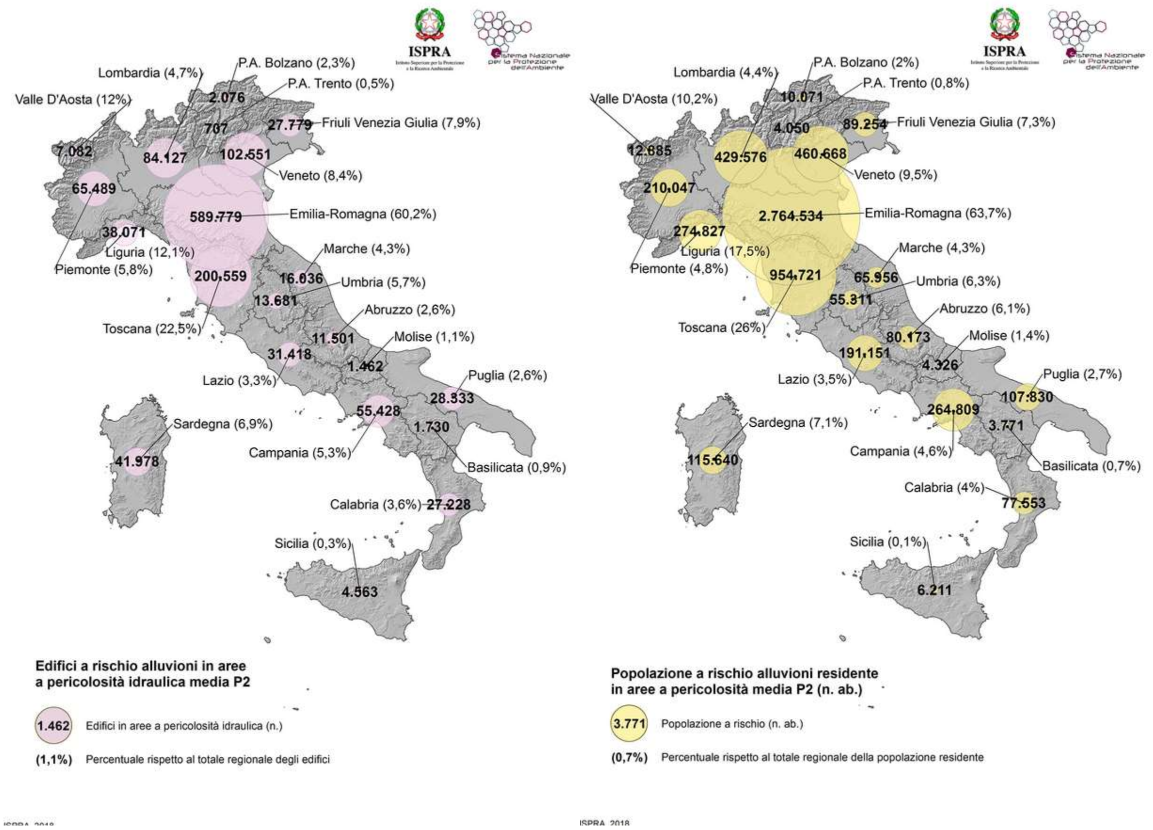

Figure 1: Buildings and people at risk of flooding in areas with medium level flood hazards [2]

For these reasons, effective flood risk management is necessary, considering also its future increase due to demographic and economic growth and climate change.

As figure 1 shows, the flood risk is usually quantified using just the number of exposed assets. Indications about the vulnerability of every single asset would be very helpful to quantify the total damage subsequent to specific flood scenarios. For this reason, a tool that allows a rapid analysis of the estimate of damage and losses due to flood events in urban areas is needed.
An assessment of damage caused by a flood event is essential for local authorities effectively implement preparedness and response actions (considering either pre and post event assessments).

In recent years, the risk of flooding has increased significantly, due to factors that increase its vulnerability and factors that increase the incidence of hazardous events.
The greatest vulnerability is due to the growth of the world population; November 15, 2022 was estimated by the United Nations as the day when the world population reached 8 billion people. Another aspect of the increase in vulnerability is the large rate of urbanization. According to United Nations data [3] the percentage of global urbanization has increased from 29% to 50% and is expected to rise to 70% in 2050 [4]. This causes an increase in the impermeable surface and changes in the environment that can intensify the effects of intense meteorological events.
However, it is not only the greater exposure of the population to hazards that can explain the increase in natural disasters, but also the frequency of destructive events linked to extreme weather events. A total of 3750 storms and floods were recorded between 2000 and 2010, accounting for two-thirds of all events. Although the time span is not yet long enough to indicate this with certainty, these data indicate that climate change is negatively correlated with the occurrence of natural disasters [4]. Statistical studies show that floods are more frequent and cause damage to much larger areas than they were 30 years ago.

The impact of flooding on the territory depends on the overall organization of the latter and on the behaviour of the population and on the severity of the flood event (water depth and flow speed). In order to characterize the magnitude of this impact on a local scale, the effects are estimated taking into account damage to buildings and artifacts, loss of stability for the people involved and mobilization of objects in the flooded area.
The aim of this thesis is to find an effective and fast way to estimate the damages and losses to buildings in urban environment, caused by floods. Therefore, for this study, only the direct physical impact of flooding on buildings will be considered, even if floods may impact also other assets such as people, economy, transport, agriculture, infrastructures, cultural heritage and society, either directly or indirectly.
As a reference vulnerability model for this thesis, it is applied the numerical functions of the so-called vulnerability curves developed by the Joint Research Centre of the European Commission (JRC), whose objective was to develop a global database containing damage curves representing the percentage damage in function of water depth, as well as the related maximum damage values for a variety of land-use assets and classes [5].
Moreover, the JRC database reports a series of maximum damage values in monetary terms, based on studies on construction costs and considering the structural and content value of the buildings. It is specified that the maximum damage values can be adapted to specific local circumstances, such as urban or rural areas or the use of specific materials.
To perform the flood damage assessment, together with the vulnerability model, the available cartography mapping all the exposed buildings and a map of the flood hazard scenario for which the damage and economic losses are to be analysed, are used as input to the procedure.
Then, a series of pre-processing of vector layers (representing the exposed elements) and raster layers (of the maximum extent of the event) have been performed in a GIS (Geographical Information System) environment. For this reason, tips and tests on how to manage the files needed for the analysis have been introduced, showing the best pre-processing methods by verifying them for a specific case study.
The procedure was implemented inside the free and open-source software QGIS, version 3.22, and the GRASS GIS plug-in, which provides access to the functionalities of GRASS GIS.

In order to classify the exposed elements, a taxonomy model in line with the one used in the JRC curves has been proposed, assuming that a user has a vector layer of the Liguria Region geotopographic database relative to buildings [6]. In addition, a taxonomy has been proposed using the classification of buildings used in the OpenStreetMap (OSM) geodatabase [7].
The final goal of the present thesis is to create a processing plugin on QGIS, with an intuitive interface, that allows estimating the percentage and economic values of flood damage for each building, in particular for residential, commercial, industrial and transport facilities buildings. The plugin can be useful for local officials to know the areas with the highest priority and to coordinate the response during a flood event, thanks to automatic processing that does not require in-depth knowledge of GIS and Python programming. The advantage is that it allows you to use the flood scenarios chosen by the user by assigning the depth and damage to each building.

Although the current version of the plugin integrates the JRC damage curves and requires the layer "Building" of the Liguria Region geotopographic database as input, it can be easily improved to cover a wider range of inputs and customised using its own damage values per m2, rather than the average European values provided by the JRC.

2. Flood risk assesment

Risk is "the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between (natural, human-induced or man-made) hazards and vulnerable conditions in a given area and time period" [8]. Whilst risk analysis can be applied in different fields, in this thesis work reference will be made to the risk from natural hazards.

The elements that define the risk are hazard, exposure and vulnerability, according to the so-called 'Risk Equation' (see Fig. 2).
In general, to analyse the risk caused by extreme natural events, it is first necessary to establish the context area (on a regional, provincial, municipal or smaller scale) and establish for that area the potentially hazardous events that can have serious impacts on the community, therefore the probability of occurrence of future extreme events (Probabilistic Hazard Assessment).
The next step is to identify the elements at risk, properly characterised according to a given taxonomy, and to establish the degree to which the elements are exposed to a particular hazard, in order to then be able to estimate the degree of damage.
Subsequently the vulnerability of the different exposed elements is assessed through a relationship between hazard intensity and expected damage, usually represented by vulnerability curves. These curves, in the case of flood, provide mathematical relationships between water depths and percentages of structural and content damage, uniquely created for specific types of buildings. Nevertheless, the risk can be viewed not only in terms of damage to buildings and the number of people affected but also in terms of economic losses, social and cultural impacts etc. projecting them into possible future scenarios.
Fig. 2 shows all the risk assessment components.

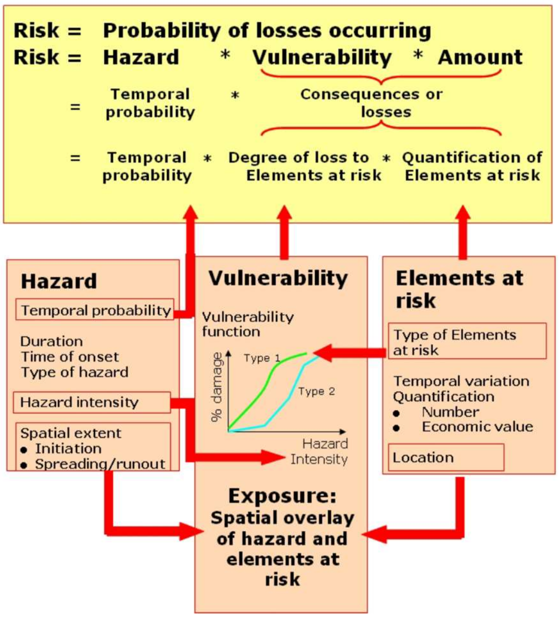

Figure 2: Risk assessment components and their relationships [4].

Risk assessment can be of different types [4]:

- Multi-hazard: when the same area is threatened by different types of hazards such as landslides, floods and earthquakes. Each of these types of hazards can be subject to different scenarios, with different magnitudes and with different probabilities of occurrence;
- Multi-sectoral: when different risk elements are subject to a certain hazard, for example if you are located in an area that includes both a rural area and an urban area. In the rural area the impact on agriculture will be very important while in urban areas the type of buildings subject to that hazard has to be considered. In both situations the population, the transport network, economic activities, etc. are important;
- Multilevel: risk assessment is carried out on different levels distinguishing different policies, i.e. national, provincial or local plans and activities;
- Multistakeholder: risk assessment includes individuals, businesses and authority organizations together;
- Multiphase: keep in mind that risk assessment must consider recovery, mitigation, and risk preparedness.

Since the risk is calculated as the product of the probability and the expected losses, it directly depends on the latter, which can be classified into different types:

- Direct losses, i.e. resulting directly from the impact of the hazard, such as flooded buildings;
- Indirect losses, which do not directly depend on the hazard such as, for example, the loss of functionality or remediation costs;
- Tangible losses, i.e. losses that have a monetary value;
- Intangible losses that cannot be assessed in monetary terms, such as casualties or fatalities.

Moreover, the risk depends on the type of element considered on which to base analyzes [4]:

- Property risk: indicating the number of buildings that might be partially damaged/ severely damaged or collapsed;
- Economic risk: indicating the amount of money that is likely to be lost as a consequence of hazardous phenomena;
- Population risk: indicating the risk fatality or injury to an individual (individual risk) or to a group of individuals (societal risk).

General	Type	Principle	
Qualitative	Qualitative	Based on relative risk classes categorized by expert judgment. Risk classes: High, Moderate and Low	
	Semi-quantitative	Based on relative ranking and weights assignments by a given criteria. Risk index: ranked values (0-1, 0-10 or 0-100). (dimensionless)	
Quantitative	Probability	Probabilistic values (0-1) for having a predefined loss over a particular time period	
	Economic risk	Quantification of the expected losses in monetary values over a specific period of time	
		Probable Maximum Loss (PML)	Probable Maximum Loss (PML) The largest loss believed to be possible in a defined return period, such as 1 in 100 years, or 1 in 250 years.
		Average Annual Loss (AAL)	Expected loss per year when averaged over a very long period (e.g., 1,000 years). Computationally, AAL is the summation of products of event losses and event occurrence probabilities for all stochastic events in a loss model.
		Loss Exceedance curve (LEC)	Risk curve plotting the consequences (losses) against the probability for many different events with different return periods.
	Population risk	Quantification of the risk to population	
		Individual risk	The risk of fatality or injury to any identifiable (named) individual who live within the zone impacted by a hazard; or follows a particular pattern of life that might subject him or her to the consequences of a hazard.
		Societal risk	The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a hazard causing a number of deaths, injury, financial, environmental, and other losses.

Figure 3: different ways of expressing the risk [4]

The individual risk can be calculated as the total risk (average number of deaths from floods) divided by the population at risk (total inhabitants of the area considered).

Social risk is usually expressed by F-N curves (Fig. 4), which are curves that plot the frequency of events causing at least N fatalities versus the number N on logarithmic scales. The frequency can be replaced by the annual probability and the curves can be constructed in spatial units. They can be constructed based on historical data regarding the number of events (floods, landslides, etc.) and relative victims. The curves can also be based on different future risk scenarios, where for a number of events with different magnitudes the number of victims is estimated [4].

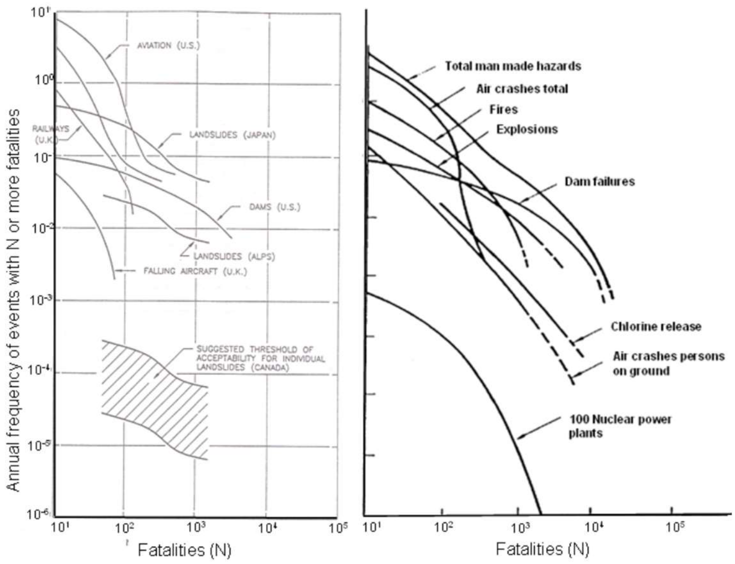

Figure 4: Examples of F-N curves [4]

Typically, the average cost per building and content per square meter is used to estimate economic losses and multiplied by the footprint of the building on the ground, is used to estimate economic losses. The monetary value can be obtained by analyzing the costs of construction and building contents, by obtaining information on real estate prices or by examining the construction costs per square meter based on the type of construction and land use. In fact, the estimation of economic losses can be done separately based on land use for residential, commercial/industrial and public buildings, for example valuating for companies the loss of production and people who work considering data of general production per employee. The estimation of economic losses can also be useful for non-life insurance at the municipal level by carrying out a cost-benefit analysis.
Economic losses are directly proportional to the level of development of a country, as the value of damaged elements increases.
To express economic losses, reference is usually made to the Probable Maximum Losses (PML) which represent the greatest possible loss in a certain return period (Fig.5), representing the risk with a curve considering all possible scenarios with the corresponding return periods (Loss Exceedance Curve, LEC).

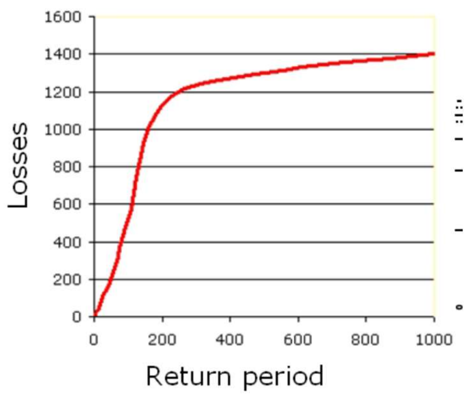

Figure 5: losses against return period [4]

To calculate the Average Annual Losses, the area under the curve shown in Fig.6 must be calculated.

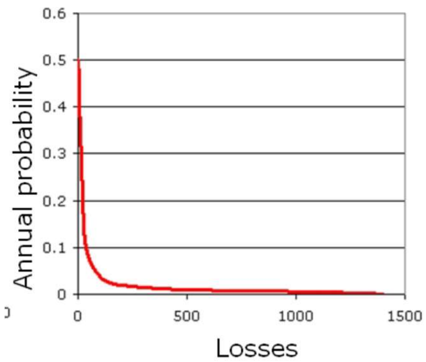

Figure 6: Loss Exceedance Curve (LEC) [4]

Risk assessment can be performed either in qualitative or quantitative terms. More specifically risk assessment approaches can be classified into:

- Qualitative methods, i.e. when it is not possible to express the hazard and vulnerability in quantitative terms due to the lack of information;
- Semi-quantitative methods, which express the risk in terms of indices, i.e. numerical values between zero and one, but which are only indications relating to the risk;
- Quantitative methods, which allow for a precise estimate of probability and expected losses. They can be deterministic, i.e. a particular event with a particular return period is considered, or non-deterministic, in which all possible events are considered which will all have different return periods.

The difference between qualitative and semi-quantitative approaches is that in semi-quantitative methods a weight is given based on certain criteria, evaluating them as numbers and it is useful as an initial screening or when the presence of numerical data is limited. A score is given to each factor to assess the extent to which that factor may be favourable or unfavourable to hazard and the occurrence of loss and damage. This approach can efficiently use the many-criteria spatial techniques implemented in GIS [4].

Quantitative risk assessment typically considers all effects combined in terms of losses for all possible scenarios that could occur. Commonly for various hazard scenarios, vulnerability is considered as a consequence of the hazard, and is then entered in a graph relating it to the probability of occurrence of events of a certain magnitude. The curve is called the risk curve, and the area under it is the total (annual) risk.

Fig. 7 shows an example of how a probabilistic analysis of flood risk is generally carried out, whereby the total consequences per scenario (LEC) are plotted for each event with a certain probability of occurrence. The consequences (losses) are the product of the vulnerability and the elements at risk, quantifiable in monetary terms. The scenarios are obtained from hydraulic modelling and the elements at risk are classified by type and for each of them a curve is plotted which represents the relationship between the depth reached by the water and the damage for the specific type of building (vulnerability curves). In the example in Fig.7, type 1 buildings will suffer more damage than the type 2.
In Fig. 8 it can be seen an example of a qualitative risk matrix.

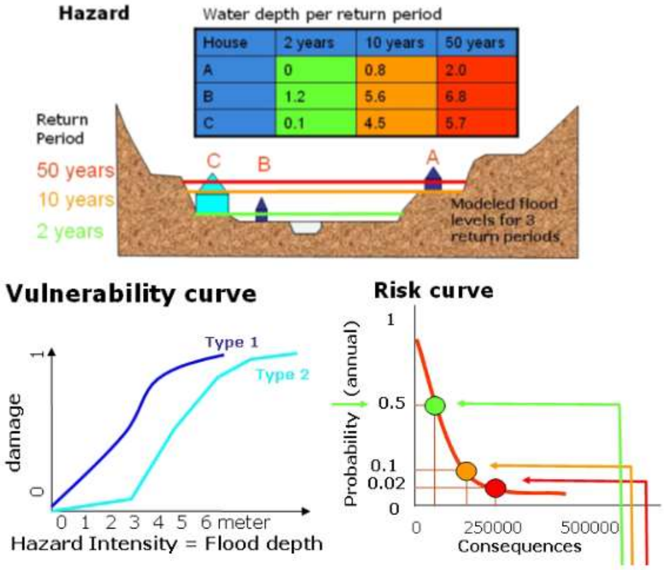

Figure 7: example of a probabilistic risk assessment, resulting in the calculation of a risk curve, or loss exceedance curve (LEC) [4].

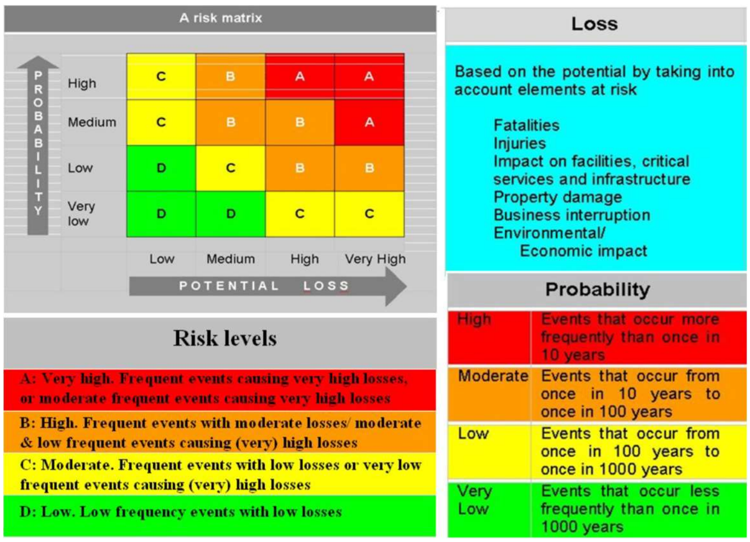

Figure 8: example of a qualitative risk matrix [4]

2.1. Hazard

Hazard is defined as “a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity” [8].

The analysis made for the hazard is valid for a specific area and is usually performed considered as a reference time a period of one year, i.e., evaluating it as the probability that an event with a certain magnitude will occur in one year.

A hazard analysis is based on historical records of hazard events which can be obtained from instrument logged information, mapped events and historical archives. The number of historical data is very important because, if the time period considered is too short and does not contain intense events (with a high return period), it will be difficult to estimate their probability. However, the historical information available is often incomplete.
The larger the data set available, the more accurate the determination of the mean annual frequency will be. It is therefore necessary to fix, in addition to the area of interest and the reference period, also the measurement of the intensity to be considered (e.g. water depth or speed).
What causes floods are mainly heavy and long-lasting rains (neglecting other variables such as urbanization). Flood magnitude is measured by the so-called ‘hydraulic magnitude’, which is the combination of the head and the speed of the current in a given area, associated with the infrequent flood scenario. Hydraulic magnitude can be classified into:

- “moderate hydraulic magnitude”: head values lower than or equal to 0.5 meters and speed lower than or equal to 1 meter per second (m/s). In cases where the speed is not determined, hydraulic head equal to or less than 0.3 meters;
- "severe hydraulic magnitude": values of head less than or equal to 0.5 meters and speed greater than 1 meter per second (m/s) or head greater than 0.5 meters and less than or equal to 1 meter and speed lower or equal to 1 meter per second (m/s). In cases where the speed is not determined, hydraulic head greater than 0.3 meters and less than or equal to 0.5 meters;
- "very severe hydraulic magnitude": head greater than 0.5 meters and less than or equal to 1 meter and speed greater than 1 meter per second (m/s) or head greater than 1 metre. In cases where the speed is not determined hydraulic head more than 0.5 meters. [9]”

In general, it can be said that low magnitude events have high frequencies (and vice versa) (Fig. 9).

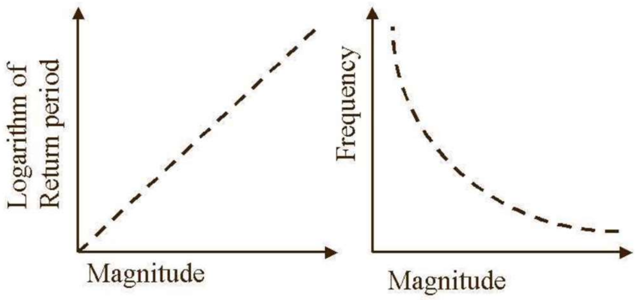

Figure 9: magnitude – frequency relation for most of the natural hazards

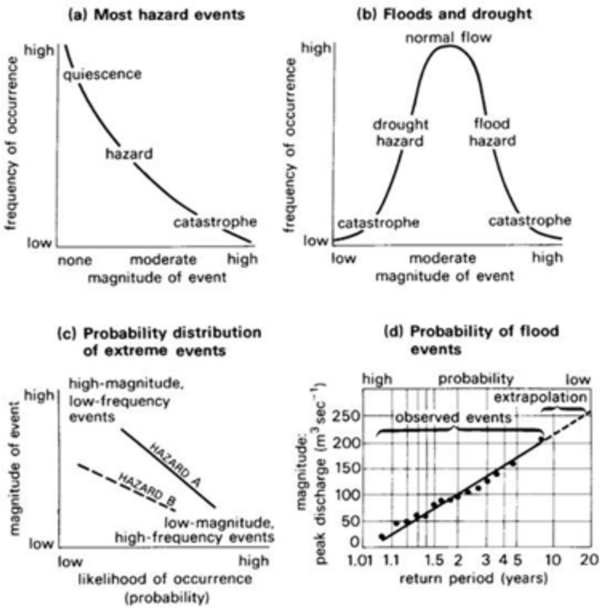

Figure 10: Relationship between magnitude and frequency of events

"Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (3) requires river basin management plans to be developed for each river basin district in order to achieve good ecological and chemical status, and it will contribute to mitigating the effects of floods. However, reducing the risk of floods is not one of the principal objectives of that Directive, nor does it take into account the future changes in the risk of flooding as a result of climate change. [10]"

"Referring the directive, member States shall, at the level of the river basin district, or unit of management, prepare flood hazard maps and flood risk maps, at the most appropriate scale for the areas identified under Article 5 [10].
Flood hazard maps shall cover the geographical areas which could be flooded according to the following scenarios:

(a) floods with a low probability, or extreme event scenarios;
(b) floods with a medium probability (likely return period ≥ 100 years);

(c) floods with a high probability, where appropriate.

For each scenario the following elements shall be shown:
(a) the flood extent;
(b) water depths or water level, as appropriate;
(c) where appropriate, the flow velocity or the relevant waterflow. [10]".

Therefore, for a probabilistic analysis of the hazard, a realistic scenario is not considered, but the component of each possible potentially damaging flood event. Probability analysis considers the uncertainties in the location, magnitude, frequency and effects of a flood event and combines each of these to obtain the probability of having different event magnitudes. The magnitude of an extreme event is inversely proportional to its probability of occurrence and the goal of frequency analysis of hydrological data is to relate the magnitude of extreme events to their probability of occurrence, through the use of a probability distribution.

It is assumed that the hydrological data are statistically independent and identically distributed and that the hydrological system that produces them is considered stochastic and independent of space and time. Often, therefore, the maximum annual values of the variables analyzed are selected with the expectation that the subsequent observations of these events will be independent.
An extreme meteoric event is a rare event, referring to its statistical distribution in a given location. The definition of "rare" varies, but usually an extreme event should normally be "rare" or "rarer" than the 10th or 90th percentile.

The Fig.10 (b) represents the probability distribution of the intensity of the flood events that occur in a given site in a year. The mean frequency is the fractile of the probability that the intensity will occur in a year, i.e., the probability that the intensity will be greater than a certain level.

The return period of a given event magnitude can be defined as the selected time period over the number of events of intensity greater than or equal to an event of a given magnitude that occurred in that period. It is therefore considered only as a mean distance between these events. The return period can also be expressed as the inverse of the mean annual probability of occurrence, which would be the average number of events in the unit of time with magnitude greater than or equal to a given magnitude of the event.

$$T_R = \frac{1}{P_s}$$

The return time is therefore the number of years that are on average between two events of intensity equal to or greater than a specific one.

To calculate the probability that an event with a certain return period occurs or that it is exceeded at least once in a period of N years, it is useful to consider the following probabilities:

- Probability that a certain event is exceeded every year: $P_s = \frac{1}{T_R}$

- Probability that a certain event occurs in N years: $P_s = 1 - \left[1 - (\frac{1}{T_R})\right]^N$.

The frequency distributions can have different shapes and there are many events that have a relationship that can be represented with probability functions, such as flood events.

The three methods for calculating the distribution of extreme values in case of right skew are Gumbel, Fresher and Weibull, all based on the Generalized Extreme Value (GEV) distribution (Fig. 11).

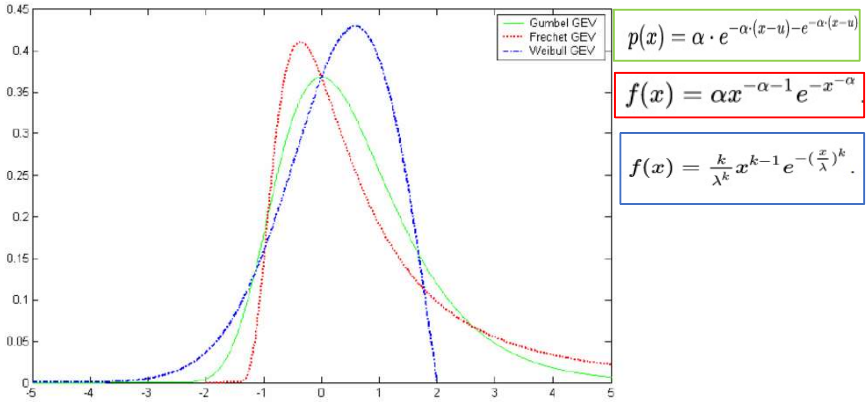

Figure 11: distribution functions of extreme values [11].

Generally, the Gumbel distribution is used for single site analysis while, for regional frequency analysis the GEV is usually used.

The statistical methods discussed are applied to extend the available data and have the occurrence frequency of natural events.
As a general rule, when working with records less than 10 years, you should avoid frequency analysis, as you are lucky to have records longer than thirty years when it comes to flooding.
It is important to specify that changing climatic conditions can alter the statistics of extreme events, in addition to changes in land use, construction of dams and changes to canals.
You must therefore pay attention to this information when analyzing historical records and observe whether the records are homogeneous (having more or less all the same characteristics), because if they are not the standard deviation will increase.

Precipitations and floods in rivers are events that cause the probability distribution to be skewed to the right (Fig. 12).

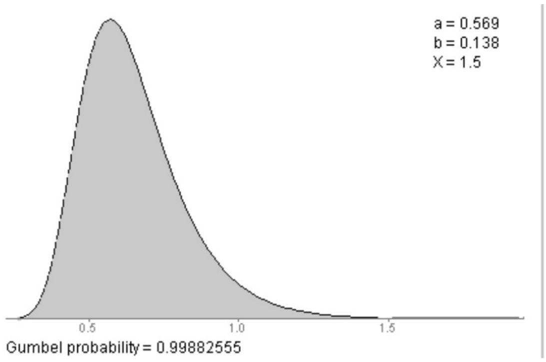

Figure 12: right-skewed Gumbel distribution [4].

This is because the distribution cannot have negative values and it could happen that there are extreme events far from the mean, in fact, events with high magnitude are infrequent and cause the distribution to be distorted to the right. Also, the longer the recording period, the more likely it is that infrequent high-magnitude events will be observed. If, on the other hand, the time interval of the measurements is smaller, the asymmetry will be smaller. Furthermore, thunderstorms with high intensity have limited extension and this means that the asymmetry increases as the size of the basin decreases. Another reason that leads to distortions is the presence of waterproof layers that do not allow water to infiltrate.

Flood forecasting is useful, but it shouldn't be the only method for estimating flood hazard in an area.

Traditional flood hazard maps show the annual probability of flooding. The relationship between the water level and the probability of occurrence is that the higher the water level, the less likely there is a depth of that type. This approach does not allow differentiation in degrees of hazards in an area because it does not consider the propagation of the flood flow. In fact, this depends on the flow of water in the area and on the characteristics of the terrain, the presence of obstacles, embankments, buildings, etc. (Fig. 13).

Flood intensifying factors:		
Catchment Conditions		
	Stable	Area, slope, altitude, shape, geology, soils
	Variable	Vegetation, climate, human action, certain soil properties (infiltration), surface resistance
Antecedent Conditions		
		Previous rain- and snow fall
Network and channel conditions		
		Pattern, channel length, stream order, profile & gradient, bifurcation ratio, roughness, human action, (local) storage

Figure 13: flood intensifying factors [4]

Traditional hazard maps do not provide enough information to develop evacuation plans useful to the authorities, so in such cases a model able to simulate flood scenarios with a 1D/2D flood propagation model can be useful (example in Fig. 14).

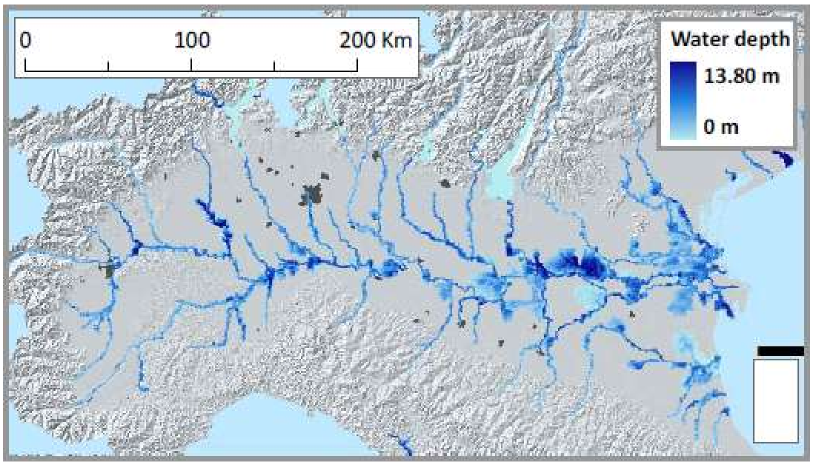

Figure 14: Pan-European hazard map calculated on the basis of EFAS (European Flood Alert System). The map represents water extent and depth for a general 100 years return period flood event. [4]

Studying hazard through models is very important to gain a better understanding of the dynamics and behaviour of river systems. However, most hydraulic and hydrological models require a very large data source and spatially distributed information regarding topography, terrain, areas covered and soil type. The data useful for the analysis of flood events are obtained through satellite and aerial sensors, at different spatial resolutions depending on the detail requested by the analysis phase (Fig. 15).

	Medium-Low Resolution	High Resolution	SAR	Other (e.g. LIDAR and SRTM)
Provision of spatial distributed data for modeling				
Validation of model results				
Elements at Risk mapping				
Post disaster rapid response data provision				

Figure 15: Use of remote sensing data for flood hazard assessment (colour code: green = generally very useful, yellow = depends on the situation; white = generally not useful.) [4]

The table cites different acquisition techniques used to described the 3D model of the terrain, as SAR, i.e. Synthetic Aperture Radar, LiDAR, i.e. Light Detection And Ranging, and SRTM, Shuttle Radar Topography Mission.
SAR technology provide high-resolution images through long-range radar propagation, allowing images to be captured at night or in adverse weather conditions.
LIDAR technology is based on laser technology which scans the entire territory through it.
The SRTM are satellite sensors that use the radar iterferometry technique which allows to obtain the altitudes of the earth's surface.

2.2. Exposure and vulnerability

"The elements at risk are all objects, persons, animals, activities and processes that may be adversely affected by hazardous phenomena, in a particular area, either directly or indirectly. This includes: buildings, facilities, population, livestock, economic activities, public services, and environment [8]." The interaction of the elements at risk with the hazard defines the exposure [8], i.e. it indicates the degree to which the elements at risk are exposed to a particular hazard. In other words, they are people, property or systems present in hazardous zones due to which they are subject to potential losses.

In order to visualize the spatial interaction between the elements at risk and the hazardous areas, a Geographic Information System (GIS) can be used, through a simple cartographic superimposition of the flood hazard map with a map of the elements at risk. Through this it will be possible then to evaluate the vulnerability of the elements at risk due to a certain hazard.

The way to classify elements at risk defines how the risk makers, emergency personnel and the public will perceive the risk. There are different classes of elements at risk which encompasses physical, economic, social and environmental aspects (Fig. 16).

Physical elements **Infrastructure,** for example: roads, railway, bridges, harbors, airports etc. **Critical facilities**, for example: emergency shelters, schools, hospitals, nursing homes, fire brigades, police etc... **Utilities**: Power supply, Water supply Services: transport, communications etc... Government services: all levels - national, provincial, local Machinery and equipment Historical structures and artifacts	**Societal elements** Vulnerable age group categories Low-income groups Landless/Homeless Disabled Gender Single parent households Etc.
Economic elements Business and trade activities, Access to work, Agricultural land, Impact on work force, Productivity cost Opportunity cost	**Environmental elements** Environmental Resources: air, water, fauna, flora Biodiversity Landscape

Figure 16: Classification of elements at risk - Asian Disaster Preparedness Center (ADPC) [4].

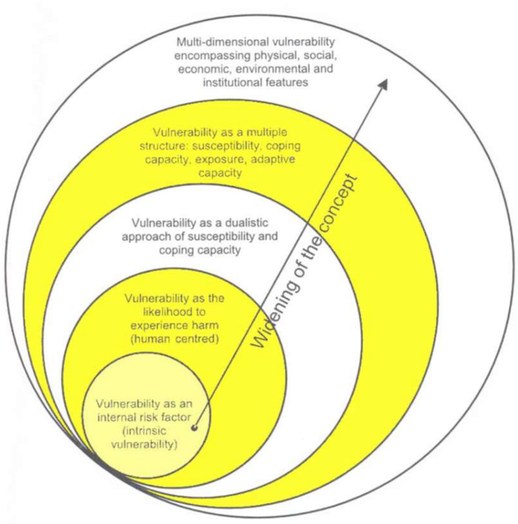

Figure 17: Key spheres of the concept of vulnerability [13]

Vulnerability is defined by UN-ISDR (United Nations Office for Disaster Risk Reduction [14] (Fig. 18) as "the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards",

Vulnerability (as it can be seen in Fig.17) is:

- Multi-dimensional (e.g., physical, social, economic, environmental, institutional, and human factors define vulnerability);
- Dynamic (vulnerability changes over time);
- Scale-dependent (vulnerability can be expressed at different scales from human to household to community to country resolution;
- Site-specific (each location might need its own approach) [4].

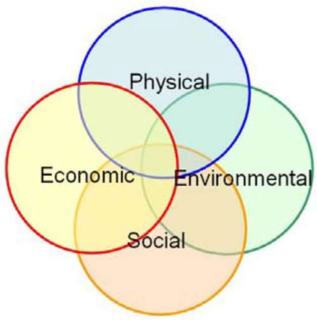

Figure 18: Indicators, Influencing vulnerability (UN-ISDR) [4].

It is specified that often for the study of vulnerability a not very detailed spatial scale is considered, while it would be more advantageous to evaluate it on a more local and objective scale [12]. What complicates vulnerability analysis is the difficulty of developing meaningful and quantifiable indicators due to the lack of data available to measure them and the lack of empirical data on flood losses to be able to link them together with the damage to the vulnerability [12].

The type of vulnerability also determines the types of losses that will occur following an extreme event. The different types of losses that a community or a system can encounter are reported in Fig.19.

	Human - social	**Physical**	**Economic**	**Cultural Environmental**
Direct losses	• Fatalities • Injuries • Loss of income or employment • Homelessness	• Structural damage or collapse to buildings • Non-structural damage and damage to contents • Structural damage infrastructure	• Interruption of business due to damage to buildings and infrastructure • Loss of productive workforce through fatalities, injuries and relief efforts • Capital costs of response and relief	• Sedimentation • Pollution • Endangered species • Destruction of ecological zones • Destruction of cultural heritage
Indirect losses	• Diseases • Permanent disability • Psychological impact • Loss of social cohesion due to disruption of community • Political unrest	• Progressive deterioration of damaged buildings and infrastructure which are not repaired	• Economic losses due to short term disruption of activities • Long term economic losses • insurance losses weaken-ing the insurance market • Less investments • Capital costs of repair • Reduction in tourism	• Loss of biodiversity • Loss of cultural diversity

Figure 19: overview of types of losses [4].

This research thesis will focus on the assessment of the vulnerability and the risk for buildings, with a specific focus on physical vulnerability, understood as “the potential for physical impact on the built environment and population” [4], and direct physical and monetary losses.

Physical vulnerability is characterized by indicators that concern the exhibited assets, dividing the indicators into tangible (expressed in monetary value) and intangible (value of human life, health and the environment). Other indicators that characterize physical vulnerability are those concerning infrastructures and services (drinking or wastewater). As far as lifelines are concerned, the indicators are divided into three categories: those that concern the financial impacts caused by a natural disaster, those that measure the loss of potential connectivity and those that measure travel times to facilities that provide critical services. Other indicators are structural and occupancy of buildings, considering structural elements as indices, including building type, material, age and number of floors, and occupancy indicators that determine the potential value of losses due to a hazard [12].

The vulnerability models combine the aforementioned indicators with information about hazard, exposure and vulnerability.

One type of model is the index-based model which evaluates vulnerability based on statistical data, such as damage and fatalities and the number of buildings that need to be repaired in an area and summing several indicators into an index which will show the vulnerability of a group of people or a country. Among the indices are considered the quality of the building structure, the surface area of the building and the occupancy of the building [12].

The majority of the vulnerability models, on the other hand, are based on the construction of damage-depth functions or vulnerability curves, which relate physical indicators to risk parameters. [12]

2.2.1. Physical vulnerability curves

Physical vulnerability of buildings is usually described by the so-called vulnerability curves, which indicate the general behaviour of buildings of a certain class (homogeneous units) in the face of an extreme event and not for individual buildings.
A homogeneous unit is a cartographic unit which has more or less the same characteristics in terms of elements at risk. For example, the same type of land use or the same types of buildings [4].
The behaviour of each single building is characterized by many factors which can vary from building to building. The ideal would be to carry out an engineering structural assessment of each building in order to determine its behaviour with respect to a certain extreme event.
This procedure would take too much time, so usually the vulnerability is analyzed for a group of buildings having similar characteristics, being the vulnerability an intrinsic quality of a structure and it does not depend on the position.

The degree of loss of a given element or set of elements at risk due to a natural phenomenon is expressed on a scale from 0 (no damage) to 1 (total damage).

The vulnerability curves (Fig. 20) are constructed by relating the intensity of the hazard and the damage data. The result of this relationship will be a curve representing a higher damage for a high level of hazard intensity. Each curve will be representative of a typology of buildings that behave more or less in the same way in the face of an extreme event.

The flood damage functions describe the relationship between hydraulic parameters and the relative damage of the element at risk. Usually the vulnerability curves provide the potential damage as a function of the water depth and only occasionally other hazard parameters such as water speed and flood duration are added. In addition to the building occupancy, building material, the number of floors and the accessibility to roads can be considered as physical indicators [12].

Vulnerability curves can be divided into two types:

- Relative curves: show the percentage of the property value as the damaged share of the total value compared to the hazard intensity.
- Absolute curves: they show the absolute amount of damage as a function of the hazard intensity; that is, the value of the good is already integrated into the damage function [4].

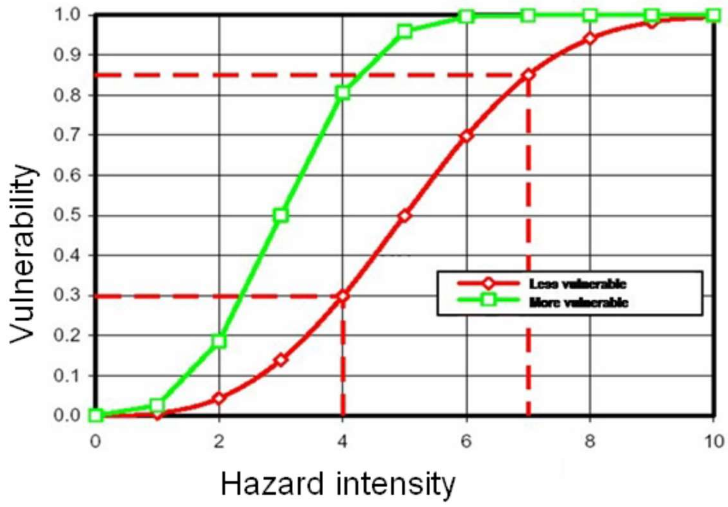

Figure 20 : vulnerability curve (in red: elements less vulnerable, in green: elements more vulnerable) [4]

The vulnerability curves are mainly applied to describe the physical vulnerability which is easily quantifiable because it directly depends on the physical impact of an extreme event.

One method used to measure physical vulnerability and to construct vulnerability curves is based on the analysis of observed data.

Flood events are relatively frequent and widespread, so it is possible to gather information on the degree of physical damage after the event occurs. This allows for a correlation between the intensity of the hazard and the depth of the water, to carry out a statistical correlation with the degree of damage and to derive a vulnerability curve.
Grouping buildings based on similar characteristics for flood response is helpful because the damage it will be observed will be as similar as possible between similar buildings versus those that have large variation within a group (Fig. 21).

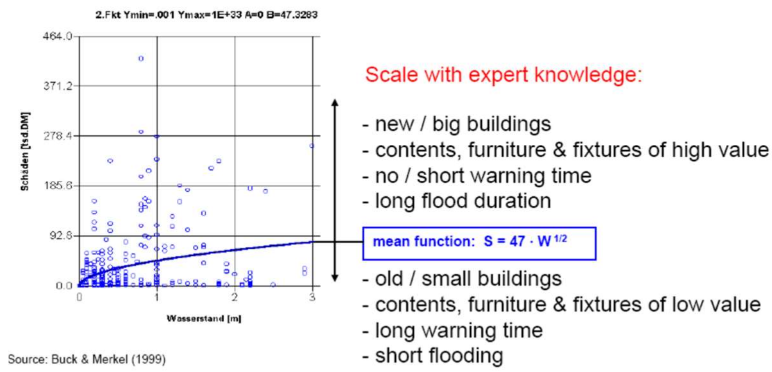

Figure 21: Example for a damage function from the HOWAS database (Flood Damage Database for Germany). [4]

In order to assess the damage, remote sensing can be used to map the extent of the phenomena in combination with a digital elevation model in order to obtain the extent of the flood and the parameters of the flood (depth). Monitoring can also be done through real-time cameras for damage mapping or using existing databases and GIS software (Fig. 22).

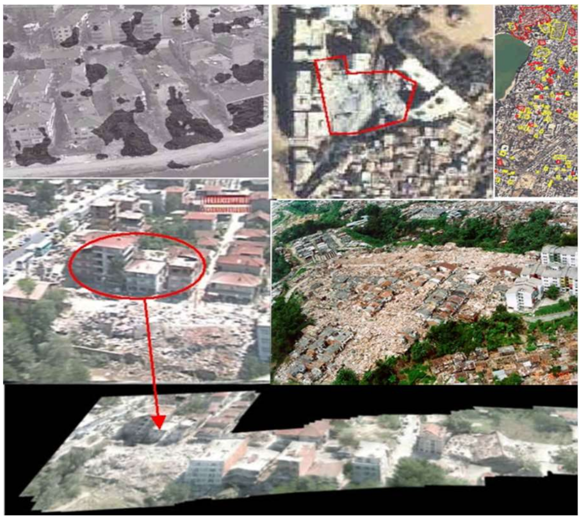

Figure 22: different approaches for using Remote Sensing data for rapid damage assessment, such as video images, oblique photographs, and high resolution satellite imagery (Source: Derya Osirik, ITC MSc student)[4]

Expert opinion is very important for estimating flood damage, specifically if post-event loss or damage data would not provide enough information to apply analytical methods for the construction of the vulnerability curves.

Analytical methods, on the other hand, study the behaviour of buildings using simulation models to tracking the vulnerability curves.

Damage to buildings caused by flooding depends on several factors (Fig.23):

- type of flood;
- water velocity: high flood velocities can cause erosion of slopes and embankments and building foundations;
- the depth of the flood which determines the surface area of the building that will be submerged by the water;
- the flood impulse which is the speed multiplied by the height;
- the duration of the flood that is important for building construction materials, because they can deteriorate under the influence of water;
- waterborne sediment will determine how much a building its contents will be damaged and how much it will cost to remediate;
- the use of the building will determine the number of people present inside in different periods of time, the content and the value of the content;
- the type of building materials will determine how they behave underwater even for long durations;
- the structural typology will determine the resistance of the building to the impact of a flood;
- the location of doors and openings will determine whether flood waters can enter the building;
- the presence of a basement, which will be more easily flooded;
- presence of flood containment structures which ensure that the building does not suffer significant damage [4].

There are two factors in particular that are worth describing in detail: the footprint of the building on the ground and the height of the building.

The building's footprint on land is used in conjunction with urban land use to estimate both the number of people buildings that are subject to a particular damage. It can be determined through cadastral maps, for example, or through the creation of high-resolution maps using LiDAR technologies.

The height of the building will determine how much surface area will be subject to flood damage. Furthermore, the taller a building is, the more it will allow the evacuation of people and contents to the upper floors. The height of the building is normally mapped in the field on the basis of house-to-house surveys; otherwise photogrammetry or LiDAR techniques are used so to determine the height of the entire building as point clouds [4].

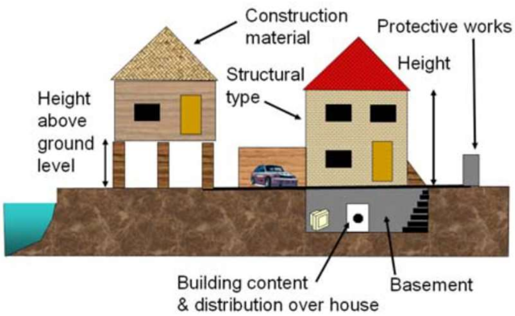

Figure 23: illustration of building characteristics that are important for flood loss assessment. [4]

3. Management of geospatial data in a GIS environment

“A Geographic Information Systems is a computerized system for collecting, storing, managing, analyzing and visualizing spatial information and related non-spatial data. The ultimate purpose of GIS is to provide support for decision making based on spatial data” (Fig. 24) [4].

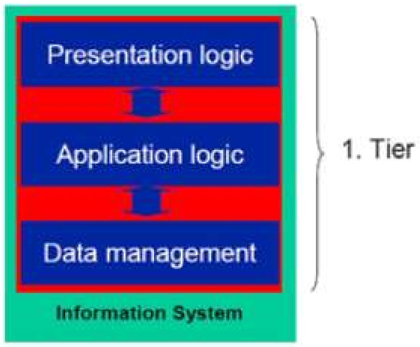

Figure 24 – GIS functions [4]

GIS allows:

- input of geospatial data in different formats;
- manipulation and management of georeferenced data, adequately described through metadata, updated and shared with other users;
- consultation of geospatial data with the aim of searching for information of a specific position
- consultation and integration of different types of data at the same time;
- data analysis of spatial and non-spatial data, for the resolution of problems through map-algebra, data interpolation and geoprocessing operations;
- viewing the data correctly overlapped to cartographic background.

The use of GIS information tools can be very useful for damage assessment. To evaluate all the risk components, spatial information is needed and it can also vary over time; in fact, a flood with a given return period has a certain extension which varies in space and in terms of intensity.
One of the most important aspects for risk management is its visualization, being a spatially variable phenomenon. Through GIS tools, therefore, it is possible to superimpose a hazard map with the elements at risk, not only on a visual level but also on an attribute level, in order to highlight the elements actually exposed to risk (Fig 25).

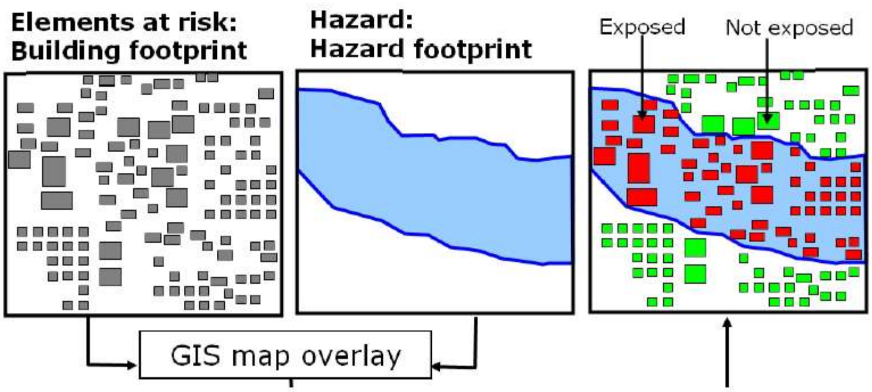

Figure 25: overlay operation to see the element exposed [4]

3.1. Types of spatial information

Spatial information is characterized by coordinates that describe the position of an object, described by a point, a line or an area depending on the shape of the object itself (in a vector data model), or by the spatial distribution of a continuous field (in a raster data model).
For the vulnerability analysis of an area subject to flooding, it will be necessary to have available digital cartography containing information on the buildings of the study area, in vector format, and on the extension of the flooded area, in raster format.

The vector map containing buildings represents them by polygonal elements and attribute information that identify the building typology. The polygonal geometry is described by a minimum of 3 vertices, each defined by X, Y (and sometimes also Z) coordinates, referred to a Datum, i.e. a Reference System and eventually a Cartographic Projection (Fig. 26). Vector maps have a nominal scale, that determine the level of detail typical of the corresponding traditional maps.
The geometric entities of the vector data can be associated to an attribute table, that provides information about the single elements.
The most used vector format is the shapefile, a vector data storage format capable of recording the position, shape and attributes of the spatial entities [15].

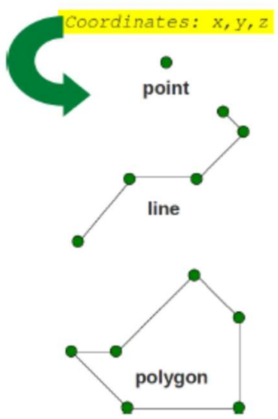

Figure 26: geometric identities of a shapefile [16]

For the assessment of flood damage, it is essential to have information both on the extent of the phenomenon and precise information determined by the event (value of the water head in correspondence with the building and the surrounding area). A flood map of a particular event will therefore be needed, i.e. a representation of the flooded areas associated with a flood event with a given return time, which is essential for assessing the hydraulic risk associated with an object in the area.
The flood map is well represented by raster data, composed by a grid of cells, each of them containing the depth value of the cell area. The smaller the dimension of a pixel, the more precise the depth value will be.
Raster data is used in GIS applications with the aim of displaying continuous fields along an area. The raster is in the correct geographic position, thanks to information relative to the coordinates of one corner of the grid in the proper datum, to the dimension of each pixel in X and Y direction and the number of pixels in row and column (Fig. 27).

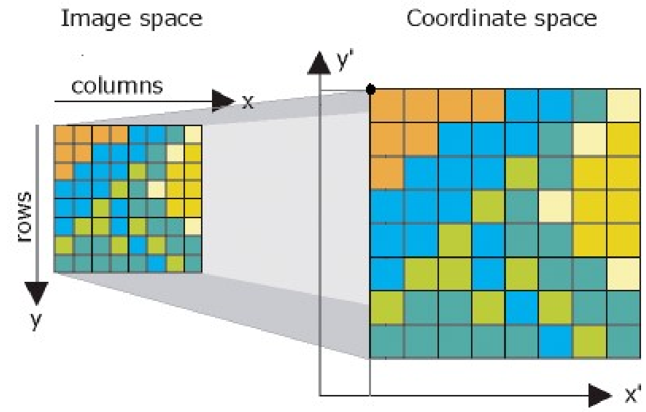

Figure 27:composition of raster file [17]

The most commonly used raster formats are TIF and ASCII GRID. The ASCII GRID format is human readable, and therefore easy to import and export from most GIS software. It consists of an initial header, which contains the information on georeferencing the field and on pixel number and dimension, then followed by the matrix, containing the values relative to each cell. To express the presence of no data in a cell, the value -9999 is used, assigned to those cells whose true value is unknown (Fig. 29). [18]

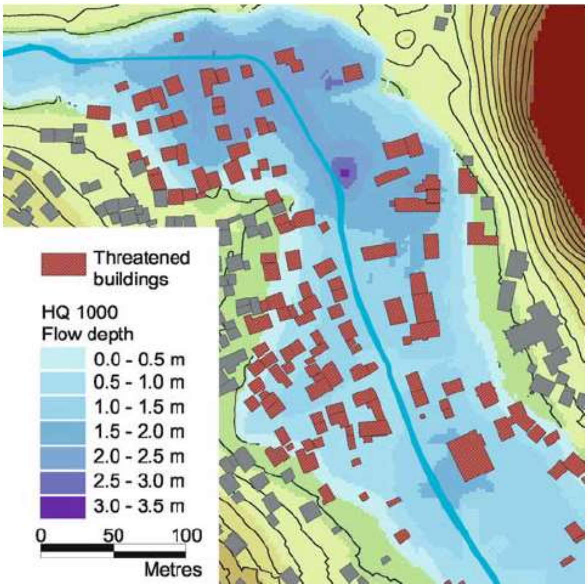

Figure 28: example of a hazard flood map with buildings' vector layer – integration of raster and vector file [19]

Raster data is therefore more efficient than vector data for representing parameters that vary continuously across the surface, such as the extent of a flood. In this case, the depth of the flood is assumed as a quantity capable of representing the effects of the flood; however, it must be taken into account that other hydraulic quantities may come into play in the assessment of flood damage such as speed, flow direction and solid transport.
A flood extent map can be the result of a simulation of a hydraulic 1-D model, representing the hydraulic heads caused by a specific flood event with a specific return time, obtained thanks to software such as HEC-RAS, which allows to perform hydraulic analyses useful for this purpose. Instead, 2D or 3D models simulate exactly how a flood flow around buildings in an urban centre would behave, often creating flood maps with no depth values inside the buildings.
However, what is necessary for this work is a raster map that also returns a water depth value inside the buildings. In case a flood map of this type is not available, it will be necessary to interpolate so that the footprint of the buildings is filled in according to the depth defined along its boundaries as realistically as possible [20].

3.2. Spatial interpolation methods

The goal of spatial interpolation is to assign a value to unsampled points through a function of the values assumed by the sampled points. The relationship defined between sampled and non-sampled points is usually defined by bearing in mind that points that are close to each other tend to similar values, while distant points differ, on average, to a greater extent.
The location of points with known values is as important as the value itself.
The problem is therefore that of finding a suitable model to express the fact that nearby points have on average similar values.
This relationship can be defined thanks to geostatistical methods (Fig. 29), that can be deterministic or stochastic:

Deterministic: the link between neighboring points is expressed by an explicit law whose parameters have physical meaning;
Stochastic: the link between neighboring points is expressed by a statistical link (covariance) which may have no physical meaning.

The interpolation can be done globally or locally: in global methods all values are used to build the model while in local methods only the values of nearby points are used to build the model.
Global methods cannot model local trends well and are therefore used to describe wide-ranging variations. [21]

Comparison between some interpolation methods

Method	Stochastic/ Deterministico	Local/ Global	Transiz.	Interp. exact	Limitations procedure	Best for	Structure output data	Load computational
Visual	Subjective/ deterministic	Global	abrupt	No	Point of View, unplayable	Images air	Polygons	nobody
contour search	deterministic	Global	abrupt	No	It requires frome Default. (Artificial)	Remote sensing	Raster	Moderate
Nearest neighbour	deterministic	Local	abrupt	Yes	A given per cell, no estimation error, depends on the disp. points	non-numeric data	Polygons	Low / Moderate
Trend	Stochastic	Global	Gradual	No	Edge effects, not rugged, no physical meaning.	Removing trend for other interp.	Points on a raster	Low / Moderate
Fourier Series	Stochastic	Global	Gradual	No	periodic data.	Dune or artifacts	Points on a raster	Moderate
Spline	deterministic	Local	Gradual	Yes	No estimate of the error.	smooth surfaces	Points on a raster	Low / Moderate
IDW	deterministic	Local	Gradual	No (+ constraints: Yup)	It depends on the conf. points and window, no error estimate	Fast smooth data Calculation	Points on a raster	Low / Moderate
Location kriging	Stochastic	Local	Gradual	Yes	stationary data, computationally heavy	Estimates prev. function and error	Points on a raster	Heavy / heavy

Figure 29 : comparisons of some interpolation methods [16]

The two most commonly used local interpolation methods are called Inverse Distance Weighted (IDW) and Triangulated Irregular Networks (TIN).

In the IDW interpolation method (Fig. 30), the sample points are weighted during the interpolation so that the influence of each point with respect to the others decreases according to the distance from the unknown point to be created. [20]

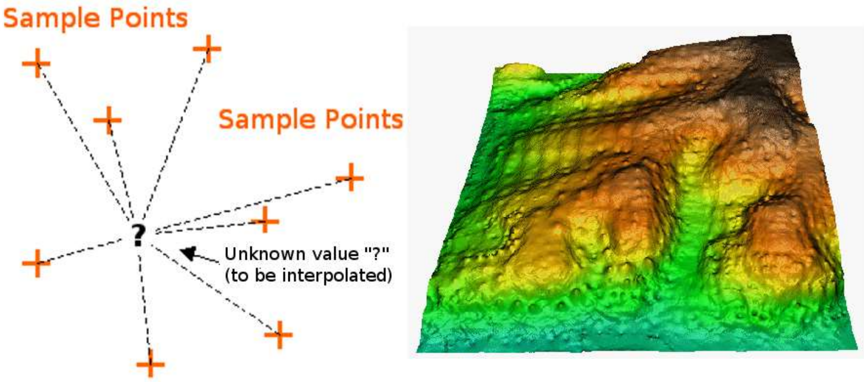

Figure 30: Schema of Inverse Distance Weighted interpolation based on the weighted distance of sampled points [20] on the left; example of DEM created by IDW interpolation on the right [22], that highlight the characteristic artefacts of bumps and holes around the sample points if a low number of point is used in the IDW interpolation.

The value at a point is given by an average of the values "around" the point of interest weighted with a function of the reciprocal distance.

$$z(x,y) = \sum_{i=1}^{n} \lambda_i z(x_i, y_i)$$

with:
n number of points in the mobile window,
xi, yi coordinates of the known points,
λ_i weight of the i-th point.
“Window” means a symmetrical area centered on a point (Fig. 31). [16]

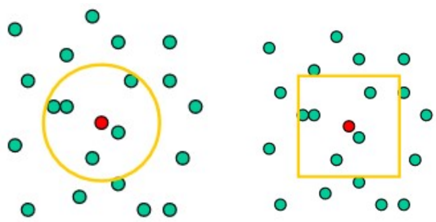

Figure 31: sample points windows [16]

The weight is assigned through a coefficient. The most commonly used weight is the inverse of the squared distance, also known as the distance coefficient.

$$z(\underline{x}_j) = \frac{\sum_{i=1}^{n} z(\underline{x}_i) d_{i,j}^{-2}}{\sum_{i=1}^{n} d_{i,j}^{-2}}$$

The IDW has the disadvantage that the quality of the interpolation decreases if the distribution of the sample points is irregular. It may also happen that in correspondence with the sample points it is possible to find points of maximum and minimum of the interpolated surface, which can lead to the formation of small vertices and depressions (Fig.30 on the right).

However, IDW is one of the fastest, simplest and most intuitive methods of spatial interpolation. Its use is always very effective if you do not have much information about the data to be processed.

The IDW provides a first interpolation through which it is possible to immediately evaluate the "spatial behavior" of the data; it allows to observe, for example, if there is a trend of some kind.

Moreover IDW is considered an exact interpolator: the expected value at a point actually sampled will be exactly equal to the measured value.

With the IDW it is possible to decide how many and which known points can have an influence on the prediction (interpolation) of any point. [23].

A typical TIN algorithm is based on the Delaunay Triangulation (Fig. 32). The goal is to create a surface formed by triangles of neighbouring contiguous points. To do this, they create circles around the sample points and their intersections are connected through a network of non-overlapping and as compact as possible triangles. [20]

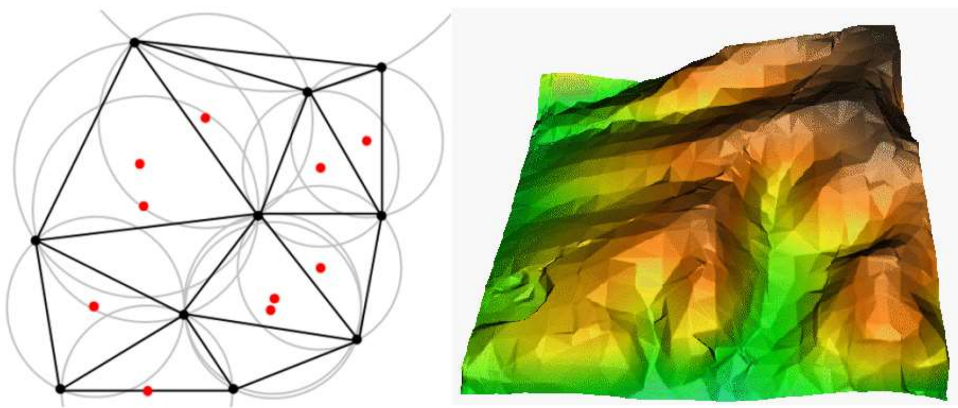

Figure 32: The Delaunay triangulation on the left [20] and interpolation of a DEM [22]

TIN interpolation then uses sample points to create a surface formed from triangles, based on the closest point information.

TIN interpolation has one drawback: the output surfaces are not smooth and may have a jagged appearance due to the discontinuous slopes at the edges of the triangles and sample points. It is specified that triangulation is usually suitable for interpolating in an area within known points.

Another type of interpolation is spline interpolation, that is a smooth curve defined mathematically by two or more points called knots. A spline takes the shape which minimizes the energy required for bending it between the fixed points, and thus adopt the smoothest possible shape. The important characteristic of spline functions is that they are piecewise polynomial function: different polynomials may be used in different parts of a curve [24].
Because splines are polynomial interpolators, the polynomial surface does not pass exactly through the observed point; hence spline are used when a margin of uncertainty is expected on the data.
Splines with tension (RST) are splines for which curvature control is exerted. Advantages of RST are that you can model functions even in cells without sampled values.
Spline allow for fast computation, they model local behaviors well, and they are effective for data visualization. The disadvantages are that high order splines do not represent angular points well and do not give indication (estimate) of approximation errors. In some cases they also introduce features not present in the surface.
This type of interpolation is extremely flexible, thanks to the configuration of parameters such as tension and smoothing (Fig. 33):

- the tension parameter is perhaps the most important in relation to the final result; it controls the size and interactions between individually interpolated regions. A high tension value forces the surface to maintain a trend, vice versa for low values. Thinking of the interpolated surface as a membrane or a sheet of rubber, the tension value allows to vary the flexibility of the membrane passing from a thin and draped surface to a thick and rigid one;
- smoothing is the parameter that allows the elimination of any "noise". It define how close the interpolated surface should be to the known points; a smoothing value of zero forces the surface to pass through the observed point, sometimes leading to unnatural surfaces. This parameter can also be configured according to the reliability of the measured data (Hargrove, 1997) [23].

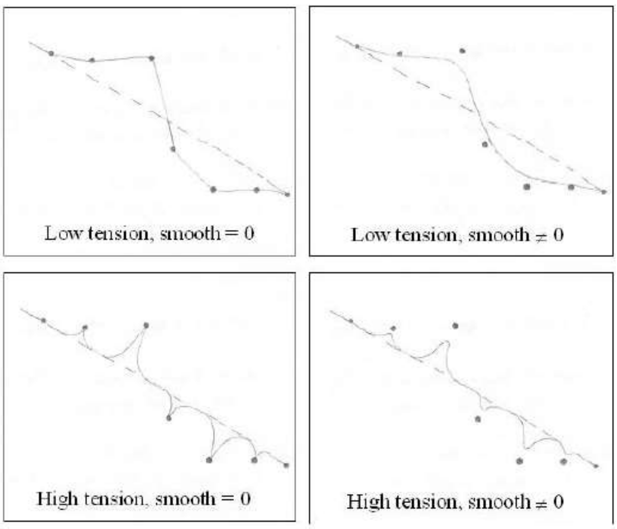

Figure 33: RST interpolation parameter [24]

B-splines can also be used, given by the sum of splines that have a null value outside their range.

$$z(x)=\sum_{i=1}^{n} z_i B\left(\frac{x-x_i}{\Delta x}\right)$$

where xi means the value at the ith node and Δx the pitch.
They give a great computational advantage, but if used to "smooth" the boundaries of a region they lead to an incorrect calculation of the area.
For bicubic splines, the estimation method is the same as for bilinear ones (one spline per node). The advantages are the smoother shape of the approximating surface [21].

Often the points available are not distributed evenly, which is why regularization is necessary. To do this we can refer to Tikhonov's regularization.
Tikhonov's method is based on the idea of a regularized solution xλ , defined as the minimum of the weighted combination of the norm of the residue and the norm (or semi-norm) of the solution. This solution is given by:

$$x_\lambda = \arg\min\left\{\|Ax-b\|_2^2+\lambda^2\|Lx\|_2^2\right\}$$

where the regularization parameter λ controls the weight given to minimization. The regularization parameter λ is very important as it controls the properties of the regularized solution; for this reason, it must be chosen with great care. Furthermore, the perturbation limits for the Tikhonov method depend on the choice of the regularization parameter. In fact, the greater the value of λ, the smaller the conditioning number of the method, and therefore the regularized solution is less sensitive to perturbations; but it is also true that the increase of λ causes the growth of the regularization error [25].

There is therefore no one interpolation method suitable for all case studies.
In practice, the selection of a particular interpolation method should depend on the sample data, the type of surface to be generated and the tolerance of estimation errors. [20]

4. The procedure for flood vulnerability and damage assessment

The objective of the work is to identify a procedure that allows to associate a percentage of damage and the maximum economic damage caused by a specific flood event to each building contained in an area of interest, through the use of vulnerability curves, representative of each type building. In this way it will be possible to quickly estimate the damage and losses due to floods.

4.1. Preprocessing of input files

First of all, in this study, any geospatial data should refer to a cartographic reference system, whose unit for expressing coordinates is meters. Pay attention to not work in a geographical reference system, whose coordinates (latitude and longitude) are in degrees. In case the QGIS algorithm "reproject layer" can be used. This algorithm does not alter the attributes.[27]”

In order to carry out the procedure for flood damage assessment, it is necessary to start from two input files: a vector cartography that represents the buildings in the area of interest and a raster map representing the flood event, with the water depth reached by the event.

In particular, if the available map represents the flow of water around the buildings, as will be demonstrated in the following chapters, it was deemed appropriate to use the TIN interpolation method to extend the water depth so to cover the footprint of the buildings. However, the following procedure was carried out for the identification of the best type of interpolation: in order to have an idea of the distribution of the data in the area, the flood maps was visualized and a case study area was identified, to which apply more interpolation methods; it was verified which was the best method by comparing the results along more than one cross-section.

In every interpolation process, in addition to the method used, the support software for calculations and processing is also very important. In this work the Free and Open-Source software QGIS, in version 3.22, and the GRASS plugin, which provides access to the GRASS GIS functionalities, have been used. In fact, QGIS provides several interpolation algorithms, in addition to the native GRASS ones.

The GRASS GIS algorithms used and compared in this study, applied to the raster flood map, are the followings:
- “*r.fill.nulls*” fills NULL pixels (no data areas) in input raster map and stores filled data to a new output raster map. The fill areas are interpolated from the no data area boundaries buffer using the regularized spline interpolation with tension (v.surf.rst) or r.resamp.bspline cubic or linear spline interpolation with Tykhonov regularization. Each area boundary buffer is set to three times the map resolution to get nominally three points around the edge. This way the algorithm interpolates into the hole with a trained slope and curvature at the edges, in order to avoid that such a flat plane is generated in a hole. The width of edge area can be adjusted by changing the edge parameter [26].

- "*r.surf.idw*" fills a grid cell (raster) matrix with interpolated values generated from input raster data points. It uses a numerical approximation technique based on distance squared weighting of the values of nearest data points. The number of nearest data points used to determine the interpolated value of a cell can be specified by the user (default: 12 nearest data points). It is appropriate for the user to use a mask when geographic region boundaries include large areas outside the general extent of the input data. [26]
It is specified that the *"r.surf.idw"* algorithm needs to process layers with depth attributes represented by integer values; so it is necessary to use the GRASS algorithm "*r.mapcalc",* that performs arithmetic on existing raster map layers, to convert the real values to integer ones [26].

Moreover, there are other algorithms that allow interpolation starting from vector data.
Since the original flood map will certainly be a raster, it is recommended to use the *"r.to.vect"* algorithm to convert the raster into vector. *"r.to.vect"* scans the named input raster map layer, extracts points, lines or area edge features from it, converts data to vector format. *"r.to.vect"* first traces the perimeter of each unique area in the raster map layer and creates vector data to represent it. The cell category values for the raster map layer will be used to create attribute information for the resultant vector area edge data.
Then, to produce a better-looking vector map, r.to.vect smoothes the corners of the vector data as they are being extracted. At each change in direction (i.e., each corner), the two midpoints of the corner cell (half the cell's height and width) are taken, and the line segment connecting them is used to outline this corner in the resultant vector map. (The cell's cornermost node is ignored.) Because vectors are smoothed by this program, the resulting vector map will not be "true" to the raster map from which it was created. The user should check the resolution of the geographic region (and the original data) to estimate the possible error introduced by smoothing [26].

The GRASS algorithms used in this study to interpolate a vector file are described in the following:
- *"v.surf.rst"* performs surface interpolation from vector points map by splines. It performs spatial approximation based on z-values (input vector map is 3D and zcolumn parameter is not given), categories (input vector map is 2D and zcolumn parameter is not given), or attributes (zcolumn parameter is given) of point or isoline data given in a vector map named input to grid cells in the output raster map elevation representing a surface. Regularized spline with tension is used for the approximation. The tension parameter tunes the character of the resulting surface from thin plate to membrane. With the smoothing parameter set to zero (smooth=0) the resulting surface passes exactly through the data points (spatial interpolation is performed) [26].
- *"v.surf.idw"* fills a raster matrix with interpolated values generated from a set of irregularly spaced vector data points using numerical approximation (weighted averaging) techniques. The interpolated value of a cell is determined by values of nearby data points and the distance of the cell from those input points. In comparison with other methods, numerical approximation allows representation of more complex surfaces (particularly those with anomalous features), restricts the spatial influence of any errors, and generates the interpolated surface from the data points. Values to interpolate are read from column option. If this option is not given than the program uses categories as values to interpolate or z-coordinates if the input vector map is 3D. If the user has a mask set, then interpolation is only done for those cells that fall within the mask [26].

- *"v.surf.bspline"* performs a bilinear/bicubic spline interpolation with Tykhonov regularization. The input is a 2D or 3D vector points map. Values to interpolate can be the z values of 3D points or the values in a user-specified attribute column in a 2D or 3D vector map. From a theoretical perspective, the interpolating procedure takes place in two parts: the first is an estimate of the linear coefficients of a spline function is derived from the observation points using a least squares regression; the second is the computation of the interpolated surface (or interpolated vector points). For optimal performance, the length of spline step should be no less than the distance between observation points. Often data points are not regularly distributed and require statistical regularization or estimation. The Tykhonov regularization parameter (lambda_i) acts to smooth the interpolation. With a small lambda_i, the interpolated surface closely follows observation points; a larger value will produce a smoother interpolation [26].

The QGIS algorithms available are:

- "TIN Interpolation" which generates a Triangulated Irregular Network interpolation of a vector of points. With the TIN method it is possible to create a surface formed by triangles of neighbouring points. To do this, circles are created around selected sample points and their intersections are connected to a network of non-overlapping and as compact as possible triangles. The resulting surfaces are not smooth. The algorithm creates both the raster layer of the interpolated values and the vector line layer with the boundaries of the triangulation [27]. This algorithm does not allow to change any parameter, only to set the interpolation method to use: Linear or Clough-Toucher (cubic);
- "IDW interpolation" which generates an Inverse Distance Weighted interpolation of a vector of points. Sample points are weighted during interpolation such that the influence of one point on another decreases with distance from the unknown point you want to create [27]. This algorithm allows you to change only the power of the distance (coefficient) and not the number of interpolation points.

As regards the input layer of the buildings, it should be noted that it could give problems regarding the geometry when running a Processing tool. In particular, the use of intersected polygons, in which two or more sides intersect each other (Fig.34), is not allowed, as it would introduce enormous difficulties in the geometric management of the objects.

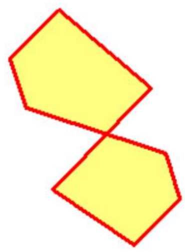

Figure 34 – intersected polygon [28]

As a workaround, when importing any vector layer into QGIS, the QGIS algorithm *"Fix geometries"* has to be run; it "attempts to recreate a valid representation of a given invalid geometry without losing any of the input vertices. Geometries that are already valid are returned without further intervention. It always returns multi-geometry layers" [27]

For the assessment of flood damage, it was decided to make use of the global flood depth-damage functions built by the Joint Research Center (JRC), the European Commission's science and knowledge service.

4.2. Flood damage assessment tool: JRC vulnerability curves

Many countries have developed flood damage models using damage-depth curves based on historical data analysis of past flood events and expert judgement. However, the damage curves may not be available for all regions of a continent and the use of different methodologies in the construction of damage models can be an obstacle to the assessment of damage in specific areas and the comparison of damages even at the national level. The goal of the JRC therefore was to develop a global database that contains damage curves representing the maximum damage values for a class of elements and class of land use as a function of water depth.

Flood damage functions, therefore, have been developed by JRC [5] at the continental level for six different impact categories: residential buildings, commerce, industry, transport, infrastructure and agriculture.

The six damage classes defined from JRC as follows [5]:

- Residential:
    - Refers to residential buildings such as houses and apartments and their contents
    - Weighted averages based on studies of building stock are used, i.e., taking account of different sizes and quality standards of houses and apartments
    - Damage to assets in residential areas which are not residential buildings (i.e., in the public area and gardens) is not included
- Commerce:
    - Refers to commercial buildings and their contents such as offices, schools, hospitals, hotels, shops, etc.
    - Weighted averages of the various building types are used based on building stock studies
    - Damage to assets in commercial areas (i.e., in the public area and vehicles) is not included
- Industry:
    - Refers to industrial buildings and their contents such as warehouses, distribution centers, factories, laboratories, etc.
    - Weighted averages of the various building types are used based on building stock studies
    - Damage to assets in industrial areas (i.e., in the public area and vehicles) is not included
- Transport:
    - Transport facilities
    - Maximum damage values from literature: very limited data
- Infrastructure
    - Roads and railroads
    - Direct damage to roads and railroads as a result of contact with (fast flowing) water

- Agriculture:
    - Based on damage resulting from flooded agricultural lands only (i.e., does not include farms, sheds, farming material, etc.)

For this thesis work, among the various damage assessment methods, the JRC method was chosen precisely because it gives the possibility of selecting curves representative of average European building typologies.

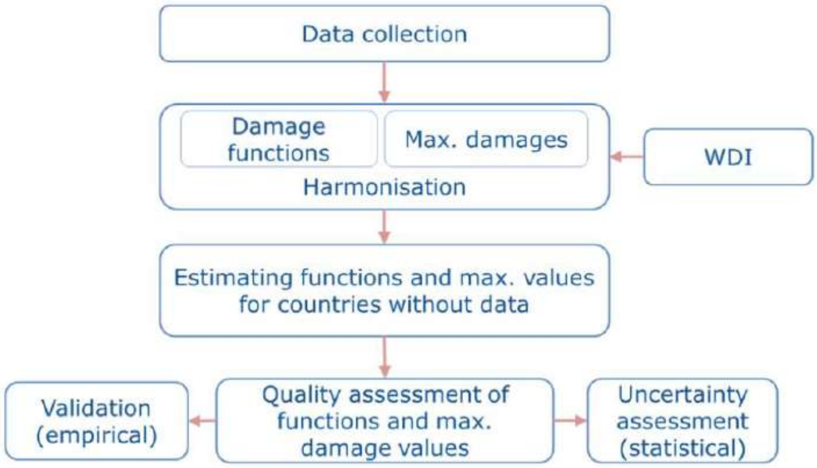

Figure 35: flowchart of the procedure for the derivation of the country-specific damage-depth functions for the six impact categories tc.) [5]

The procedure for the construction of the curves by the JRC (Fig. 35) began with the data collection, then a review of the data on flood damage in the literature was performed. Hence, they moved on to the damage functions, normalizing, if necessary, to fit the 0-1 range of the damage percentage for which the functions are built, ensuring an average value for all the damage curves for each continent.

Continental damage functions by land use class were then derived and generic damage curves were created for agriculture and roads due to the limited amount of data available. For the determination of the maximum damage values, the damage values were harmonized at the 2010 price levels and in euros, adjusted where the damage functions were normalised. Construction cost values have been amortised based on regression analyzes to extend the data to countries where the maximum damage level for residential, commercial and industrial buildings is not known. This is because maximum damage values may not be available for every country and may show significant variation, due to not knowing exactly the dimensions of the objects and how they are differentiated in each class (residential, commercial and industrial), that is, if it is talking about rural houses, warehouses, shops, factories, etc. For this reason, in the study done by the JRC, a global set of maximum damage values for buildings was created, through the methods described above, based on socio-economic indicators of world development. The maximum damage values then provide the value of the asset and, combined together, produce the monetary value of the damage.

Damage to buildings (residential, commercial and industrial) is given by three different measures, based on: the building (structure, content and total), land use and the object.

The building-based damage value is about the maximum damage per square meter if the single building footprint is used for the calculation, as for the land use based damage calculation it is done considering the maximum damage per square meter using land use maps containing houses, streets, empty spaces between individual buildings. As for the object-based damage calculation it means that it is applied when only the locations of the houses are known and will be applied to the case of a building having general characteristics.

The JRC specifies that the inventory of damage models show a wide variety of information relating to different types of buildings, whether it is talking about rural or urban environments. Different maximum damage values can also be used if the exposure data allow differentiation between different types of built environment. A study on flooding in Mozambique by the World Bank (2000) compared the urban residential environment and the rural residential environment, showing that there is a factor of 6 difference in the maximum damage between urban and rural houses, including the content, considering equal size. Since rural houses, on the other hand, are relatively smaller than urban houses, it has been considered that the value per square meter of the amortized reconstruction cost per square meter becomes a factor of 3.

By calculating the sample standard deviation for each flood depth, the JRC obtained an indication of the uncertainty of the maximum damage values. It is also specified that the maximum damage values for the three types of buildings can be further adjusted through a regulation sheet that manipulates various hypotheses such as the calculation of the amortised value considered as a share of the construction cost. Data on construction costs refer to the costs relating to the building itself; however, flood damage also includes damage to building contents.

For an overall methodology, the JRC therefore uses the following percentages for the maximum damage to contents/inventory (Tab 1). These numbers are user adjustable to allow for maximum flexibility and to integrate the study with future knowledge.

Table 1 : Contents damage as % of building damage from JRC

Class	Contents damage
Residential	50
Commercial	100
Industrial	150

The depth damage functions, therefore, represent the relationship between hydraulic parameters and economic damage of some types of assets. In order to verify these functions, the JRC needed some information: exposure (number of exposed elements and related assets), maximum flood depth (model of the maximum variation of flood depth over the whole area), and the damage recorded (total damage reported in the flooded area).

As for damage data, it is difficult to find data because geographically dispersed and unavailable; so the JRC focused on several test sites to test the performance of the developed global damage functions and maximum damage values:

- the first is in New York City (USA), considering the damage caused by hurricane Sandy in 2012, as detailed information on the extent of the flooding and fairly precise records of the total damage are available;
- the second is Jakarta (Indonesia), as a hydrological model of the 2007 floods is available and a damage assessment estimate is present.

The functions are defined for a water depth level between 0 and 6 m and do not consider the increase in vulnerability depending on the number of floors above ground and underground. In the JRC method both riverine and marine flooding are included and for this reason the assessment of the damage of a generic flood event is considered.
The damage functions in the JRC research were therefore mainly developed for urban environments as data on maximum damages comes from construction cost surveys which mainly concern the costs of urban building types.

For the calculation of the vulnerability, therefore, reference is made to the depth-damage curves proposed by the JRC and the functions that best fit the mentioned curves have been extrapolated. The functions were then obtained by interpolating the data provided by the Joint Research Center through trend lines, also called regression lines. They graphically show the trend of a data series and are typically lines or a curve connecting two or more points in a series.
The type of polynomial trend line is then considered, being the latter the one that best fits the available points.

Table 2: Average continental damage function for Europe – Residential, commercial and industrial buildings

	Damage factor					
Depth [m]	*Residential*	*Commercial*	*Industrial*	*Transport*	*Infrastructure roads*	*Agriculture*
0	0	0	0	0	0	0
0,5	0,25	0,15	0,15	0,32	0,25	0,30
1	0,40	0,3	0,27	0,54	0,42	0,55
1,5	0,50	0,45	0,40	0,70	0,55	0,65
2	0,60	0,55	0,52	0,83	0,65	0,75
3	0,75	0,75	0,70	1	0,80	0,85
4	0,85	0,9	0,85	1	0,90	0,95
5	0,95	1	1	1	1	1
6	1	1	1	1	1	1

Table 3: JRC curve functions obtained through the regression lines

	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	$y = -0{,}0007x^6 + 0{,}0125x^5 - 0{,}0833x^4 + 0{,}265x^3 - 0{,}4939x^2 + 0{,}8364x - 0{,}0012$
Infrastructure roads	$y = -0{,}00008x^5 - 0{,}0011x^4 + 0{,}0262x^3 - 0{,}1655x^2 + 0{,}5609x + 0{,}002$
Agriculture	$y = 0{,}0003x^5 - 0{,}0081x^4 + 0{,}0748x^3 - 0{,}3284x^2 + 0{,}7935x - 0{,}005$

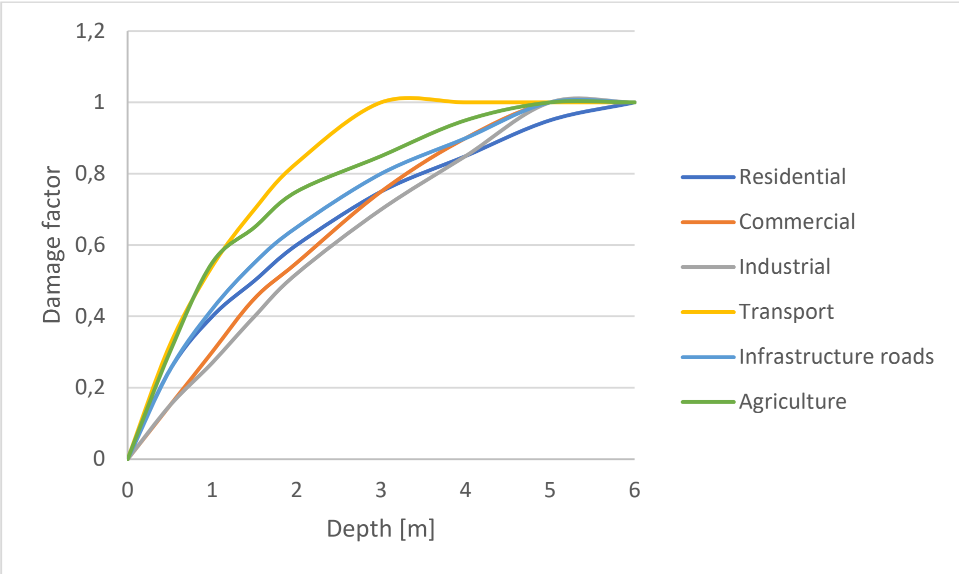

Figure 36 : Damage curve - depth for residential, commercial and industrial building categories – EUROPE

Damage curves are differentiated by continent and these maximum damage values are used to calculate country-specific damage values (Fig. 36).
In this work of thesis, it is considered the measure of damage building based.
For residential, commercial and industrial buildings, the maximum damage value was considered as the sum of the damage to the contents and the structure.
It is highlighted that the Transport and Infrastructure (roads) maximum damage values are computed based on continent-specific maximum damage values (Tab. 4) scaled by the country-to-continent per capita Gross Domestic Product (GDP) level. For countries without the continent-specific maximum damage value a global value is provided [5].
For the Agricultural damage, the maximum damage value is given as the agricultural value added (see the report [5]) 1 Euros per hectare in 2010 price level. Additionally, the agricultural area (km2) for each country is provided [5].

Calculation of country-level Maximum Damage, for countries in a continent with a max damage value [5]:
*"max damage Transport/Infrastructure (country) = continental average max damage * GDP (country) / GDP (continental average)"*

Table 4: GDP (continental average)

		GDP (2010 US$)
Maximum damage (average)	Europe	43097
	C/S America	10978
	Asia	2834
	Global	18970

Table 5: Maximum damage values for each impact category defined at country and continental level – Europe (price level 2007), Italy (price level 2010)

	Average maximum damage value (Europe) [€/m2]	Average maximum damage value (Italy) [€/m2]
Residential	750	739
Commercial	621	1028
Industrial	534	838
Transport	751	625
Infrastructure roads	24	21
Agriculture	0,77	0,22

It is specified that the maximum damage values found in the literature are not available for each country and a significant variation is noted due to the use of the land, the unknown dimensions of the objects, the different methods and sources for determining a maximum damage figure, etc...
It therefore highlights the fact that these curves are averaged on a European behaviour and not specific to Italy and that a research work would be appropriate to determine data that are also applicable to the Italian territory.

4.3. Taxonomy of buildings

A fundamental step of the flood risk analysis consists in the introduction of a correct taxonomy. In a specific area, the flood risk can be non-homogeneous and to evaluate it, it is possible to identify characteristics through which buildings can be grouped into classes with similar behavior to flooding. It is therefore necessary to find a taxonomy aligned to the one applied to develop the JRC curves to ensure an easy matching between elements at risk and vulnerability curves, and to collect a set of information on the buildings based on the available data.

Below, an example is shown, useful to a possible user, of how some of the building typologies that can be encountered in an Italian context have been identified and grouped, in particular, for the case study, the Liguria Region.
It is therefore assumed being a user with different sources available:

- an official source from the Liguria region, i.e. the geotopographic database – CTR (Regional Technical Map) [6];
- a source of data from the OSM project (Open Street Map [7]).

It should be remembered that the objective of the work is to correlate, at a certain depth reached by the water during a flood, the damage caused to buildings, therefore the damage classes of the JRC agriculture and infrastructures are excluded, as they are not specific to buildings.

Table 6: taxonomy from OSM (Open street Map) data

RESIDENTIAL	**COMMERCIAL**				**INDUSTRIAL**	**TRANSPORT**
	Religious	***Generico commerciale***	***Government***	***Education***		
apartment	bell	animal_shelter	emergency_service	childcare	Silos	train_station
garage	monastery	arts_centre	fire_station	college	waste_transfer_station	transportation
house	place_of_worship	bank	police	kindergarten	industrial	roof
barracks	basilica	bar	townhall	school	hangar	
cabin	cathedral	cafe	government	seminary	digester	
detached	chapel	canteen	gatehouse	university	service	
dormitory	church	car_wash	military		transformer_tower	
ger	mosque	cinema			water_tower	
houseboat	synagogue	clinic			bunker	
Residential	temple	community_centre			construction	
semidetached_house	presbytery	conference_centre			animal_breeding	
terrace	Religious	courthouse			farm	
hut	shrine	crematorium			barn	
garages		doctors			conservatory	
		fast_food			cowshed	
		ferry_terminal			farm_auxiliary	
		funeral_hall			greenhouse	
		grave_yard			slurry_tank	
		hospital			stable	
		kennel			sty	
		library				
		marketplace				
		Neviera				
		nightclub				
		nursing_home				
		office				
		parking				
		planetarium				

		post_office				
		prison				
		public_bath				
		public_building				
		restaurant				
		shelter				
		social_centre				
		social_facility				
		studio				
		taxi				
		theatre				
		toilets				
		world_heritage				
		pharmacy				
		veterinary				
		casino				
		events_venue				
		gambling				
		planetarium				
		fitness_centre				
		sports_centre				
		refugee_site				
		commercial				
		hangar				
		hotel				
		retail				
		kiosk				
		supermarket				
		warehouse				
		bakehouse				
		civic				
		public				
		grandstand				
		pavillion				
		riding_hall				
		sports_hall				
		stadium				
		shed				
		garages				
		castle				
		beach_hut				
		ruins				
		tent				

In particular, the geotopographic database of the Liguria Region provides a layer called "IMMOBILI E ANTROPIZZAZIONI" (code: 02). The layer collects the definition of all those objects that derive from anthropic activity in the territory, and which do not constitute transport infrastructure (described instead in the specific layer).
The following topics belong to it:

- built-up (both residential and industrial as well as service sector activities);
- artifacts (works that do not have a stable character in terms of habitability and human location) variously located in the territory;
- transport works (works like the artefacts but of greater complexity);
- soil protection works;
- hydraulic works for defense and hydraulic regulation.

In particular, the layer 'Edificato' (code 0201) brings together the definition of buildings, understood as stable constructions, in masonry, wood, prefabricated panels or other materials, covered with a roof, intended for most cases for the permanent residence of man or to the performance of work or recreational sporting activities, and the related volumetric or architectural characteristics [29].

It is therefore chosen to apply the case study to the "EDIFICATO" vector layer provided by the topographic database of the Liguria Region, since it defines buildings used as homes or for production and work activities.

Table 7: taxonomy from geotopographic database Regione Liguria - CTR – layer EDIFICATO (0201)

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
		Ricreativo-sede di attività culturali-cinema	Militare-Prigione		Industriale-stazione di telecomunicazioni	Servizi di trasporto stradale-casello autostradale
		Ricreativo-sede di attività culturali-museo			Industriale-edificio di teleriscaldamento	Servizi di trasporto stradale-parcheggio multipiano o coperto
		Ricreativo-sede di attività sportive			Industriale-edificio di area ecologica	Servizi di trasporto stradale-stazione di rifornimento carburante autostradale
		Ricreativo-sede di attività sportive-palestra			Agricolturale	Servizi di trasporto stradale-stazione di rifornimento carburante stradale
		Ricreativo-sede di attività sportive-piscina coperta			Agricolturale-fienile	Hangar
		Ricreativo-sede di attività sportive-palaghiaccio			Agricolturale-fattoria	Servizi di trasporto-altri impianti-stazione marittima
		Ricreativo-altre attività			Agricolturale-stalla	Servizi di trasporto-altri impianti-stazione metropolitana
		Ricreativo-altre attività-campeggio			Serra	Servizi di trasporto-altri impianti-stazione funivia
		Servizio pubblico-ASL - sede di ospedale			capannone	Servizi di trasporto-altri impianti-stazione cabinovia
		Servizio pubblico-ASL - sede di servizio socio assistenziale			edificio rurale	Servizi di trasporto-altri impianti-stazione seggiovia
		Servizio pubblico-sede di clinica			Mulino	Servizi di trasporto-altri impianti-stazione ski-lift
		Servizio pubblico- ASL - sede generica				Servizi di trasporto-altri impianti-stazione funicolare
		Servizio pubblico-sede di poste-telegrafi				Servizi di trasporto-altri impianti-edificio marittimo
		Impianto sportivo				
		Struttura ospedaliera				
		Struttura ricettiva				
		Gradinata di campo sportivo				
		Loculo/tomba cimiteriale				
		Pensilina/tettoia				
		Vasca generica				
		Vasca/piscina scoperta				
		Torre/porta				
		Amministrativo-municipio				
		generica				
		castello				

		anfiteatro				
		Faro				
		Osservatorio				
		Palazzetto dello sport				
		Stadio				
		Servizio pubblico				

The layer of our interest is an extraction of the most significant cartographic elements present on the regional Geotopographic Database at a scale of 1:5000 (Fig.37).

Figure 37: vector layer "EDIFICATO" from geodatabase of Regione Liguria – CTR

The user will therefore have the objective of classifying the buildings and structures indicated in a specific field of the attribute table of his own buildings shapefile and create a taxonomy parallel to that of the JRC curves.
An example of an attribute table belonging to the "Edificato" vector layer containing the buildings from the CTR (geotopographic database) is shown (Fig. 38).

ogr_fid	id	tipo_edil	def_tipo_e	cat_uso	def_cat_us
230232	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale
230655	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale
230655	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale
237520	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale
238104	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale
238526	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale
238757	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa
238760	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa
238761	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa
238763	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa
238912	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa
239932	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale

Figure 38: shapefile table layer "EDIFICATO" – CTR

To simplify the building classification procedure, it was decided to associate each element indicated in the shapefile attribute table with a number representing each damage category of the JRC curves, for example:

- "Residential":**1**;
- "Commercial":**2**;
- "Industrial":**3**;
- "Transport:**4**.

The user should have a field of the attributes table of his vector layer with labels indicating the buildings inserted in tab.5. It is therefore advisable to carry out a reclassification work following the example above, and to create a new field in the attribute table characterized only by the numbers corresponding to the class of the building elements present in the input vector. Below is an example of what the new field should look like, called "Building_typology" (Fig. 39).
To do this, the QGIS "field calculator" algorithm was used, which allows you to perform calculations on the basis of the values of existing attributes or defined functions.

A basic algorithm of this type was used for the thesis work:

```
CASE
WHEN "def_cat_us" = 'Residenziale-Abitativa' THEN 1
WHEN "def_cat_us" = 'Residenziale' THEN 1

WHEN "def_cat_us" = 'Amministrativo' THEN 2
WHEN "def_cat_us" = 'Amministrativo-municipio' THEN 2
WHEN "def_cat_us" = 'Amministrativo-sede provincia' THEN 2
WHEN "def_cat_us" = 'Amministrativo-sede regione' THEN 2
WHEN "def_cat_us" = 'Amministrativo-sede ambasciata' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico' THEN 2
```

WHEN "def_cat_us" = 'Servizio pubblico- ASL - sede generica' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-ASL - sede di servizio socio assistenziale' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-ASL - sede di ospedale' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-sede di clinica' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-sede di poste-telegrafi' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-sede di scuola, università, laboratorio di ricerca' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-sede di tribunale' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-sede di polizia' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-sede di vigili del fuoco' THEN 2
WHEN "def_cat_us" = 'Servizio pubblico-casello forestale' THEN 2
WHEN "def_cat_us" = 'Militare' THEN 2
WHEN "def_cat_us" = 'Militare-Caserma' THEN 2
WHEN "def_cat_us" = 'Militare-Prigione' THEN 2
WHEN "def_cat_us" = 'Luogo di culto' THEN 2

WHEN "def_cat_us" = 'Servizi di trasporto' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto aereo' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto aereo - Aerostazione' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto aereo - Stazione eliporto'THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto stradale' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto stradale - Stazione autolinee' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto stradale-parcheggio multipiano o coperto' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto stradale-casello autostradale' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto stradale-stazione di rifornimento carburante autostradale' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto stradale-stazione di rifornimento carburante stradale' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto ferroviario' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto ferroviario- stazione passeggeri ferrovia' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto ferroviario-deposito ferroviario per vagoni, rimessa locomotive' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto ferroviario-casello ferroviario' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto ferroviario-fermata ferroviaria' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto ferroviario-scalo merci' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti-stazione marittima' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti-stazione metropolitana' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti-stazione funivia' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti-stazione cabinovia' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti-stazione seggiovia'THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti-stazione ski-lift' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti-stazione funicolare' THEN 4
WHEN "def_cat_us" = 'Servizi di trasporto-altri impianti-edificio marittimo'THEN 4

WHEN "def_cat_us" = 'Commerciale' THEN 3
WHEN "def_cat_us" = 'Commerciale-sede di banca' THEN 3
WHEN "def_cat_us" = 'Commerciale-sede di centro commerciale' THEN 3
WHEN "def_cat_us" = 'Commerciale-mercato' THEN 3
WHEN "def_cat_us" = 'Commerciale-sede di supermercato, ipermercato' THEN 3
WHEN "def_cat_us" = 'Commerciale-sede di albergo, locanda' THEN 3
WHEN "def_cat_us" = 'Commerciale-ostello della gioventù' THEN 3
WHEN "def_cat_us" = 'Industriale' THEN 3
WHEN "def_cat_us" = 'Industriale-stabilimento industriale' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto di produzione energia' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto di produzione energia-centrale elettrica' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto di produzione energia-centrale termoelettrica' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto di produzione energia-centrale idroelettrica' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto di produzione energia-centrale nucleare' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto di produzione energia-stazione/sottostazione elettrica' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto di produzione energia-stazione di trasformazione' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto di produzione energia-centrale eolica' THEN 3
WHEN "def_cat_us" = 'Industriale-impianto tecnologico' THEN 3
WHEN "def_cat_us" = 'Industriale-depuratore' THEN 3
WHEN "def_cat_us" = 'Industriale-inceneritore' THEN 3
WHEN "def_cat_us" = 'Industriale-stazione di telecomunicazioni' THEN 3
WHEN "def_cat_us" = 'Industriale-edificio di teleriscaldamento' THEN 3
WHEN "def_cat_us" = 'Industriale-edificio di area ecologica' THEN 3
WHEN "def_cat_us" = 'Agricolturale' THEN 3
WHEN "def_cat_us" = 'Agricolturale-fattoria' THEN 3
WHEN "def_cat_us" = 'Agricolturale-stalla' THEN 3
WHEN "def_cat_us" = 'Agricolturale-fienile' THEN 3

WHEN "def_cat_us" = 'Ricreativo' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività culturali' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività culturali-biblioteca' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività culturali-cinema' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività culturali-teatro, auditorium' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività culturali-museo' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività culturali-pinacoteca' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività sportive' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività sportive-piscina coperta' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività sportive-palestra' THEN 2
WHEN "def_cat_us" = 'Ricreativo-sede di attività sportive-palaghiaccio' THEN 2
WHEN "def_cat_us" = 'Ricreativo-altre attività' THEN 2

WHEN "def_cat_us" = 'Ricreativo-altre attività-campeggio' THEN 2

ELSE 0

END

Obviously, this is only one example of how a classification of this type can be done and it would be ideal to do it for all the elements present in Tab.7.

ogr_fid	id	tipo_edil	def_tipo_e	cat_uso	def_cat_us	Building_typology
230232	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
230655	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
230655	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
237520	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
238104	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
238526	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
238757	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa	1
238760	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa	1
238761	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa	1
238763	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa	1
238912	213112_020102...	0201020101	Generica	020102020101	Residenziale-Abitativa	1
239932	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
239933	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
239934	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
239980	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
240066	213112_020102...	0201020101	Generica	020102020801	Industriale-stabilimento industriale	3
240444	213112_020102...	0201020101	Generica	020102020702	Commerciale-sede di centro commerciale	2
240493	213112_020102...	0201020101	Generica	020102020702	Commerciale-sede di centro commerciale	2

Figure 39: reclassification of buildings based on the defined taxonomy JRC

4.4. Damage determination

In order to associate damage caused to a building by the depth of the water reached by a flood event, two ways of proceeding have been analysed.

The first method consists of having points of known coordinates representing the building with the associated depth value given by the flood raster map.

A centroid is defined for each polygon, belonging to a vector file; it represents its central point or the centre of gravity of the element, therefore, it can be outside the boundaries of the element. In particular, a polygon is said to be convex if all its angles are less than 180°, so it will have its centroid inside it. A polygon with at least one angle greater than 180° is said to be concave. Also for concave polygons the centroid is defined, which can also fall outside the figure.
Centroid is very useful to assign a punctual information to an areal entity (Fig. 40-41).

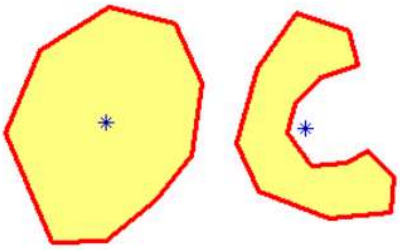

Figure 40: concave and convex polygons and relative centroid [28]

In order to assign a centroid to each polygon, the QGIS *"Centroids"* algorithm is used. Input file should be the vector of buildings with the geometries corrected by the QGIS "*Fix Geometries"* algorithm.
The attributes of the points in the output layer are the same as the original elements. [27]

Figure 41: layer EDIFICATO with the corresponding centroids superimposed

The available flood map consists of a grid of pixels, whose depth parameter is encoded in the value of each of the pixels. Therefore, once the centroid has been defined for each polygon, it will be necessary to associate to each of them the value of the areal entity of the depth reached by the flood taken from the flooding raster map present in the same position as that pixel.

To do this it will be necessary to extract these values and aggregate them over a defined area. It is recommended to use the QGIS algorithm *"Sample Raster Values"* that extracts raster values at the point locations. If the raster layer is multiband, each band is sampled. The attribute table of the resulting layer will have as many new columns as there are bands in the raster layer [27].
In this first method the flood map with filled NULL, corresponding to the footprint of the building then interpolated by TIN interpolation, is used.
The resulting output will be a vector layer containing one more field in the attribute table, named with a user-chosen prefix.

An example of how the attribute table will look like is shown below, naming the prefix of the new field “Depth” (Fig.42).

ogr_fid	id	tipo_edil	def_tipo_e	cat_uso	def_cat_us	Building_typology	Depth1
203241	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,87587125
203866	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,6931
200751	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,60380952
202277	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,54296042
200779	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,48776
200709	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,47307045
200722	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,44699167
200316	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,43826384
202235	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,43435
213604	213154_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,39816395
202279	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,396004
202281	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,39381224
202861	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,342982

Figure 42: flood depth associated with each building in the layer EDIFICATO

Once this is done, you will have to create another field in the attribute table of the vector layer obtained from sampling the raster values of the flood map, containing the values of the damage percentages associated with each building through the use of the functions obtained for the JRC vulnerability curves mentioned in previous chapters (Tab.3).

It is worked with a basic algorithm of this type:

```
if( "Building_typology" = 1, ((0.0006* ("Depth1")^5)+(-0.0103* ("Depth1")^4)+( 0.0722*("Depth1")^3) +(-0.2528* ("Depth1")^2)+(0.5873* ("Depth1"))+ 0.0031) ,if( "Building_typology" = 2, ((-0.0004* ("Depth1")^5)+(0.0054* ("Depth1")^4)+(-0.0247*("Depth1")^3) +(0.0184* ("Depth1")^2)+(0.3051* ("Depth1"))- 0.0013) ,if( "Building_typology" = 3, ((-0.0007* ("Depth1")^5)+(0.0097* ("Depth1")^4)+(-0.0431*("Depth1")^3) +(0.0537* ("Depth1")^2)+(0.255* ("Depth1"))+ 0.0033) ,if( "Building_typology" = 4, ((-0.0007* ("Depth1")^6)+(0.0125* ("Depth1")^5)+(-0.0833*("Depth1")^4) +(0.265* ("Depth1")^3)+(-0.4939* ("Depth1")^2)+(0.8364* ("Depth1"))-0.0012),0))))
```

Below is an example of how the final attribute table should look, with the new field characterized by the damage value associated with each building, called for example "Perc_damage" (Fig. 43).

ogr_fid	id	tipo_edil	def_tipo_e	cat_uso	def_cat_us	Building_typology	Depth1	Perc_damage
203241	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,87587125	0,3663240652
203866	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,6931	0,3104741272
200751	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,60380952	0,2801231977
202277	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,54296042	0,2581437373
200779	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,48776	0,2372297165
200709	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,47307045	0,2315009747
200722	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,44699167	0,2211560542
200316	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,43826384	0,2176432169
202235	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,43435	0,2160595873
213604	213154_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,39816395	0,2011687522
202279	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,396004	0,2002655
202281	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,39381224	0,1993472635
202861	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,342982	0,1775681671
204941	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,337524	0,175173404
203212	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,32586154	0,1700190479
201175	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,32143889	0,1680510234
205246	213153_020102...	0201020101	Generica	020102020101	Residenziale-A...	1	0,31976875	0,1673059065

Figure 43: damage percentages defined by the JRC vulnerability curves associated with each building of the layer EDIFICATO

The last step is to create a new field in the attribute table of the vector layer where the taxonomy has been defined, obtained from the fields calculator, containing the maximum economic values of the damage associated with each building. To do this, reference is made to the Euro/m2 economic values in Tab5.

To do this step it was necessary to create a new field in the attribute table of the vector layer obtained from the QGIS *"fix geometries"* algorithm containing the area values of each building in the layer, thanks to the *"$area"* function of the *"field calculator"* which returns the area of the current item. The area calculated by this function respects both the current project's ellipsoid setting and the area unit settings (make sure it is in m).

The basic algorithm for obtaining the new field (Fig. 44) using the "field calculator", called "Max_ec_dam", is shown below:

*if("Building_typology" = 1, ("Area"*739) ,if("Building_typology" = 2, ("Area"*1028) ,if("Building_typology" = 3, ("Area"*838) ,if("Building_typology" = 4, ("Area"*625),0))))*

	tipo_edil	cat_uso	def_cat_us	Area	Building_typology	Max_ec_dam	Depth1	Perc_damage
1	0201020101	020102020101	Residenziale-A...	32,644	1	24123,8408	0,96785004	0,391641465
2	0201020101	020102020101	Residenziale-A...	55,386	1	40930,6068	0,77304982	0,3358794362
3	0201020101	020102020101	Residenziale-A...	500,428	1	369816,4182	0,58094284	0,2719915025
4	0201020101	020102020101	Residenziale-A...	218,420	1	161412,0898	0,55381511	0,2621453335
5	0201020101	020102020101	Residenziale-A...	43,284	1	31986,8666	0,47241813	0,231244949
6	0201020101	020102020101	Residenziale-A...	354,315	1	261838,6802	0,45786735	0,2254976241
7	0201020101	020102020101	Residenziale-A...	194,927	1	144051,2396	0,45052575	0,2225711914
8	0201020101	020102020101	Residenziale-A...	240,506	1	177734,0665	0,42722842	0,213164667
9	0201020101	020102020101	Residenziale-A...	259,769	1	191969,2911	0,41046722	0,2062825463
10	0201020101	020102020101	Residenziale-A...	398,589	1	294556,9976	0,39863255	0,2013644954
11	0201020101	020102020101	Residenziale-A...	341,107	1	252077,7598	0,39676807	0,2005852082
12	0201020101	020102020101	Residenziale-A...	136,268	1	100702,2809	0,39400001	0,199425996
13	0201020101	020102020801	Industriale-stab...	123,104	3	103160,7757	0,37617154	0,1047172996
14	0201020101	020102020101	Residenziale-A...	83,308	1	61564,3717	0,33349799	0,1733998257

Figure 44: damage percentages and max economic damage defined by the JRC vulnerability curves associated with each building of the layer EDIFICATO

The second method for estimating damage involves the use of a flood map that takes into account the footprint of the buildings. This method can be considered better because it allows you to identify buildings that do not suffer damage, due to the fact, for example, that they are located in raised areas or covered by protective works. However, this method can also be used with full maps, because it takes the average around the building.

The first step is to overlay the flood map raster with the buildings in such a way that the depth values surrounding the building are averaged and can be associated with it.
To do this it was necessary to increase the area of the polygon representing the building with the QGIS "buffer" algorithm which "produces a buffer area for all elements in an input vector, using a fixed or dynamic distance. The segments parameter controls the number of line segments to use to approximate a quarter circle when creating smooth offsets. The end cap style parameter controls how line endings are handled in the buffer. The join style parameter specifies whether round, miter or beveled joins should be used when offsetting corners in a line. The miter limit parameter is only applicable for miter join styles, and controls the maximum distance from the offset curve to use when creating a mitered join" [27].
In the present thesis work, a buffer area of 2 m is used so that it can overlap with the floodmap raster. Anyway, it is recommended to analyse the input vector layer to avoid buildings overlapping too much with each other if too close. The parameters “square” end cap style and the “miter” join style were used.

Subsequently, the QGIS algorithm "zonal statistic" is used. “With the *Zonal statistics* plugin, you can analyze the results of a thematic classification. It allows you to calculate several values of the pixels of a raster layer with the help of a polygonal vector layer. Choosing a color band, the plugin generates output columns in the vector layer with an user-defined prefix and calculates for each polygon, statistics on pixels that are within. The available statistics are:

- **Count**: to count the number of pixels;
- **Sum**: to sum the pixel values;
- **Mean**: to get the mean of pixel values;
- **Median**: to get the median of pixel values;
- **StDev**: to get the standard deviation of pixel values;
- **Min**: to get the minimum of pixel values;
- **Max**: to get the maximum of pixel values;
- **Range**: to get the range (max - min) of pixel values;
- **Minority**: to get the less represented pixel value;
- **Majority**: to get the most represented pixel value;
- **Variety**: to count the number of distinct pixel values. [27]"

The vectorial layer obtained from the QGIS "buffer" algorithm was inserted as an input layer and through the calculation of the mean statistic of the depth values contained in the pixels of the raster map (surrounding the building) a new field was created, named for example "WaterDepth_mean".

At this point the "WaterDepth_mean" field has been joined at the vectorial layer of the buildings (obtained through the QGIS "zonal statistic" algorithm) using the QGIS *"join attributes table"* algorithm that "takes an input vector and creates a new vector layer, i.e. an extended version of the input vector, with additional attributes in its attribute table. These additional attributes and their values are derived from a second vector. For each vector an attribute is selected which determines the joining criterion" [27].
The two attributes have been merged taking as reference the "id" field of the original vector of the buildings.

Subsequently, working on the extended vector layer with the new field containing the depths of the buildings ("WaterDepth_mean"), the QGIS "field calculator" algorithm was used to add another 4 new fields to the shapefile.
One field will be necessary for the classification of buildings according to the JRC taxonomy seen for the previous method, one will contain the areas for each polygon calculated with the "$area" function, necessary for the third field which will contain the economic values of damage according to the specified in Tab.4 and the last field will contain the percentage of damage of the buildings, according to the JRC curves (Tab. 3).
The algorithms are the same used for the first method, it is specified that the new field containing the percentages of damage to buildings is the one obtained from the QGIS "zonal statistic" algorithm.
An example of how the final attribute table of the buildings shapefile will look is shown in Fig. 45.
It is specified that cells with a "NULL" damage percentage mean that the building does not suffer damage.

	id	def_cat_us	WaterDepth_mean	Building_typology	Area	Max_ec_dam	Perc_damage
	213154_020102...	Residenziale-A...	1,8434956701512033	1	371,216	274328,8111	0,573
	213153_020102...	Residenziale-A...	1,2828875513126452	1	32,644	24123,8456	0,467
	213154_020102...	Industriale-stab...	1,1312668493815832	3	104,028	87175,1923	0,313
	213153_020102...	Residenziale-A...	1,1138776499581964	1	145,206	107307,4427	0,429
	213153_020102...	Servizio pubblic...	1,0589701142804375	2	189,902	195219,5776	NULL
	213154_020102...	Industriale-stab...	1,034236412556445	3	247,583	207474,5620	0,287
	213153_020102...	Residenziale-A...	1,033378231279347	1	196,221	145007,4360	0,409
	213153_020102...	Servizio pubblic...	1,0296750664710999	2	257,822	265040,7277	NULL
	213153_020102...	Residenziale-A...	1,0157688679173589	1	146,194	108037,6951	0,404
0	213153_020102...	Residenziale-A...	0,9609385553288133	1	126,175	93243,3966	0,39
1	213154_020102...	Industriale-stab...	0,9279171397811488	3	144,096	120752,2680	0,258
2	213154_020102...	Residenziale-A...	0,8854068659631342	1	317,004	234265,9923	0,369
3	213154_020102...	Residenziale-A...	0,8602533065008394	1	835,698	617580,8107	0,362
4	213153_020102...	Residenziale-A...	0,8324554728137122	1	6,302	4657,3394	0,354
5	213154_020102...	Industriale-stab...	0,7663356872165904	3	30,310	25399,4838	0,214
6	213153_020102...	Residenziale-A...	0,6573317071847748	1	113,130	83602,9098	0,299
7	213153_020102...	Residenziale-A...	0,6537524078573499	1	18,347	13558,5504	0,297
8	213153_020102...	Residenziale-A...	0,651820395523921	1	55,386	40930,6088	0,297
9	213153_020102...	Residenziale-A...	0,5988876728932987	1	354,935	262297,2711	0,278

Figure 45: taxonomy, water depth field, damage percentages and max economic damage defined by the JRC vulnerability curves associated with each building of the layer EDIFICATO

It is also advisable to color the buildings based on the percentage of damage, following the value scale in Tab.8, in order to have a better view of the damage.

Table 8: damage percentage color legend

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

4.5. Processing plugin

In this thesis work it was decided to automate the procedure for determining the damage caused by floods to buildings, creating a plugin in QGIS that allows to associate the vulnerability curves of buildings as automatically as possible, defining attributes of the latter.
The best option for creating a plugin is to add it as a Processing algorithm because it allows to integrate it better within QGIS and make processes faster.
The plugin expects the user to import a vector which will have all the information regarding the buildings of that vector layer in a field of the attribute table.

A problem has been encountered regarding the classification step of the buildings in question (Fig.39), being a procedure for which a more in-depth knowledge of algorithms in Python language is necessary.

The solution was to impose a classification made by the user, then impose a pre-processing of the imported vector layer, before being able to insert it in the plugin.
Despite this, possible ways have been analyzed regarding the classification of words related to buildings.
One of these is to be able to work only on the word referred to the building classes envisaged by the CTR and use Python algorithms that allow you to select the words involved in order to then be able to associate them with the number corresponding to the category of curve used.
Another possibility, perhaps simpler, is to use the identification codes of each category that are provided by the CTR topographical database for the classification algorithm.

The idea, therefore, is to find a Python function that can take the terms characterizing the building and associate it with one that is part of the classification, even if the user has a map with only a similar prefix; otherwise a function able to recognize a part of the representative code of the building and associate the identification number of the specific JRC curve category with the corresponding word should be found.
In any case, any application other than CTR or OSM will require pre-processing by the user regarding the classification of buildings into the correct taxonomy.

Note that it is very difficult for the procedure to fit all possible input building layers, as the names of the fields containing building information are not known a priori, depending on the structure of the individual layer used. It is therefore again specified that the processing plugin created is suitable for the vectorial layer "EDIFICATO" (CTR) and that the name of the field with the attributes of our interest for the classification is known. The ideal procedure should start reading the attribute table of any input vector and allowing the user to select the relevant field for classification.

The plugin script was created using the graphical modeller as support, which allows all algorithms to be executed in sequence and exported to Python.
The graphical modeler (Fig. 46) allows you to create complex models using a simple and easy-to-use interface. When working with a GIS, most analysis operations are not isolated, rather part of a chain of operations. Using the graphical modeler, that chain of operations can be wrapped into a single process, making it convenient to execute later with a different set of inputs [30]. No matter how many steps and different algorithms it involves, a model is executed as a single algorithm, saving time and effort.
The modeler has a working canvas where the structure of the model and the workflow it represents are shown. The left part of the window is a panel with two tabs that can be used to add new elements to the model.

To create the model, all the inputs and algorithms necessary for the process to be performed have been defined. Raster and vector layers are selected from a list of model input data by type or algorithm-generated layers already added to the model.
When the output of a previous algorithm is used as input to another algorithm, the modeler implicitly sets the previous algorithm as the parent of the current one (and places the

corresponding arrow on the modeler's canvas). However, in some cases an algorithm may depend on another even if it does not use any output object from it [30].

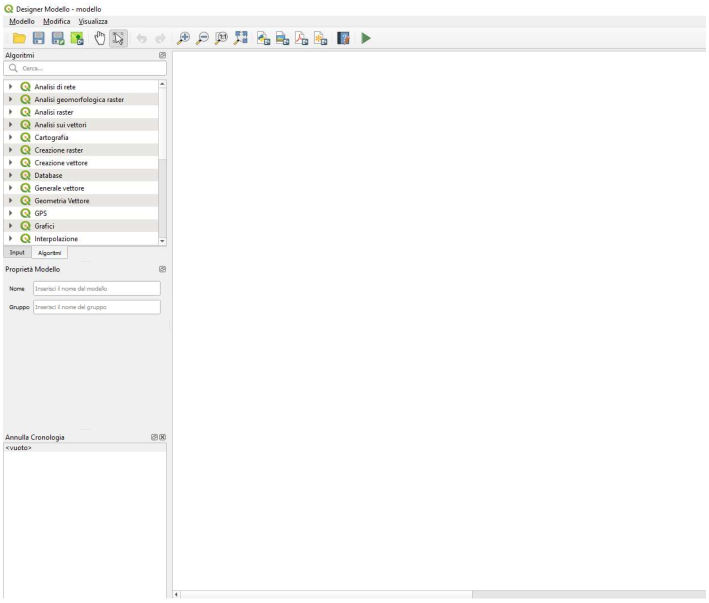

Figure 46: graphical modeler – QGIS

Subsequently, the "Plugin builder" (Fig. 47) was used to create the processing plugin, which can then be viewed in the processing tools.

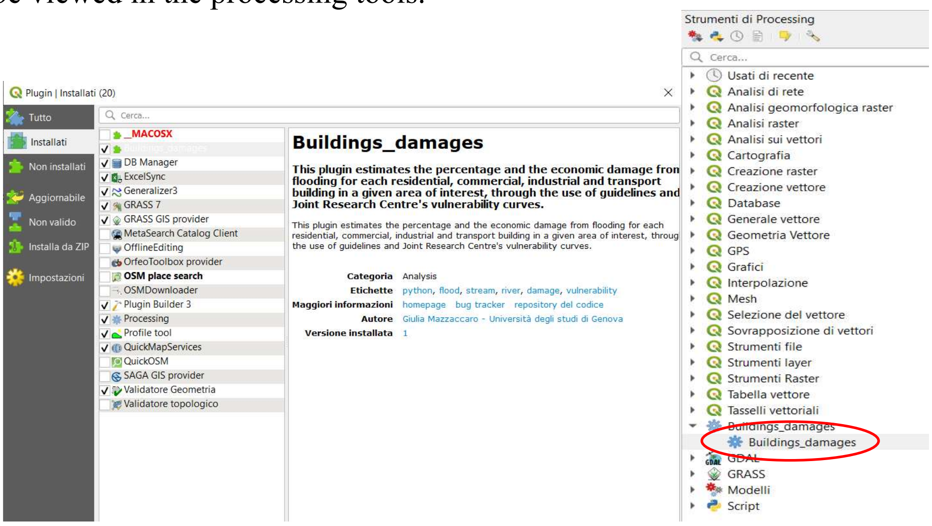

Figure 47: processing plugin installed

The created plugin contains a source and algorithm file, both commented and containing information on how to modify them.

Two scripts corresponding to the two different methods for determining damage to buildings, seen in section 4.4, are shown in the annex.
As for the first method shown, in the plugin user manual, it is specified that the user will have to pre-process the shape file of the buildings at his disposal and the raster of the flood

map using interpolation functions, if it contains areas of NULL values (please refer to chapter 4.1.).
In fact some problems in inserting the interpolation functions inside the plugin were encountered. Anyway, it is specified that the recommended interpolation methods are the IDW and TIN ones.

The representative flow diagram of all the processes that characterize the plugin is shown in Fig. 48.

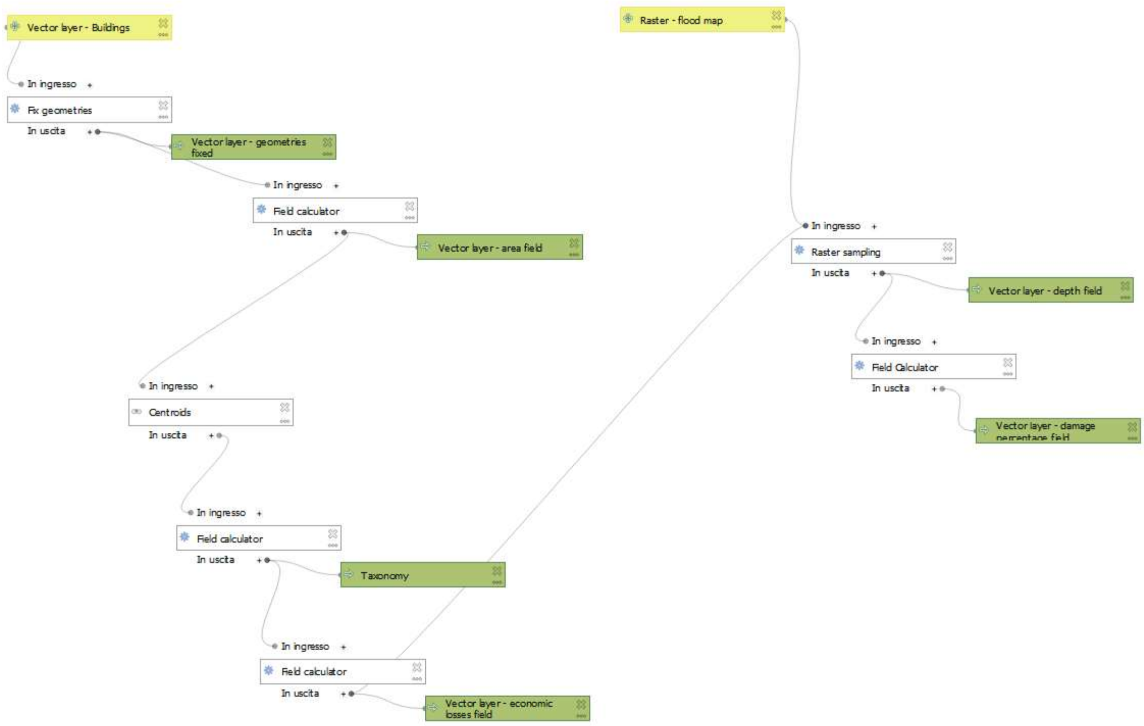

Figure 48: flowchart of all the steps for the automatic determination of flood damage -1st method

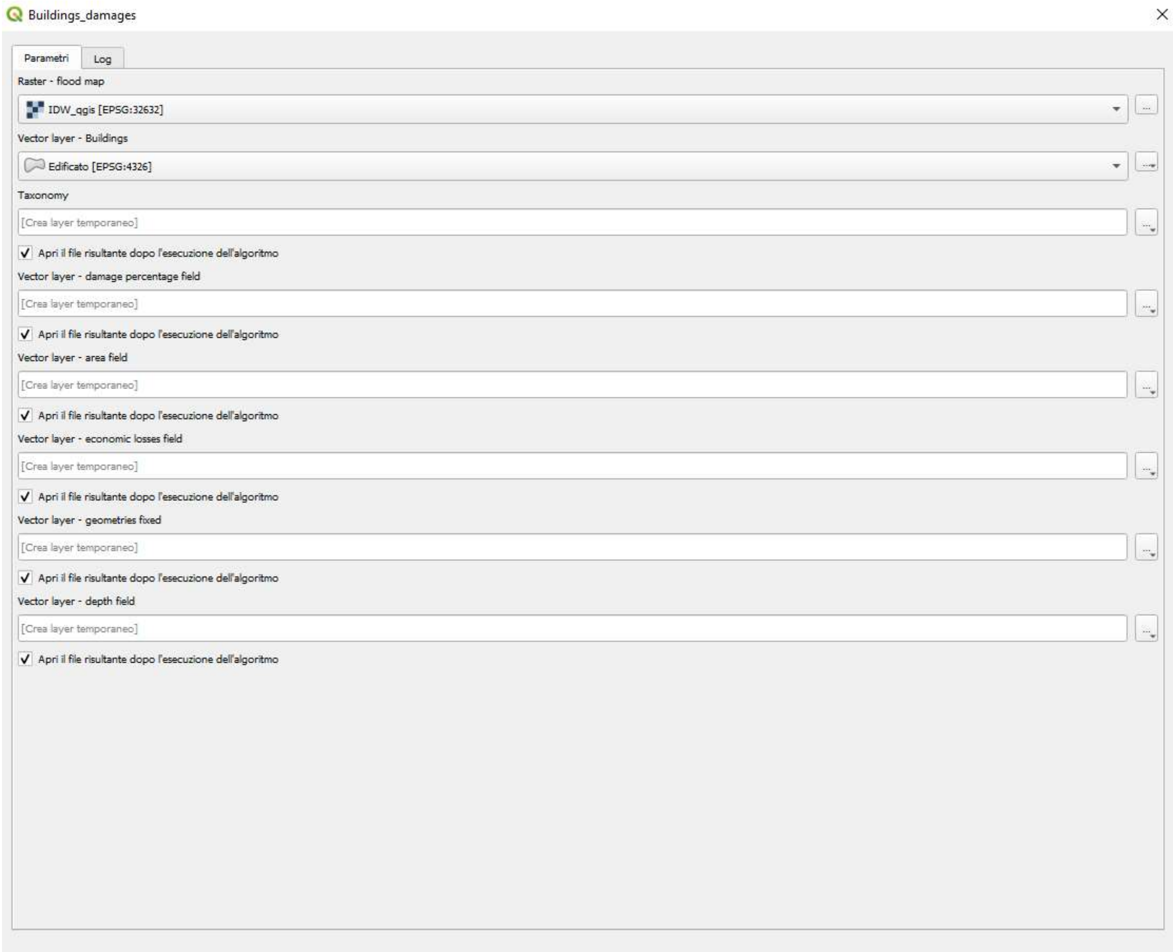

Figure 49: processing plugin interface – 1st method

In the Annex the algorithm that allows the creation of the plugin is shown.

The representative flow diagram of the second method and of all the processes that characterize the plugin is shown in Fig. 50.

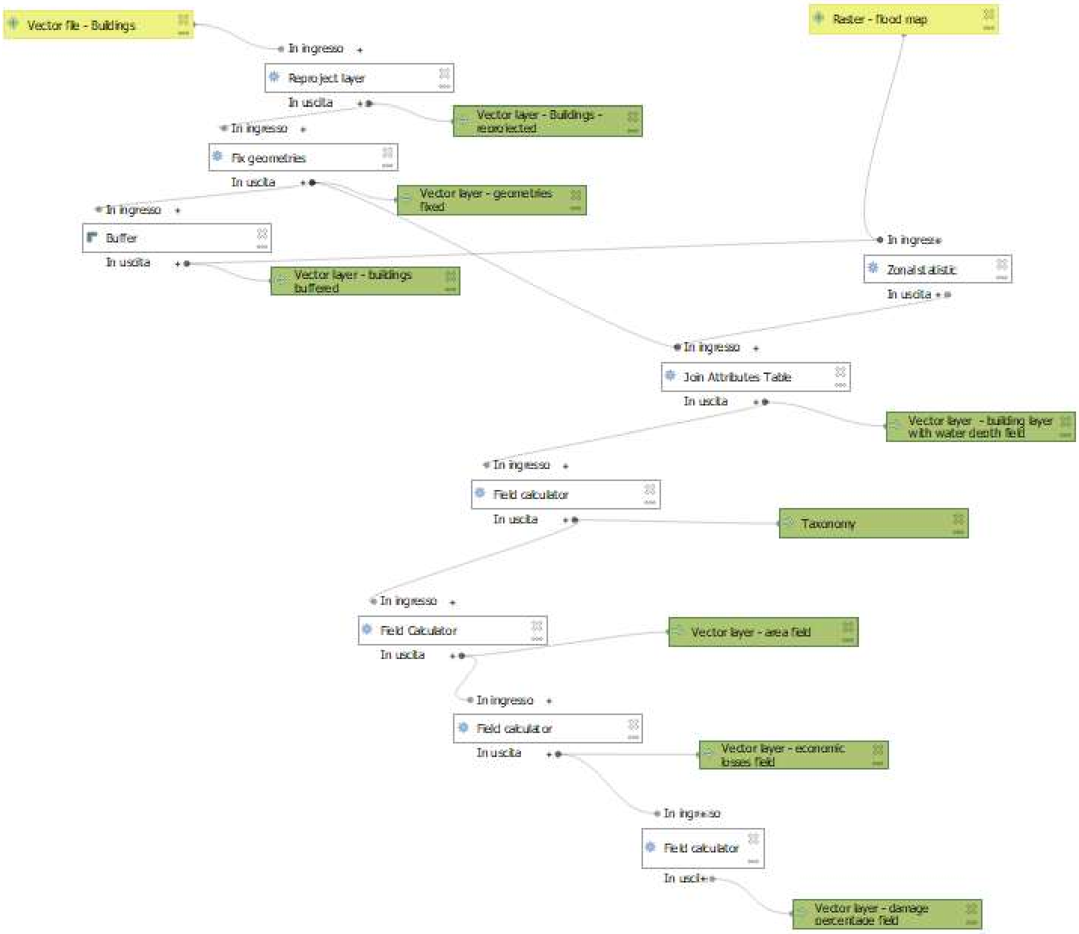

Figure 50: flowchart of all the steps for the automatic determination of flood damage – 2nd method

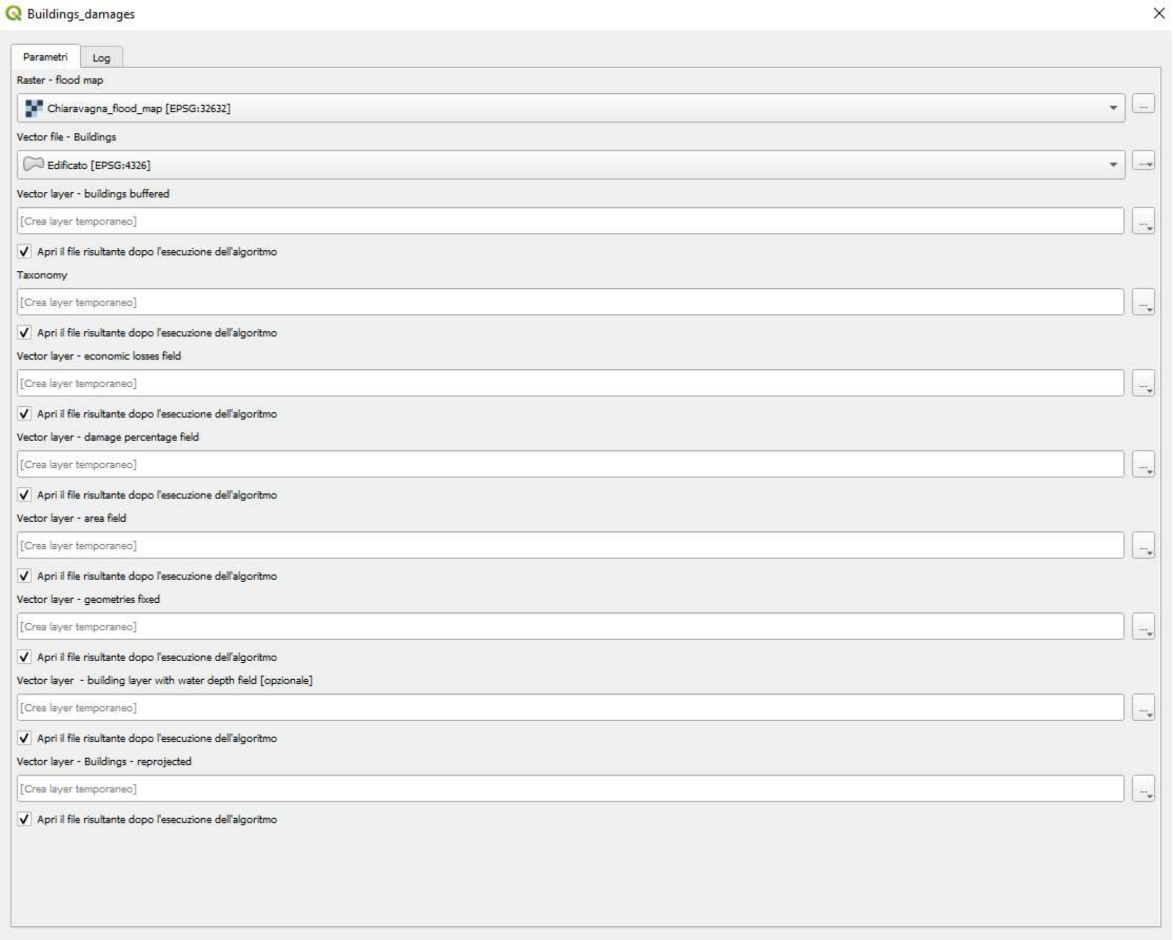

Figure 51: processing plugin interface – 2nd method

In the Annex the algorithm that allows the creation of the plugin is shown.

5. Application to a case study

The flood event of the 4 October 2010 that affected the Chiaravagna stream (Genoa) has been considered as a case study for the application of the developed methodology. More specifically, the map of the maximum extent of the flooding of the Chiaravagna stream has been used as input hazard map to assess the flood damage to buildings by applying the automatic GIS procedure developed in this thesis.

The event of the 4 October 2010 recorded rains with particularly high quantities over short durations and extraordinary intensities over very short durations. The accumulated over 6 hours locally reached 400 mm (Monte Gazzo) recording extraordinary intensities (Pero: 20mm in 5 minutes, Monte Gazzo: 140mm/hour). The consequent rise in the water levels of the watercourses was particularly significant: there was flooding and considerable damage in the provinces of Genoa and Savona. Four torrents emerged from the banks in the Genoese area: Teiro, Arrestra, Chiaravagna, and Molinassi [31].

If initially it seemed there had been no victims but only considerable material damage and situations of danger and terror for the population, subsequently it was ascertained the disappearance of a worker from the quarries of Monte Gazzo, found lifeless a few days later in the sea in front of Sestri [32].

Figure 52: Cars piled up by the Molinassi stream and photos of the flooding of the event on 4 October 2010 [33]

The flood map of this specific event was obtained from the bathymetry representing the elevations of the streets and buildings above the ground (Fig. 53) and from a raster representing the elevations of the water free surface with respect to the reference surface (Fig. 54). Free surface elevations are provided only on roads, as the hydraulic model simulates the propagation taking buildings into account. The depth of the flood is obtained by the difference between the depth of the free surface and the bathymetry (Fig.55).

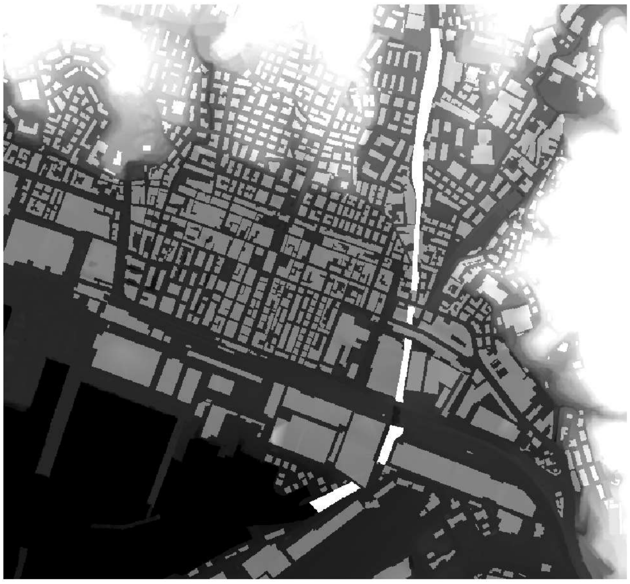

Figure 53: Bathymetry raster data (courtesy of DHI Italia and Regione Liguria)

Figure 54: raster data: elevations of the free surface with respect to the reference surface (courtesy of DHI Italia and Regione Liguria)

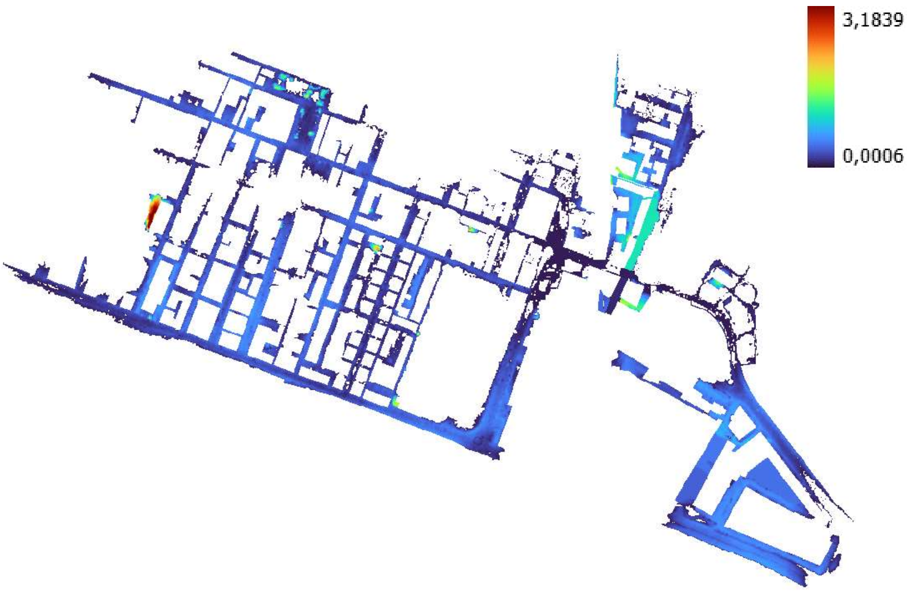

Figure 55: raster data – free surface height of the flood event obtained by the difference between free surface height and bathymetry

By superimposing it on an OpenStreetMap background, it is possible to visualize the area of interest (Fig. 56).

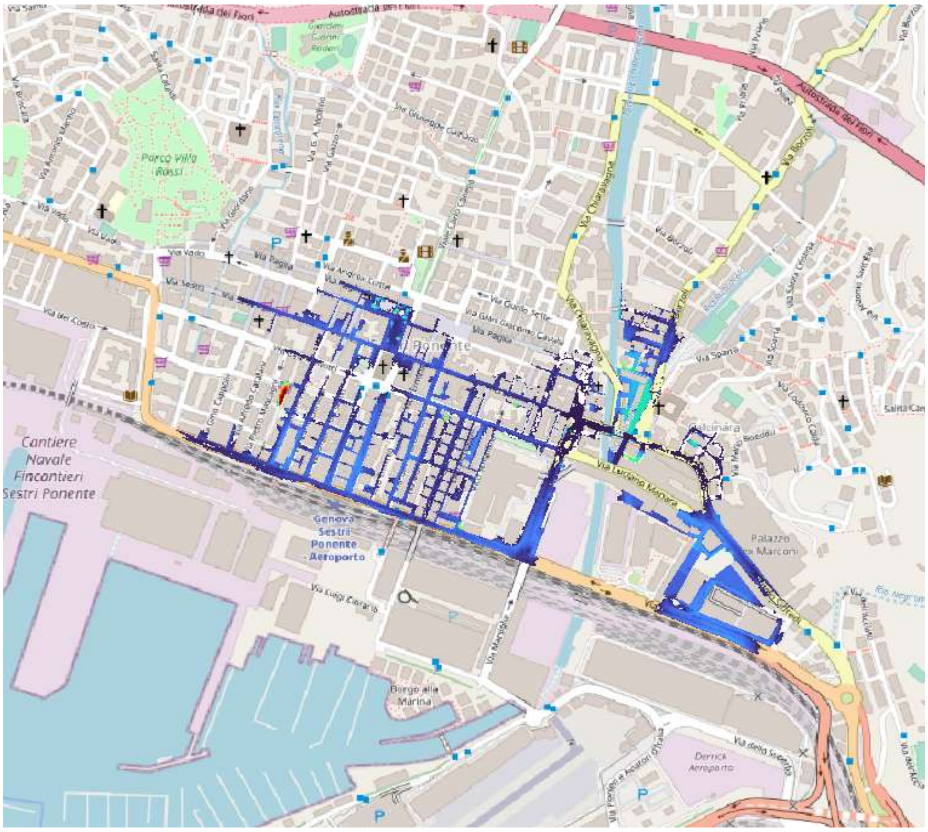

Figure 56: water depth of the flood event with OSM background

Inside the case study area there are very localized maxima, due to errors in the bathymetry (Fig. 53).

The raster files available for the case study are raster files in ASCII grid format with NULL values, as described in the header of the files (Fig. 57 – 58).

```
ncols         1681
nrows         1549
xllcorner     487268.903400000010
yllcorner     4918186.491499999538
cellsize      1.000000000000
NODATA_value  -9999
 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
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```

Figure 57: raster data in ASCII grid format - elevations of the free surface with respect to the reference surface

```
ncols         1681
nrows         1549
xllcorner     487268.903400000010
yllcorner     4918186.491499999538
cellsize      1.000000000000
NODATA_value  -9999
40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000
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40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000 40.0000
```

Figure 58: bathimetry raster data in ASCII grid format

The coordinates of the lower left corner of the lower left cell of the matrix are defined in WGS 84/UTM 32 (Fig. 59).

Figure 59: characteristics of the reference system WGS 84/ UTM 32 [34]

A raster file is therefore obtained representing the depth reached by the water starting from the ground level, with a resolution of 1x1 pixel.

5.1. Interpolation of the flood map

Because the flood map has NULL values inside the footprint of the buildings, all the possible QGIS and GRASS algorithms mentioned in the section 4.1. for the interpolation of a raster map are applied. A smaller area was selected (Fig. 60) to speed up the computation of the results and keeping the 1x1 resolution.

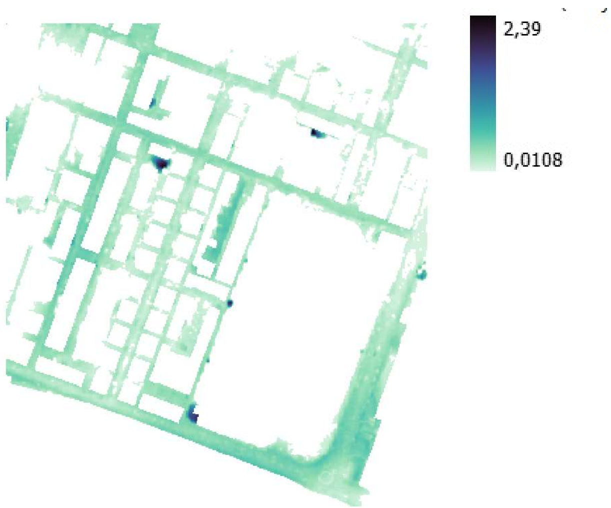

Figure 60: clipped raster data - water depth of flood event

The first test was performed executing the GRASS *"r.fill.nulls"* algorithm, which uses a spline interpolation technique to fills in dataless areas (NULL) of the raster layer. The user can decide to use Regularized Spline with Tension (RST) or bispline algorithm.
The first tests were performed with RST, changing the tension value.

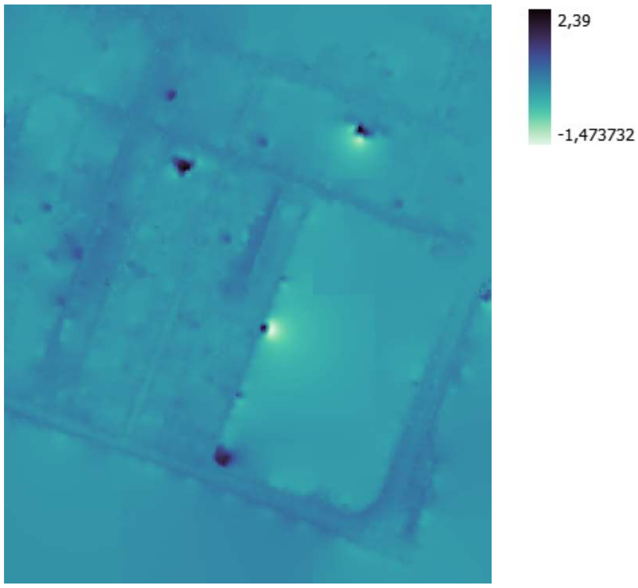

Figure 61: spline interpolation RST – tension parameter 40 - r.fill.nulls algorithm

The peculiarity of this type of interpolation is that in some NULL cells the interpolated values result to be negative (Fig. 61-62-63); this is not acceptable, being water depth values.

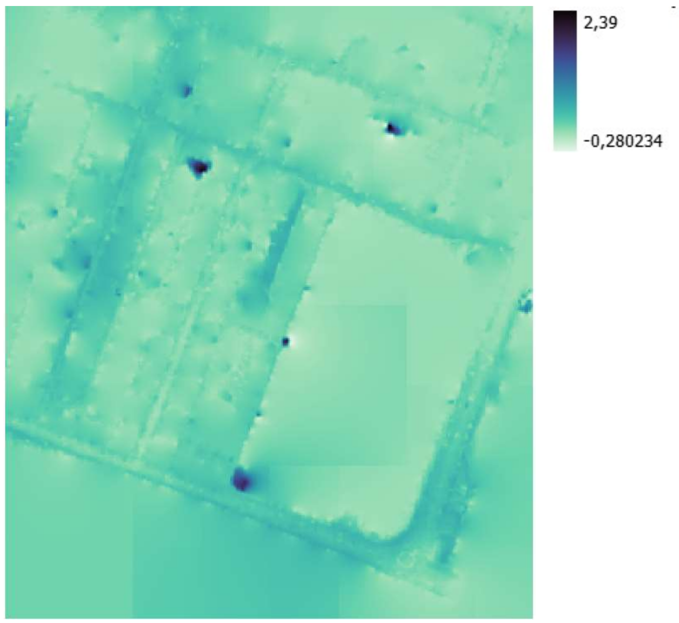

Figure 62: spline interpolation RST – tension parameter 100 - r.fill.nulls algorithm

By increasing the tension value, squares (sharp surfaces) are appearing (Fig. 62). Moreover, negative values are observed too, even if close to 0. By lowering the tension to 10, even more negative values appear (Fig. 63).

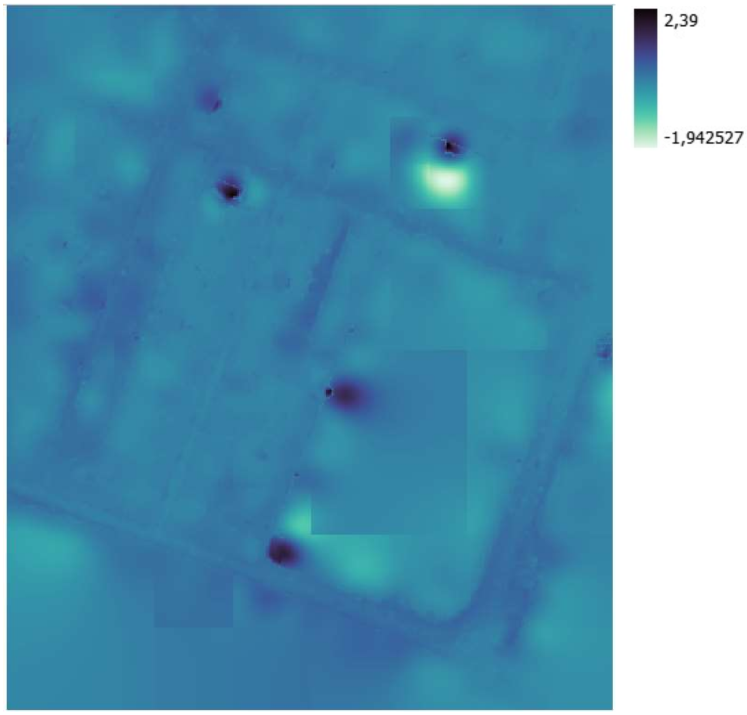

Figure 63: spline interpolation RST – tension parameter 10 - r.fill.nulls algorithm

Also bilinear and bicubic algorithms were tested (Figs. 64 and 65) with results similar to fig. 61.

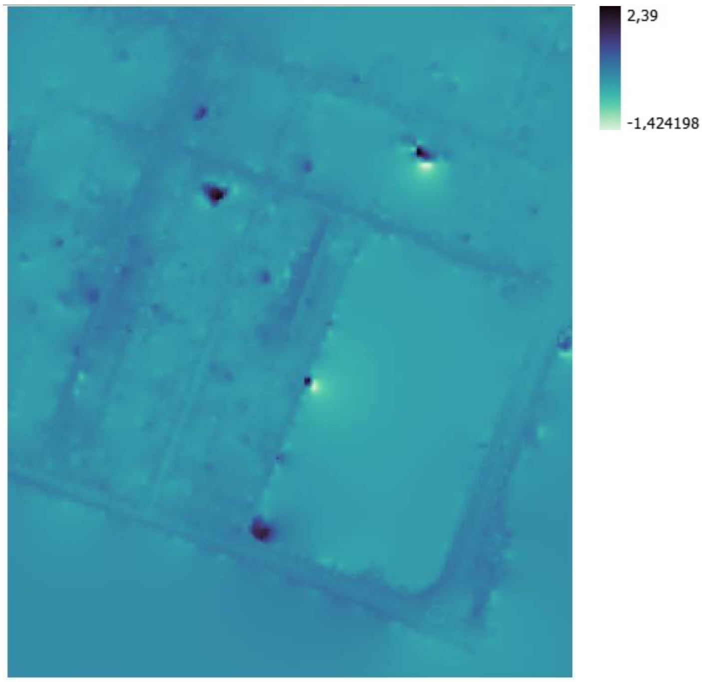

Figure 64: spline interpolation bilinear -tension parameter 40- r.fill.nulls algorithm

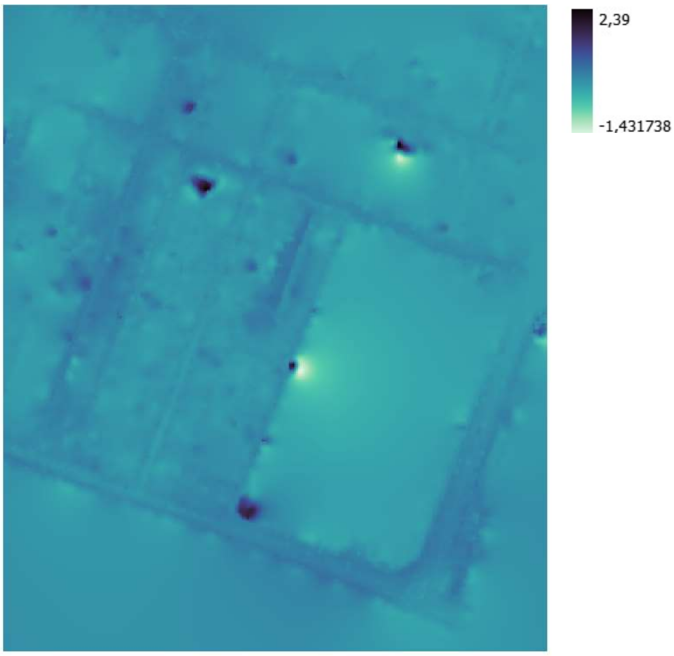

Figure 65: spline interpolation bicubic- tension parameter 40 - r.fill.nulls algorithm

Then IDW interpolation was tested using the *"r.surf.idw"* algorithm (Fig. 66 – 67).
Because it doesn't work with maps with real values, it was necessary to pre-process the raster data by running the GRASS algorithm *"r.map.calc",* which calculates a new raster map by applying an expression to round the cell values to whole numbers, in this case to mm.
An important parameter for this algorithm is the used number of closer sample points. By default the algorithm uses 12 points, but it could be changed. Instead, the IDW algorithm available inside QGIS thanks to a GRASS plugin does not give the possibility to set the distance coefficient, that is fixed to 2.

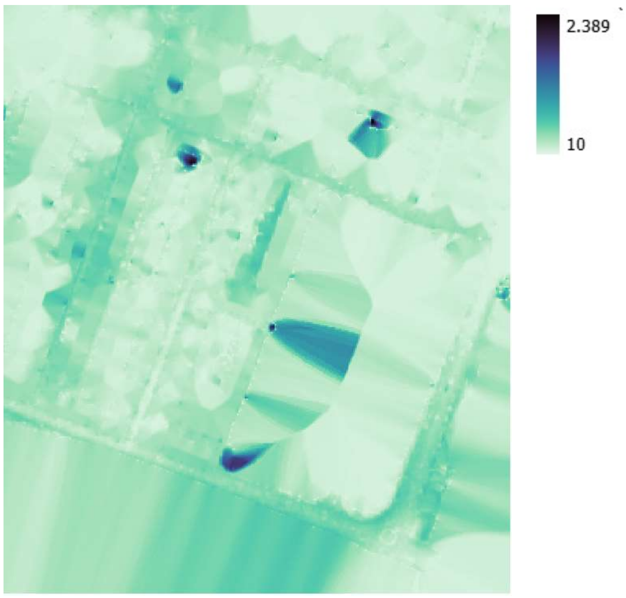

Figure 66: IDW interpolation - parameter 12 npoints - r.surf.idw algorithm

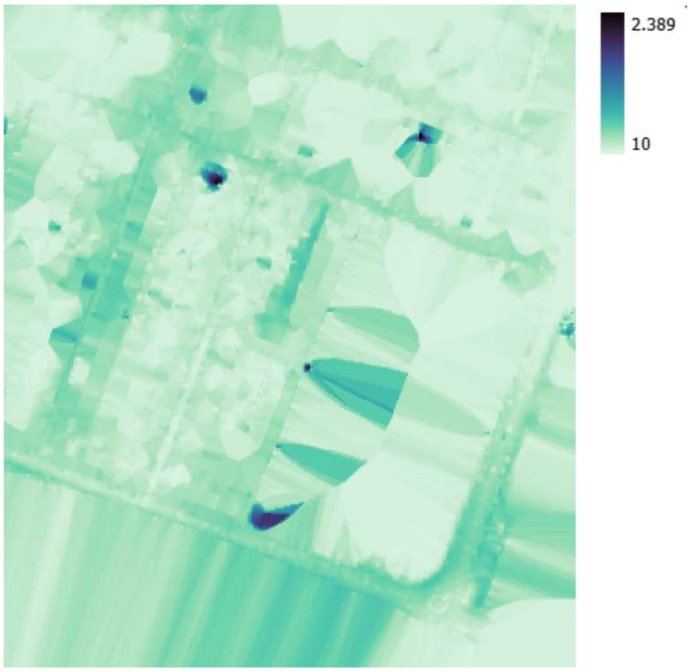

Figure 67: IDW interpolation- parameter 4 npoints - r.surf.idw algorithm

The Figures 66 and 67 are related to 12 and 4 points.
Because the sample points used for IDW interpolation are spread along the boundary of the building footprints, the resulting surface has some not realistic artefacts (Fig. 66-67).

A test was performed also applying the IDW and TIN interpolation plugins native in QGIS. They both need a vector point layer as input, hence the flood map was converted into vector through the GRASS algorithm *"r.to.vect"* (Fig. 68).
The result of IDW interpolation is shown in Fig. 69, using a distance coefficient equal to 2 and 12 sample points (that is not possible to modify). The result of TIN interpolation is shown in Fig. 70. They both properly reproduce the flood map within the footprint of the building.

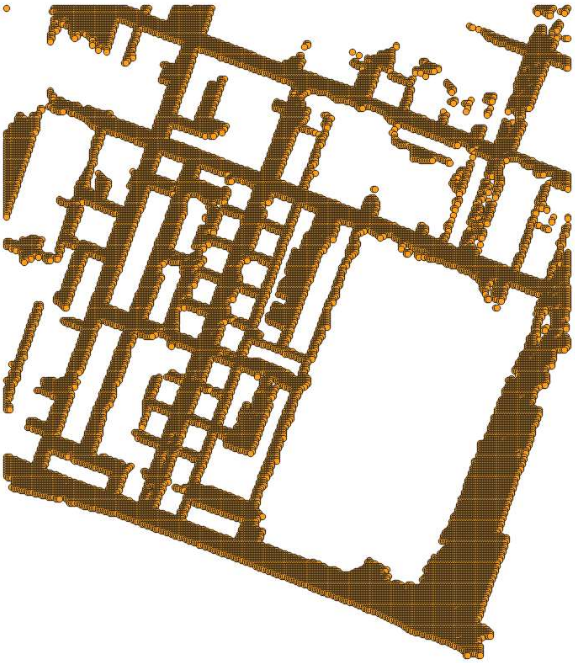

Figure 68: flood depth raster layer converted to vector layer (points)

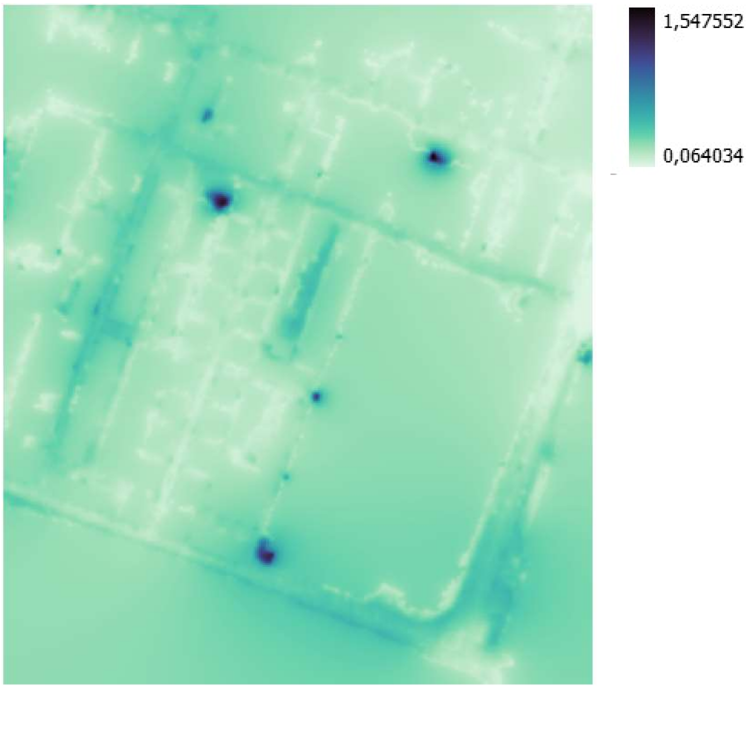

Figure 69: IDW interpolation – QGIS plugin

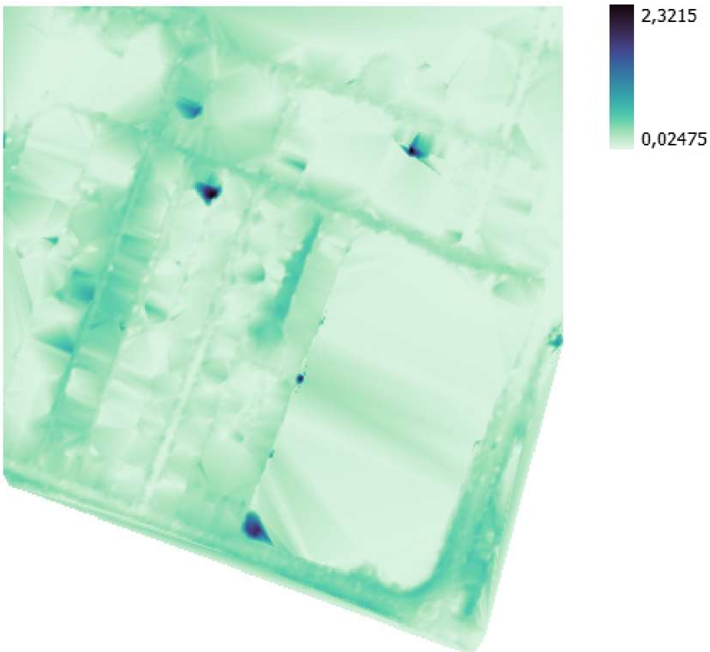

Figure 70: TIN interpolation – QGIS plugin

Also the GRASS algorithm *"v.surf.rst",* which uses a spline interpolation technique from vector points maps, was applied with different tension parameters (Fig. 71-72-73).

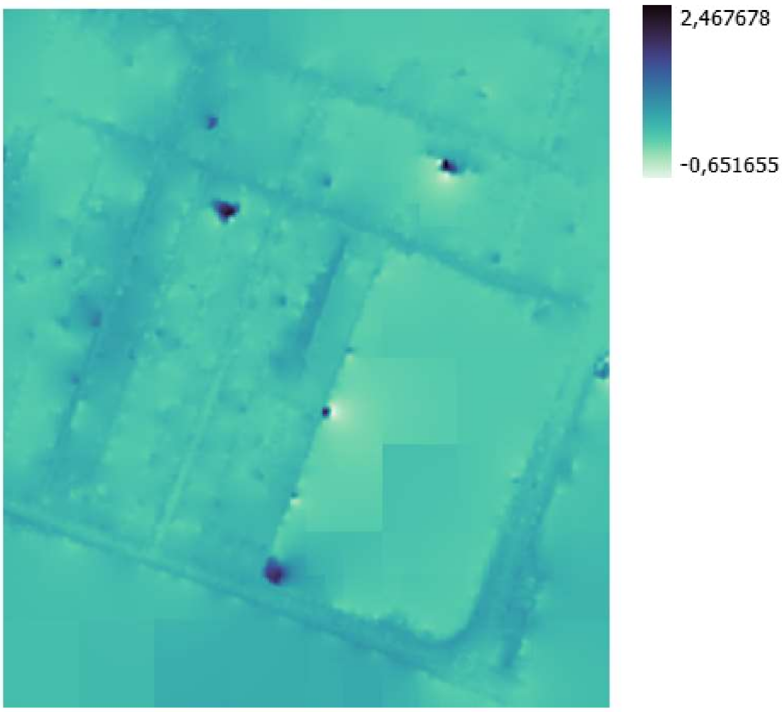

Figure 71: spline interpolation RST – tension parameter 40– v.surf,rst algorithm

In case of tension equal to 40, the behaviour is similar to the GRASS algorithm *"r.fillnulls"* used directly by raster (Fig. 61).

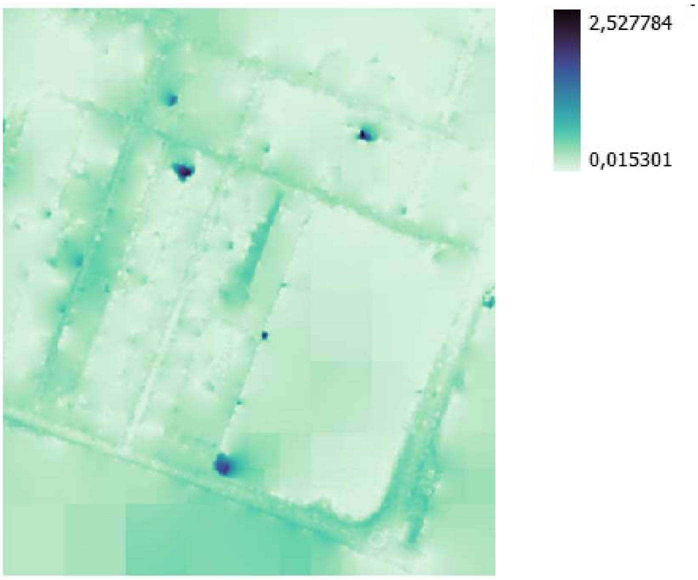

Figure 72: spline interpolation RST – tension parameter 100 – "v.surf,rst" algorithm

By increasing the tension value to 100 (Fig. 72), no negative values but squares (sharp surfaces) appear.

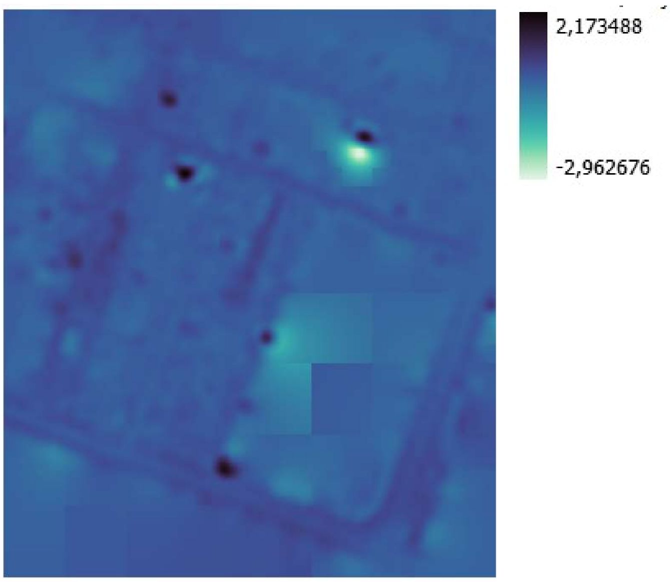

Figure 73: spline interpolation RST – tension parameter 10 – "v.surf,rst" algorithm

By lowering the tension value to 10(Fig. 73), the negative values increase.

Also IDW interpolation from vector using the GRASS algorithm *"v.surf.idw"* is tested (Fig. 74 – 75). Unlike the GRASS algorithm *"r.surf.idw"* from raster, it allows to set both the distance coefficient and the number of sample points. For the present test, however the distance coefficient, i.e. the power parameter, was set to 2. Greater values of power parameter assign greater influence on closer points.

Furthermore, the present algorithm does not require integer values as attributes.

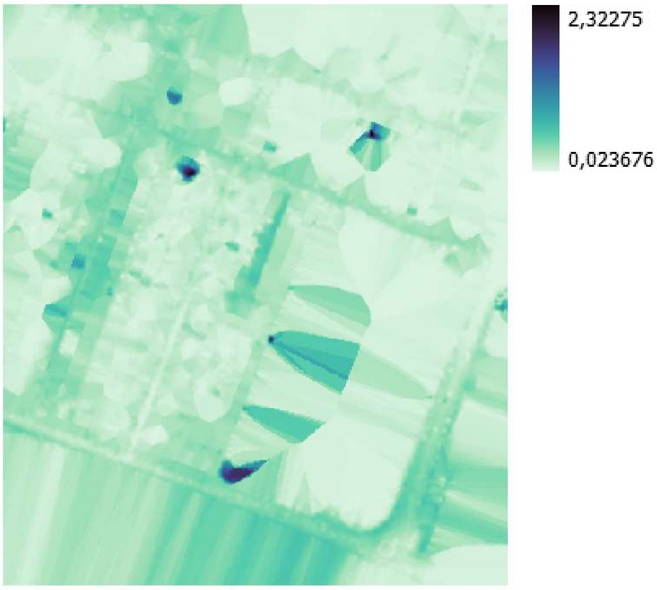

Figure 74: IDW interpolation- parameter 4 npoints - v.surf.idw algorithm

The result in Fig. 74 is very similar to Fig.66, presenting artifacts. The same happen changing the number of points in Fig.75.

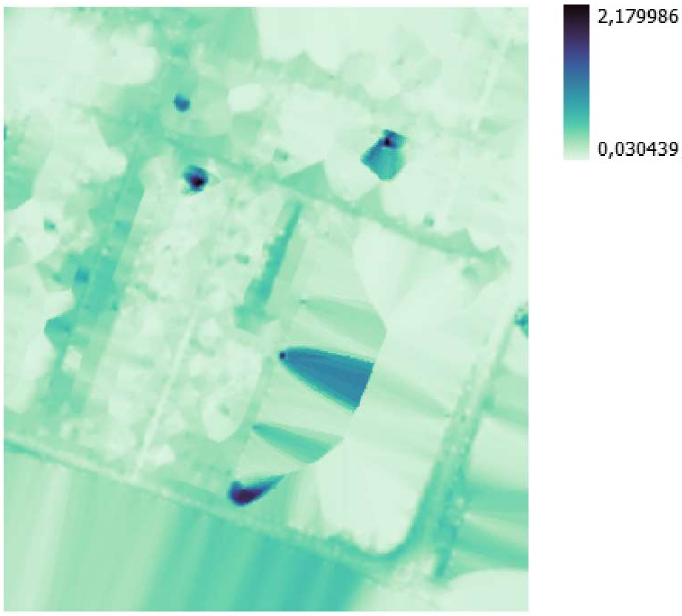

Figure 75: IDW interpolation - parameter 12 npoints - v.surf.idw algorithm

The last tested interpolation algorithm was *"v.surf.bspline"*. It does not allow changing the tension parameter, unlike the *"r.fill.nulls"* GRASS algorithm; instead, it uses the parameter relative to the Tykhonov regularization (λ).
Exaggeratedly negative, unacceptable values are observed for both bilinear and bicubic interpolation (Fig. 76-77).

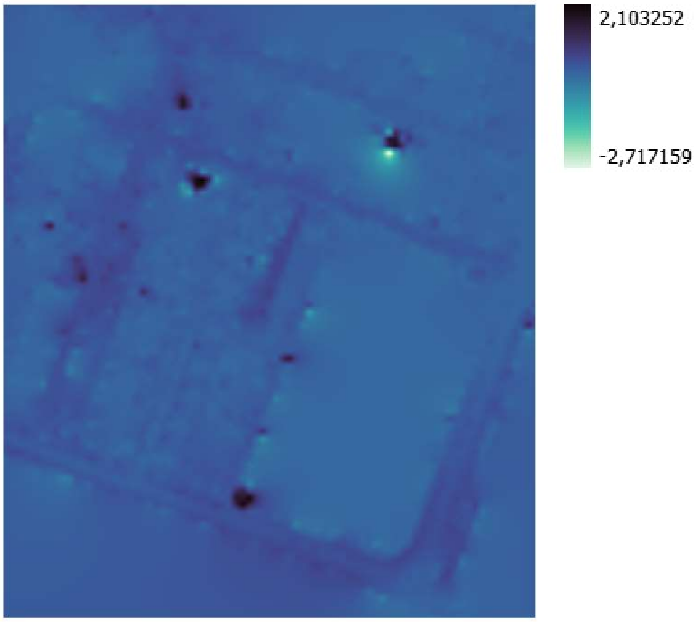

Figure 76: bspline interpolation bilinear – tension parameter 40 - v.surf.bspline algorithm

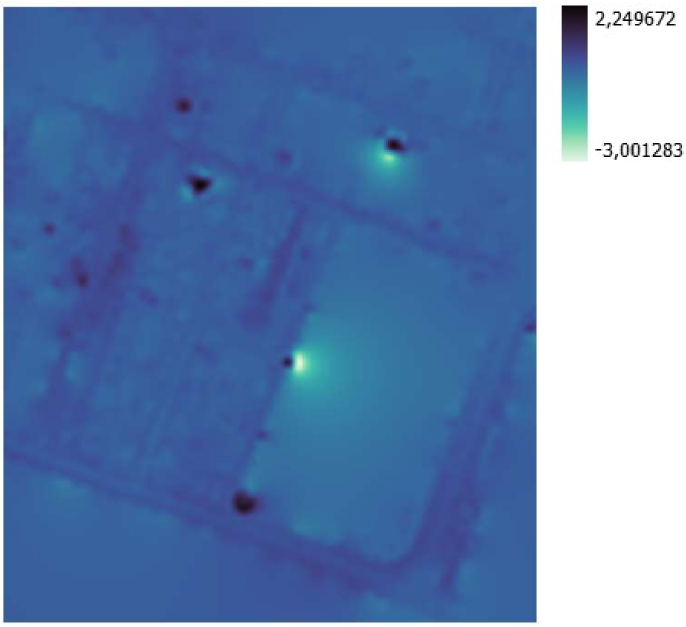

Figure 77: bspline interpolation bicubic – tension parameter 40– v.surf.bspline algorithm

Through the QGIS plugin "Profile tool" it is possible to perform profiles of the maps interpolated with the heights reached by the flood and represent them through a graph. In particular, two lines, plotted in Fig. 78 -79, are considered significative and particularly difficult. The goal is to understand, at the point where I have no data, which is the best fit.
Note that the interpolated surface should model the position of the water; therefore, between a high and a low level the trend in 1D should be linear, with the exception of slopes due to the fact if it has a higher altitude from one point to another as shown in Fig. 80: the profile tool connects the sampled points bordering a null area with a line; the resulting interpolated profile should look like it.
In the following Figures comparisons between different interpolations techniques are shown. Note that the symbol STAR is used to show the large area of interpolated NULL values on which attention is focused.
The results show artifacts produced by the different interpolation techniques which do not reproduce the expected conformation.

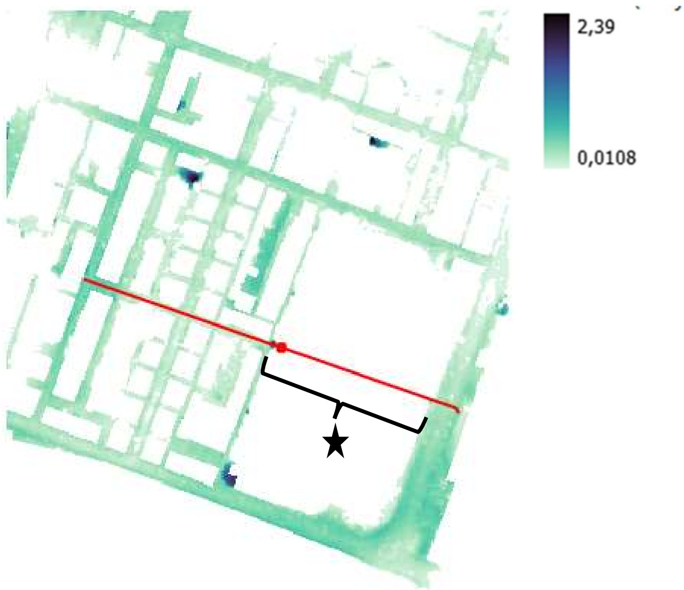

Figure 78:original raster layer – 1st section

Figure 79: original raster layer – 2nd section

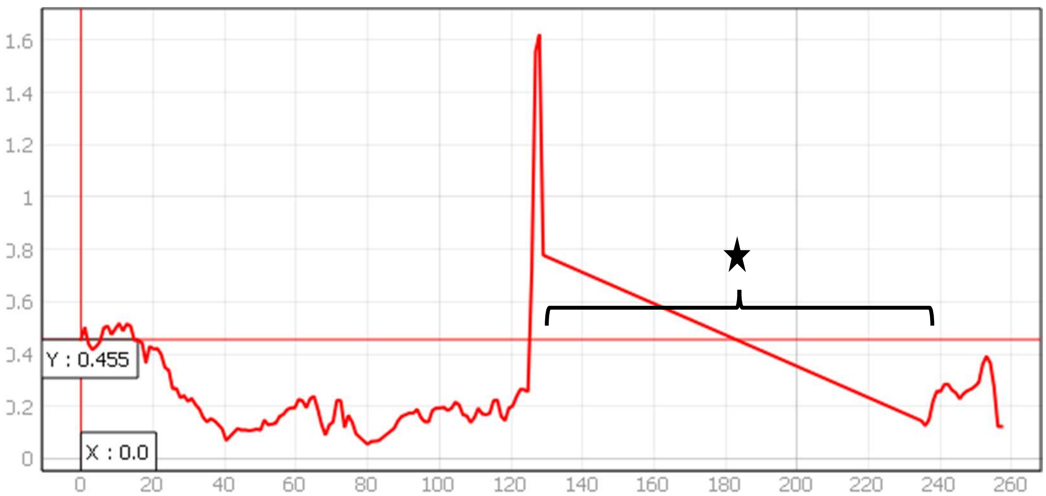

Figure 80:original profile vector layer – 1st section

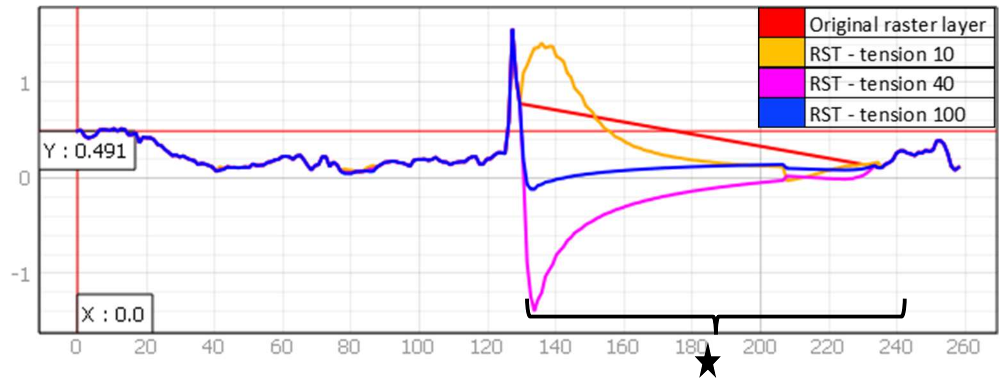

Figure 81: Spline RST comparison for the different tension parameter – from raster – 1st section

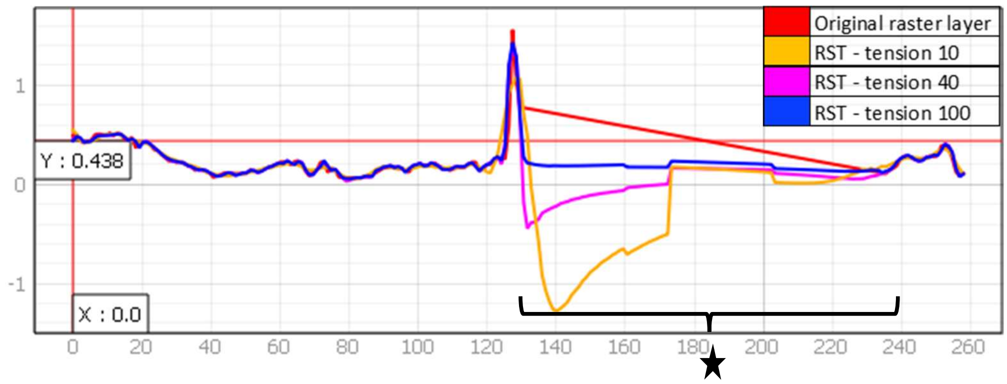

Figure 82 - Spline RST comparison for different tension parameter – from vector – 1st section

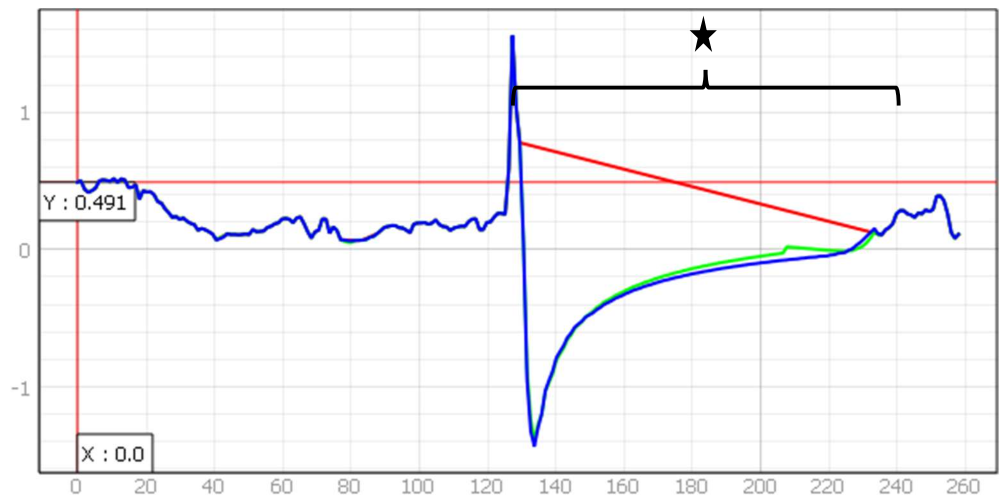

Figure 83:spline interpolation bilinear (green) and bicubic (blue) – tension parameter 40 – from raster – 1st section

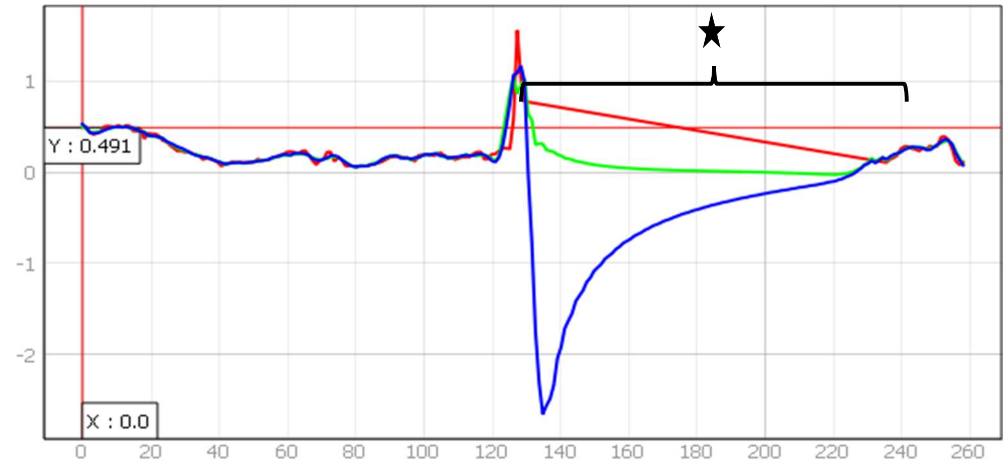

Figure 84 - spline interpolation bilinear (green) and bicubic (blue) – tension parameter 40 – from vector - 1st section

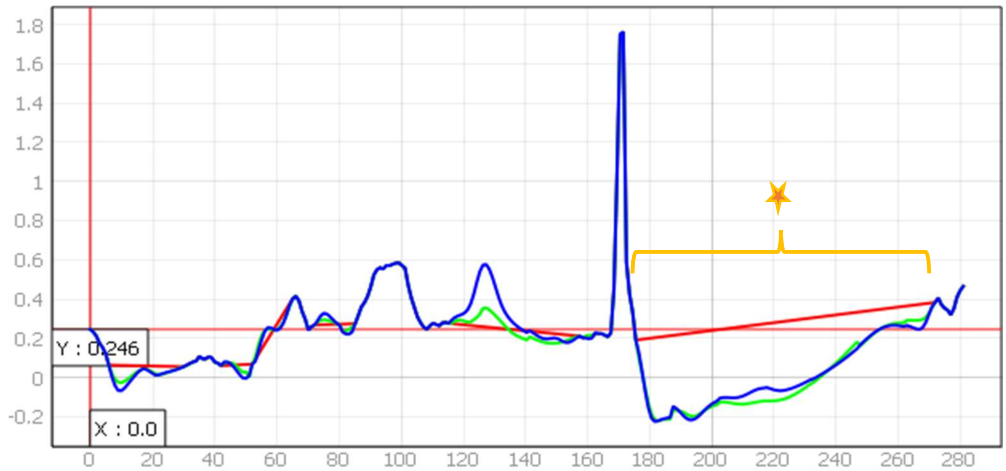

Figure 85: spline interpolation bilinear (green) and bicubic (blue) – tension parameter 40 – from vector – 2nd section

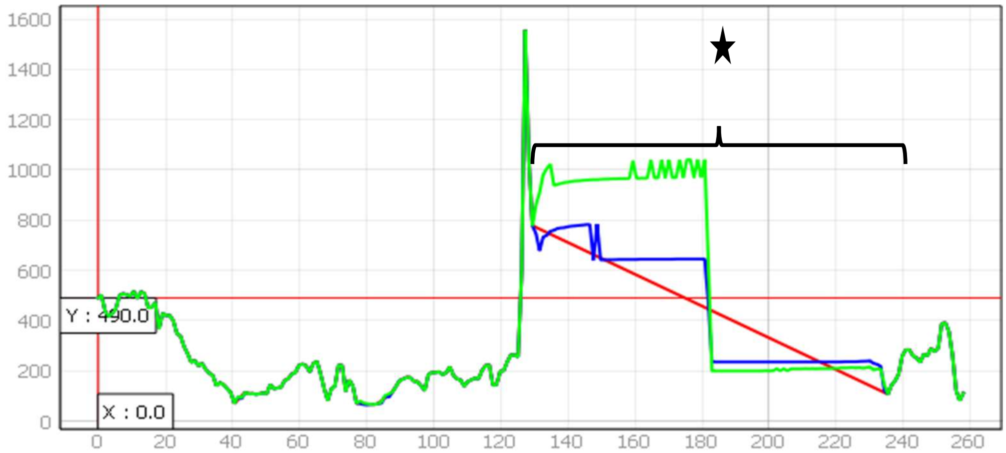

Figure 86: IDW fron GRASS algorithm – from raster – integer value of depth (mm)

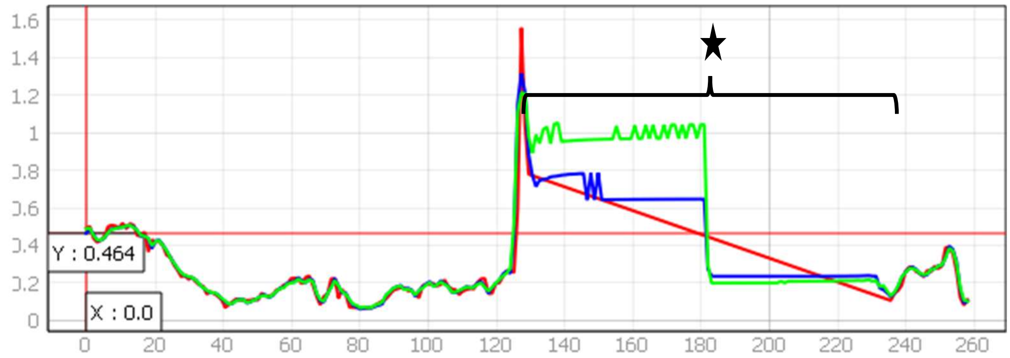

Figure 87: IDW from GRASS algorithm – from vector – integer value of depth (mm)

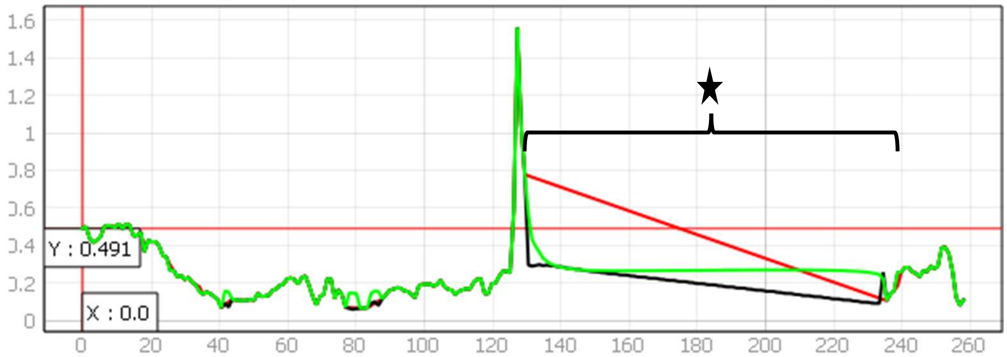

Figure 88: IDW (green) and TIN (black) comparison - interpolation from vector – QGIS plugin

Spline RST interpolations (Fig. 81- 82) produce unacceptable negative data at NULL values, both for raster and vector interpolation, except for the interpolation from vector layer with tension parameter 100, which exhibits an apparent acceptable behavior but unrealistic artefacts (Fig. 72).
Linear and bicubic bspline interpolation from raster has negative depth values which are unacceptable (Fig. 83), while bilinear interpolation from vector layer has all positive values along the first section taken into consideration (Fig. 84) but not along the second one (Fig. 85).
Figures 86-87 represent the result of the IDW GRASS algorithm, both from raster and vector layer; the profile assumes a stepped trend in the part of missing data, unrealistic and not ideal for the representation of a water profile.
Pay attention that the scale in Fig. 87-88 has changed because for the GRASS *"r.surf.idw"* algorithm it was necessary to have integer values of water depth, hence the values were converted from m to mm.
A realistic water profile is observed only with the TIN and IDW interpolation from a vector layer, despite the presence of an anomalous peak in the last known points before the NULL ones (Fig.88). Note that the maximum points are clearly lowered using the interpolation algorithm QGIS IDW from vector, compared to the original profile.
Note also that the maximum displayed in the graphs are due to errors in the bathymetry (Fig. 53), probably due to depressions in the used DEM.
Concluding, if interpolation of flooding map is needed, the TIN and IDW interpolation method from vector data implemented in QGIS plugin are recommended, taking into account a possible high computational effort.

Pay attention that TIN interpolation does not interpolate values outside the area of interest, although it would be useful to see how flooding propagates.

5.2. Results of the implemented procedure

The procedure for flood vulnerability and damage assessment implemented thanks to the two plugins presented in section 4.5. is here applied.

The results of the plugin relative to the 1st method (Fig. 48, 49), presented in chapter 4.4, are here illustrated.
In addition to the vector layer of the buildings, the raster map interpolated with the IDW and TIN method (using the QGIS algorithms) has been used as input.
The buildings subject to damage and coloured with the legend presented in Tab. 8 are shown in Fig. 89 and 90 depending on the interpolation technique.

Figure 89: damage to buildings – method 1 – raster flood map interpolated with TIN

Figure 90: damage to buildings – method 1 – raster flood map interpolated with IDW

The results of the plugin built with method 2 (Fig. 50, 51), presented in section 4.4, are illustrated in the Fig. 91-93. In this case the inputs are the vectorial layer of the buildings and the original raster map that considers the footprints of the buildings (Fig. 55) or the raster map derived by the original one but with the footprints of the building interpolated with TIN or IDW method.

Figure 91: damage to buildings – method 2 – original raster flood map (courtesy of DHI Italia and Regione Liguria)

It is considered the case in which the inserted inputs are, in addition to the vector layer of the buildings, the raster map interpolated with the TIN and IDW method.

Figure 92: damage to buildings – method 2 – original flood map interpolated with TIN

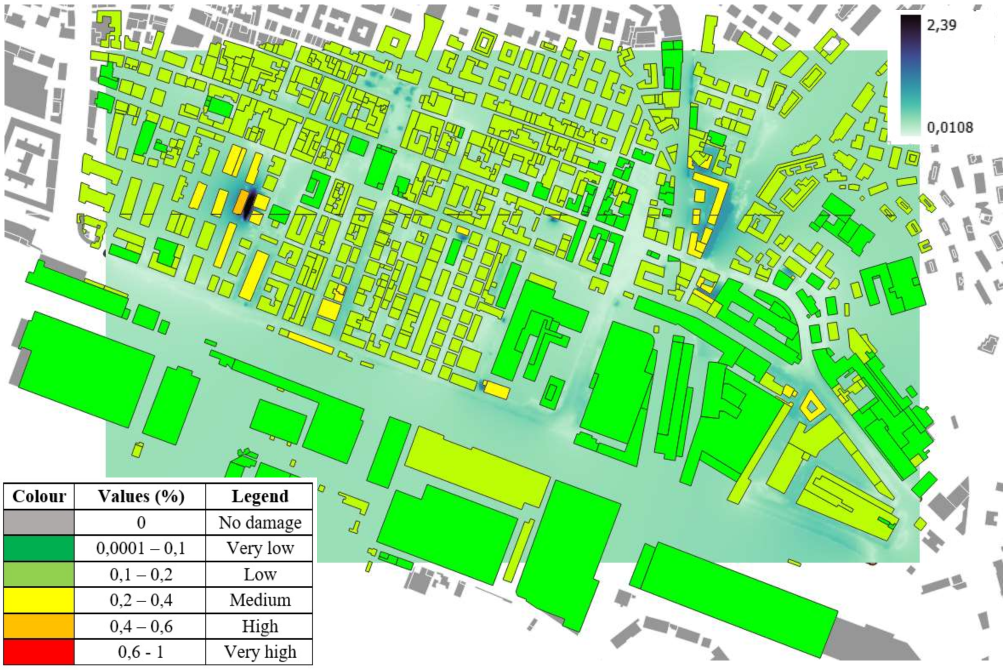

Figure 93:damage to buildings – method 2 – original flood map interpolated with IDW

Fig. 94 shows the map of buildings colored according to the economic damage, from the JRC guidelines (Tab.5)

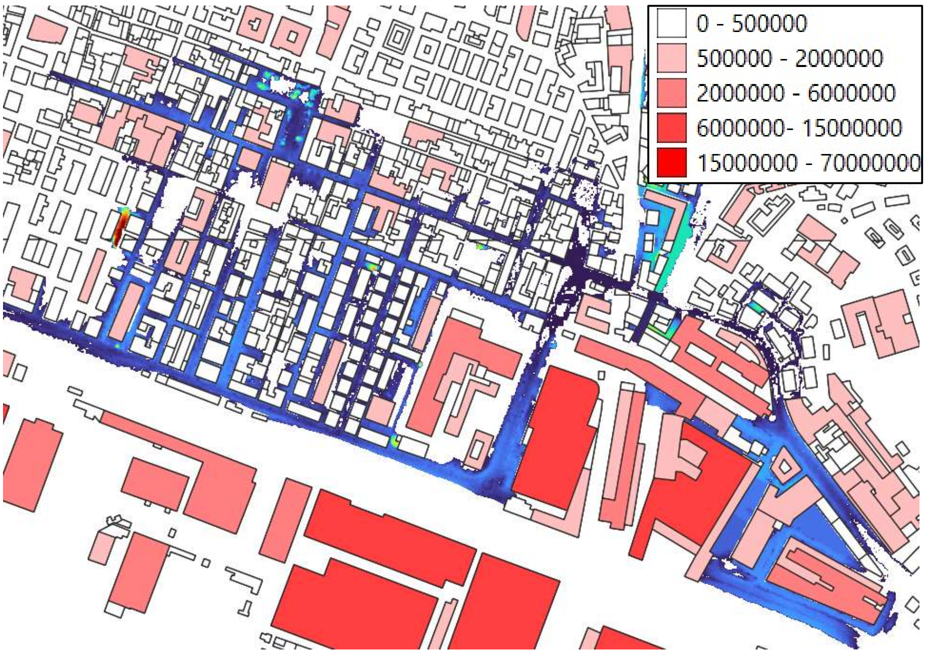

Figure 94: economic damages (€) – JRC guidelines

Figs. 89 and 92 show that the flood map interpolated with the TIN method (QGIS algorithm) following the method 1 or 2 present similar results except for few buildings. In particular the method 1 for some buildings applies more damage than method 2. This can probably be due to the fact that the first method associates the depth values to the buildings in the centroid of the polygon, while the second method averages the values of the flood map pixels that are inside the vector layer polygon.
Remember that the TIN interpolation method allows an interpolation only within the area with non-NULL values.

Also Figs. 90 and 93 show similar results. The only difference is that IDW interpolation method also interpolates outside the area of non-NULL values, allowing you to see how the event would propagate.

The method 2 that uses the original flood map, with no depth values in correspondence of the footprints of the building (Fig.91), allows to avoid possible overestimations of the damages caused by interpolation, and allows to visualize those buildings that do not suffer damage because they are protected from flooding by walls or because on raised ground.
The advantage of method 2 is that it allows to use a raster map which does not require preprocessing, being that the computation time of the results of the interpolation is relatively high. Furthermore, for the interpolation of these types of data, it is necessary to switch from a raster map to a vector map in points, risking altering the values that are well represented by the raster map.

6. Conclusions

This research thesis aimed at defining an automatic GIS-based method to estimate the damage caused by floods to buildings in an urban environment. More specifically, a processing plugin has been implemented in QGIS to estimate the percentage and the economic damage from flooding for each residential, commercial, industrial and transport building in a given area of interest. The developed plugin included a series of algorithms to associate a flood water depth, and the relative percentage and economic damage to each building.

To perform the flood damage assessment implemented in the developed plugin, it is applied a vulnerability model and it is used as input (i) a vector map representing the polygons of the buildings exposed to flood; (ii) a raster map representing the maximum extension of the considered flood scenario and containing for each pixel the values of the water depth reached at each point, obtained from a hydraulic simulation model.

As a vulnerability model, the global flood depth-damage functions provided by the Joint Research Center (JRC) were used, which allowed for the assessment of the maximum direct tangible physical damage for the categories of residential, commercial, industrial and transport buildings. Moreover, JRC methodology also provide the average values of the maximum damage (€/m2) at the European level and the average values of maximum damage in Italy for each land use category.

To estimate the flood depth for each building, two different procedures were analyzed in a GIS environment.

The first procedure consists in associating to each building, specifically to the centroid, a water depth value contained in that point in the pixel of the flood map raster. This first method can be easily applied when 'complete' flood maps, i.e. maps that also cover the footprint of the buildings, are available as input. In the case that it is not possible to have a map of this type, and available flood maps have been obtained already taking into account building footprints, it will be necessary to proceed with a pre-processing through spatial interpolation. There are a large number of interpolation methods and algorithms from the QGIS software (version 3.22) and the GRASS GIS plugin, and some of them have been analyzed in this study. It has been shown that the interpolation methods that are most consistent with the trend of the water profile are the IDW and TIN methods, performed with the use of QGIS algorithms.

The second procedure can also be directly implemented with maps obtained from simulations that take into account the footprint of the buildings. The depth of the water, in fact, is associated with each building through an average of the values of all the pixels of the flood map that are located around the perimeter of the building, performing a buffering operation on the polygons of the buildings in order to contain the values of the water that surround them.

In order to be able to associate the damage to the buildings, a taxonomy parallel to that of the JRC curves was proposed, requesting as input the "Edificato" layer of the CTR (Carta Tecnica Regionale) of the Liguria Region.

The developed plugin and the different results obtained applying both water depth computational procedures have been tested through an application to a case study: the flooding of the Chiaravagna stream (Genoa) during the event of 4 October 2010.
It has therefore been demonstrated that for a better assessment of the damages, the second method for the evaluation of the building water depth is more suitable, in fact it allows the use of maps without the need for pre-processing- Moreover, taking into account the footprint of the buildings, it allows for a better assessment of the damages also avoiding overestimations.

The plugin is currently customized for using as input exposure layer the layer “Edificato” from Regione Liguria. Future developments can easily adapt the plugin to be used for various applications and using a wider range of input data.
It could also be useful to improve the procedure making it possible to compare the absolute height of the base of the building and the height of the water depth and take into account the presence of any protective walls.

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8. Annex

Algorithm 1st method

```
# -*- coding: utf-8 -*-

"""
/***************************************************************************
 Buildings_damages
                                 A QGIS plugin
 This plugin estimates the percentage and the economic damage from flooding for each residential, commercial, industrial and transport building in a given area of interest, through the use of guidelines and Joint Research Centre's vulnerability curves
 Generated by Plugin Builder: http://g-sherman.github.io/Qgis-Plugin-Builder/
                              -------------------
        begin                : 2022-12-09
        copyright            : (C) 2022 by Giulia Mazzaccaro - Università degli studi di Genova
        email                : giulia.mazzaccaro@gmail.com
 ***************************************************************************/

/***************************************************************************
 *                                                                         *
 *   This program is free software; you can redistribute it and/or modify  *
 *   it under the terms of the GNU General Public License as published by  *
 *   the Free Software Foundation; either version 2 of the License, or     *
 *   (at your option) any later version.                                   *
 *                                                                         *
 ***************************************************************************/
"""

__author__ = 'Giulia Mazzaccaro - Università degli studi di Genova'
__date__ = '2022-12-09'
__copyright__ = '(C) 2022 by Giulia Mazzaccaro - Università degli studi di Genova'

# This will get replaced with a git SHA1 when you do a git archive

__revision__ = '$Format:%H$'

"""
Model exported as python.
Name : Buildings_damages
Group : Buildings_damages
With QGIS : 32207
"""

from qgis.core import QgsProcessing
from qgis.core import QgsProcessingAlgorithm
from qgis.core import QgsProcessingMultiStepFeedback
from qgis.core import QgsProcessingParameterRasterLayer
from qgis.core import QgsProcessingParameterVectorLayer
from qgis.core import QgsProcessingParameterFeatureSink
import processing


class Buildings_damages(QgsProcessingAlgorithm):

    def initAlgorithm(self, config=None):
        self.addParameter(QgsProcessingParameterRasterLayer('rasterfloodingmap', 'Raster - flood map', defaultValue=None))
        self.addParameter(QgsProcessingParameterVectorLayer('vectorfilebuildings', 'Vector layer - Buildings', types=[QgsProcessing.TypeVectorPolygon], defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('Taxonomy', 'Taxonomy', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
```

```
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerDamagePercentageField', 'Vector layer - damage percentage field', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerAreaField', 'Vector layer - area field', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerEconomicLossesField', 'Vector layer - economic losses field', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerGeometriesFixed', 'Vector layer - geometries fixed', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerDepthField', 'Vector layer - depth field', type=QgsProcessing.TypeVectorPoint, createByDefault=True, defaultValue=None))

    def processAlgorithm(self, parameters, context, model_feedback):
        # Use a multi-step feedback, so that individual child algorithm progress reports are adjusted for the
        # overall progress through the model
        feedback = QgsProcessingMultiStepFeedback(7, model_feedback)
        results = {}
        outputs = {}

        # Fix geometries
        alg_params = {
            'INPUT': parameters['vectorfilebuildings'],
            'OUTPUT': parameters['VectorLayerGeometriesFixed']
        }
        outputs['FixGeometries'] = processing.run('native:fixgeometries', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerGeometriesFixed'] = outputs['FixGeometries']['OUTPUT']

        feedback.setCurrentStep(1)
        if feedback.isCanceled():
            return {}

        # Field calculator
        alg_params = {
            'FIELD_LENGTH': 10,
            'FIELD_NAME': 'Area',
            'FIELD_PRECISION': 3,
            'FIELD_TYPE': 0,  # Reale
            'FORMULA': ' $area',
            'INPUT': outputs['FixGeometries']['OUTPUT'],
            'OUTPUT': parameters['VectorLayerAreaField']
        }
        outputs['FieldCalculator'] = processing.run('native:fieldcalculator', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerAreaField'] = outputs['FieldCalculator']['OUTPUT']

        feedback.setCurrentStep(2)
        if feedback.isCanceled():
            return {}

        # Centroids
        alg_params = {
            'ALL_PARTS': False,
            'INPUT': outputs['FieldCalculator']['OUTPUT'],
            'OUTPUT': QgsProcessing.TEMPORARY_OUTPUT
        }
        outputs['Centroids'] = processing.run('native:centroids', alg_params, context=context, feedback=feedback, is_child_algorithm=True)

        feedback.setCurrentStep(3)
        if feedback.isCanceled():
            return {}
```

```
# Field calculator
alg_params = {
    'FIELD_LENGTH': 4,
    'FIELD_NAME': 'Building_typology',
    'FIELD_PRECISION': 0,
    'FIELD_TYPE': 1,  # Intero
    'FORMULA': 'CASE \r\nWHEN "def_cat_us" = \'Residenziale-Abitativa\' THEN 1\r\nWHEN "def_cat_us" =
\'Residenziale\' THEN 1\r\n\r\nWHEN "def_cat_us" = \'Amministrativo\' THEN 2\r\nWHEN "def_cat_us" =
\'Amministrativo-municipio\' THEN 2\r\nWHEN "def_cat_us" = \'Amministrativo-sede provincia\' THEN 2\r\nWHEN
"def_cat_us" = \'Amministrativo-sede regione\' THEN 2\r\nWHEN "def_cat_us" = \'Amministrativo-sede ambasciata\'
THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico- ASL - sede
generica\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-ASL - sede di servizio socio assistenziale\' THEN
2\r\nWHEN "def_cat_us" = \'Servizio pubblico-ASL - sede di ospedale\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio
pubblico-sede di clinica\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di poste-telegrafi\' THEN 2\r\nWHEN
"def_cat_us" = \'Servizio pubblico-sede di scuola, università, laboratorio di ricerca\' THEN 2\r\nWHEN "def_cat_us" =
\'Servizio pubblico-sede di tribunale\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di polizia\' THEN
2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di vigili del fuoco\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio
pubblico-casello forestale\' THEN 2\r\nWHEN "def_cat_us" = \'Militare\' THEN 2\r\nWHEN "def_cat_us" = \'Militare-
Caserma\' THEN 2\r\nWHEN "def_cat_us" = \'Militare-Prigione\' THEN 2\r\nWHEN "def_cat_us" = \'Luogo di culto\'
THEN 2\r\n\r\nWHEN "def_cat_us" = \'Servizi di trasporto\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto
aereo\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto aereo - Aerostazione\' THEN 4\r\nWHEN "def_cat_us" =
\'Servizi di trasporto aereo - Stazione eliporto\'THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale\' THEN
4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale - Stazione autolinee\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi
di trasporto stradale-parcheggio multipiano o coperto\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale-
casello autostradale\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale-stazione di rifornimento carburante
autostradale\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale-stazione di rifornimento carburante
stradale\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi
di trasporto ferroviario- stazione passeggeri ferrovia\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario-
deposito ferroviario per vagoni, rimessa locomotive\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario-
casello ferroviario\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario-fermata ferroviaria\' THEN
4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario-scalo merci\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di
trasporto-altri impianti\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri impianti-stazione marittima\' THEN
4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri impianti-stazione metropolitana\' THEN 4\r\nWHEN "def_cat_us"
= \'Servizi di trasporto-altri impianti-stazione funivia\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri
impianti-stazione cabinovia\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri impianti-stazione
seggiovia\'THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri impianti-stazione ski-lift\' THEN 4\r\nWHEN
"def_cat_us" = \'Servizi di trasporto-altri impianti-stazione funicolare\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di
trasporto-altri impianti-edificio marittimo\'THEN 4\r\n \r\nWHEN "def_cat_us" = \'Commerciale\' THEN 3\r\nWHEN
"def_cat_us" = \'Commerciale-sede di banca\' THEN 3\r\nWHEN "def_cat_us" = \'Commerciale-sede di centro
commerciale\' THEN 3\r\nWHEN "def_cat_us" = \'Commerciale-mercato\' THEN 3\r\nWHEN "def_cat_us" =
\'Commerciale-sede di supermercato, ipermercato\' THEN 3\r\nWHEN "def_cat_us" = \'Commerciale-sede di albergo,
locanda\' THEN 3\r\nWHEN "def_cat_us" = \'Commerciale-ostello della gioventù\' THEN 3\r\nWHEN "def_cat_us" =
\'Industriale\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-stabilimento industriale\' THEN 3\r\nWHEN "def_cat_us"
= \'Industriale-impianto di produzione energia\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto di produzione
energia-centrale elettrica\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto di produzione energia-centrale
termoelettrica\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto di produzione energia-centrale idroelettrica\'
THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto di produzione energia-centrale nucleare\' THEN 3\r\nWHEN
"def_cat_us" = \'Industriale-impianto di produzione energia-stazione/sottostazione elettrica\' THEN 3\r\nWHEN
"def_cat_us" = \'Industriale-impianto di produzione energia-stazione di trasformazione\' THEN 3\r\nWHEN "def_cat_us"
= \'Industriale-impianto di produzione energia-centrale eolica\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto
tecnologico\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-depuratore\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-
inceneritore\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-stazione di telecomunicazioni\' THEN 3\r\nWHEN
"def_cat_us" = \'Industriale-edificio di teleriscaldamento\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-edificio di area
ecologica\' THEN 3\r\nWHEN "def_cat_us" = \'Agricolturale\' THEN 3\r\nWHEN "def_cat_us" = \'Agricolturale-fattoria\'
THEN 3\r\nWHEN "def_cat_us" = \'Agricolturale-stalla\' THEN 3\r\nWHEN "def_cat_us" = \'Agricolturale-fienile\'
THEN 3\r\n\r\n\r\nWHEN "def_cat_us" = \'Ricreativo\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività
culturali\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività culturali-biblioteca\' THEN 2\r\nWHEN
"def_cat_us" = \'Ricreativo-sede di attività culturali-cinema\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di
attività culturali-teatro, auditorium\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività culturali-museo\'
THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività culturali-pinacoteca\' THEN 2\r\nWHEN "def_cat_us" =
\'Ricreativo-sede di attività sportive\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività sportive-piscina
coperta\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività sportive-palestra\' THEN 2\r\nWHEN
```

```
"def_cat_us" = \'Ricreativo-sede di attività sportive-palaghiaccio\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-altre attività\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-altre attività-campeggio\' THEN 2\r\n\r\nELSE 0\r\n\r\nEND ',
            'INPUT': outputs['Centroids']['OUTPUT'],
            'OUTPUT': parameters['Taxonomy']
        }
        outputs['FieldCalculator'] = processing.run('native:fieldcalculator', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['Taxonomy'] = outputs['FieldCalculator']['OUTPUT']

        feedback.setCurrentStep(4)
        if feedback.isCanceled():
            return {}

        # Field calculator
        alg_params = {
            'FIELD_LENGTH': 10,
            'FIELD_NAME': 'Max_ec_dam',
            'FIELD_PRECISION': 4,
            'FIELD_TYPE': 0,  # Reale
            'FORMULA': 'if( "Building_typology" = 1, ("Area"*739) ,if( "Building_typology" = 2, ("Area"*1028) ,if( "Building_typology" = 3, ("Area"*838) ,if( "Building_typology" = 4, ("Area"*21),0))))',
            'INPUT': outputs['FieldCalculator']['OUTPUT'],
            'OUTPUT': parameters['VectorLayerEconomicLossesField']
        }
        outputs['FieldCalculator'] = processing.run('native:fieldcalculator', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerEconomicLossesField'] = outputs['FieldCalculator']['OUTPUT']

        feedback.setCurrentStep(5)
        if feedback.isCanceled():
            return {}

        # Raster sampling
        alg_params = {
            'COLUMN_PREFIX': 'Depth',
            'INPUT': outputs['FieldCalculator']['OUTPUT'],
            'RASTERCOPY': parameters['rasterfloodingmap'],
            'OUTPUT': parameters['VectorLayerDepthField']
        }
        outputs['RasterSampling'] = processing.run('native:rastersampling', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerDepthField'] = outputs['RasterSampling']['OUTPUT']

        feedback.setCurrentStep(6)
        if feedback.isCanceled():
            return {}

        # Field Calculator
        alg_params = {
            'FIELD_LENGTH': 20,
            'FIELD_NAME': 'Perc_damage',
            'FIELD_PRECISION': 10,
            'FIELD_TYPE': 0,  # Reale
            'FORMULA': 'if( "Building_typology" = 1, ((0.0006* ("Depth1")^5)+(-0.0103* ("Depth1")^4)+( 0.0722*("Depth1")^3) +(-0.2528* ("Depth1")^2)+(0.5873* ("Depth1"))+ 0.0031) ,if( "Building_typology" = 2, ((-0.0004* ("Depth1")^5)+(0.0054* ("Depth1")^4)+(-0.0247*("Depth1")^3) +(0.0184* ("Depth1")^2)+(0.3051* ("Depth1"))-0.0013) ,if( "Building_typology" = 3, ((-0.0007* ("Depth1")^5)+(0.0097* ("Depth1")^4)+(-0.0431*("Depth1")^3) +(0.0537* ("Depth1")^2)+(0.255* ("Depth1"))+ 0.0033) ,if( "Building_typology" = 4, ((-0.0007* ("Depth1")^6)+(0.0125* ("Depth1")^5)+(-0.0833*("Depth1")^4) +(0.265* ("Depth1")^3)+(-0.4939* ("Depth1")^2)+(0.8364* ("Depth1"))-0.0012),0))))',
            'INPUT': outputs['RasterSampling']['OUTPUT'],
            'OUTPUT': parameters['VectorLayerDamagePercentageField']
        }
```

```
        outputs['FieldCalculator'] = processing.run('native:fieldcalculator', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerDamagePercentageField'] = outputs['FieldCalculator']['OUTPUT']
        return results

    def name(self):
        return 'Buildings_damages'

    def displayName(self):
        return 'Buildings_damages'

    def group(self):
        return 'Buildings_damages'

    def groupId(self):
        return 'Buildings_damages'

    def createInstance(self):
        return Buildings_damages()
```

Algorithm 2nd method

```
# -*- coding: utf-8 -*-

"""
/***************************************************************************
 Buildings_damages
                         A QGIS plugin
 This plugin estimates the percentage and the economic damage from flooding for each residential, commercial, industrial and transport building in a given area of interest, through the use of guidelines and Joint Research Centre's vulnerability curves.
 Generated by Plugin Builder: http://g-sherman.github.io/Qgis-Plugin-Builder/
                              -------------------
        begin                : 2022-12-09
        copyright            : (C) 2022 by Giulia Mazzaccaro - Università degli studi di Genova
        email                : giulia.mazzaccaro@gmail.com
 ***************************************************************************/

/***************************************************************************
 *                                                                         *
 *   This program is free software; you can redistribute it and/or modify  *
 *   it under the terms of the GNU General Public License as published by  *
 *   the Free Software Foundation; either version 2 of the License, or     *
 *   (at your option) any later version.                                   *
 *                                                                         *
 ***************************************************************************/
"""

__author__ = 'Giulia Mazzaccaro - Università degli studi di Genova'
__date__ = '2022-12-09'
__copyright__ = '(C) 2022 by Giulia Mazzaccaro - Università degli studi di Genova'

# This will get replaced with a git SHA1 when you do a git archive

__revision__ = '$Format:%H$'

from qgis.core import QgsProcessing
from qgis.core import QgsProcessingAlgorithm
from qgis.core import QgsProcessingMultiStepFeedback
from qgis.core import QgsProcessingParameterRasterLayer
from qgis.core import QgsProcessingParameterVectorLayer
from qgis.core import QgsProcessingParameterFeatureSink
import processing


class Buildings_damages(QgsProcessingAlgorithm):

    def initAlgorithm(self, config=None):
        self.addParameter(QgsProcessingParameterRasterLayer('rasterfloodingmap', 'Raster - flood map', defaultValue=None))
        self.addParameter(QgsProcessingParameterVectorLayer('vectorfilebuildings', 'Vector file - Buildings', types=[QgsProcessing.TypeVectorPolygon], defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerBuildingsBuffered', 'Vector layer - buildings buffered', type=QgsProcessing.TypeVectorPolygon, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('Taxonomy', 'Taxonomy', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerEconomicLossesField', 'Vector layer - economic losses field', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerDamagePercentageField', 'Vector layer - damage percentage field', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerAreaField', 'Vector layer - area field', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
```

```
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerGeometriesFixed', 'Vector layer - geometries fixed', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerBuildingLayerWithWaterDepthField', 'Vector layer - building layer with water depth field', optional=True, type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, defaultValue=None))
        self.addParameter(QgsProcessingParameterFeatureSink('VectorLayerBuildingsReprojected', 'Vector layer - Buildings - reprojected', type=QgsProcessing.TypeVectorAnyGeometry, createByDefault=True, supportsAppend=True, defaultValue=None))

    def processAlgorithm(self, parameters, context, model_feedback):
        # Use a multi-step feedback, so that individual child algorithm progress reports are adjusted for the
        # overall progress through the model
        feedback = QgsProcessingMultiStepFeedback(9, model_feedback)
        results = {}
        outputs = {}

        # Reproject layer
        alg_params = {
            'INPUT': parameters['vectorfilebuildings'],
            'OPERATION': '',
            'TARGET_CRS': 'ProjectCrs',
            'OUTPUT': parameters['VectorLayerBuildingsReprojected']
        }
        outputs['ReprojectLayer'] = processing.run('native:reprojectlayer', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerBuildingsReprojected'] = outputs['ReprojectLayer']['OUTPUT']

        feedback.setCurrentStep(1)
        if feedback.isCanceled():
            return {}

        # Fix geometries
        alg_params = {
            'INPUT': outputs['ReprojectLayer']['OUTPUT'],
            'OUTPUT': parameters['VectorLayerGeometriesFixed']
        }
        outputs['FixGeometries'] = processing.run('native:fixgeometries', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerGeometriesFixed'] = outputs['FixGeometries']['OUTPUT']

        feedback.setCurrentStep(2)
        if feedback.isCanceled():
            return {}

        # Buffer
        alg_params = {
            'DISSOLVE': False,
            'DISTANCE': 2,
            'END_CAP_STYLE': 2,  # Quadrato
            'INPUT': outputs['FixGeometries']['OUTPUT'],
            'JOIN_STYLE': 1,  # Seghettato
            'MITER_LIMIT': 2,
            'SEGMENTS': 5,
            'OUTPUT': parameters['VectorLayerBuildingsBuffered']
        }
        outputs['Buffer'] = processing.run('native:buffer', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerBuildingsBuffered'] = outputs['Buffer']['OUTPUT']

        feedback.setCurrentStep(3)
        if feedback.isCanceled():
            return {}
```

```
    # Zonal statistic
    alg_params = {
        'COLUMN_PREFIX': 'WaterDepth_',
        'INPUT': outputs['Buffer']['OUTPUT'],
        'INPUT_RASTER': parameters['rasterfloodingmap'],
        'RASTER_BAND': 1,
        'STATISTICS': [2],  # Media
        'OUTPUT': QgsProcessing.TEMPORARY_OUTPUT
    }
    outputs['ZonalStatistic'] = processing.run('native:zonalstatisticsfb', alg_params, context=context, feedback=feedback, is_child_algorithm=True)

    feedback.setCurrentStep(4)
    if feedback.isCanceled():
        return {}

    # Join Attributes Table
    alg_params = {
        'DISCARD_NONMATCHING': False,
        'FIELD': 'id',
        'FIELDS_TO_COPY': ['WaterDepth_mean'],
        'FIELD_2': 'id',
        'INPUT': outputs['FixGeometries']['OUTPUT'],
        'INPUT_2': outputs['ZonalStatistic']['OUTPUT'],
        'METHOD': 1,  # Prendi solamente gli attributi del primo elemento corrispondente (uno a uno)
        'PREFIX': '',
        'OUTPUT': parameters['VectorLayerBuildingLayerWithWaterDepthField']
    }
    outputs['JoinAttributesTable'] = processing.run('native:joinattributestable', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
    results['VectorLayerBuildingLayerWithWaterDepthField'] = outputs['JoinAttributesTable']['OUTPUT']

    feedback.setCurrentStep(5)
    if feedback.isCanceled():
        return {}

    # Field calculator
    alg_params = {
        'FIELD_LENGTH': 1,
        'FIELD_NAME': 'Building_typology',
        'FIELD_PRECISION': 0,
        'FIELD_TYPE': 0,  # Reale
        'FORMULA': 'CASE \r\nWHEN "def_cat_us" = \'Residenziale-Abitativa\' THEN 1\r\nWHEN "def_cat_us" = \'Residenziale\' THEN 1\r\n\r\nWHEN "def_cat_us" = \'Amministrativo\' THEN 2\r\nWHEN "def_cat_us" = \'Amministrativo-municipio\' THEN 2\r\nWHEN "def_cat_us" = \'Amministrativo-sede provincia\' THEN 2\r\nWHEN "def_cat_us" = \'Amministrativo-sede regione\' THEN 2\r\nWHEN "def_cat_us" = \'Amministrativo-sede ambasciata\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico- ASL - sede generica\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-ASL - sede di servizio socio assistenziale\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-ASL - sede di ospedale\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di clinica\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di poste-telegrafi\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di scuola, università, laboratorio di ricerca\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di tribunale\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di polizia\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-sede di vigili del fuoco\' THEN 2\r\nWHEN "def_cat_us" = \'Servizio pubblico-casello forestale\' THEN 2\r\nWHEN "def_cat_us" = \'Militare\' THEN 2\r\nWHEN "def_cat_us" = \'Militare-Caserma\' THEN 2\r\nWHEN "def_cat_us" = \'Militare-Prigione\' THEN 2\r\nWHEN "def_cat_us" = \'Luogo di culto\' THEN 2\r\n\r\nWHEN "def_cat_us" = \'Servizi di trasporto\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto aereo\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto aereo - Aerostazione\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto aereo - Stazione eliporto\'THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale - Stazione autolinee\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale-parcheggio multipiano o coperto\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale-casello autostradale\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale-stazione di rifornimento carburante autostradale\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto stradale-stazione di rifornimento carburante stradale\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario- stazione passeggeri ferrovia\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario-
```

```
deposito ferroviario per vagoni, rimessa locomotive\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario-
casello ferroviario\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario-fermata ferroviaria\' THEN
4\r\nWHEN "def_cat_us" = \'Servizi di trasporto ferroviario-scalo merci\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di
trasporto-altri impianti\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri impianti-stazione marittima\' THEN
4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri impianti-stazione metropolitana\' THEN 4\r\nWHEN "def_cat_us"
= \'Servizi di trasporto-altri impianti-stazione funivia\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri
impianti-stazione cabinovia\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri impianti-stazione
seggiovia\'THEN 4\r\nWHEN "def_cat_us" = \'Servizi di trasporto-altri impianti-stazione ski-lift\' THEN 4\r\nWHEN
"def_cat_us" = \'Servizi di trasporto-altri impianti-stazione funicolare\' THEN 4\r\nWHEN "def_cat_us" = \'Servizi di
trasporto-altri impianti-edificio marittimo\'THEN 4\r\n \r\nWHEN "def_cat_us" = \'Commerciale\' THEN 3\r\nWHEN
"def_cat_us" = \'Commerciale-sede di banca\' THEN 3\r\nWHEN "def_cat_us" = \'Commerciale-sede di centro
commerciale\' THEN 3\r\nWHEN "def_cat_us" = \'Commerciale-mercato\' THEN 3\r\nWHEN "def_cat_us" =
\'Commerciale-sede di supermercato, ipermercato\' THEN 3\r\nWHEN "def_cat_us" = \'Commerciale-sede di albergo,
locanda\' THEN 3\r\nWHEN "def_cat_us" = \'Commerciale-ostello della gioventù\' THEN 3\r\nWHEN "def_cat_us" =
\'Industriale\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-stabilimento industriale\' THEN 3\r\nWHEN "def_cat_us"
= \'Industriale-impianto di produzione energia\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto di produzione
energia-centrale elettrica\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto di produzione energia-centrale
termoelettrica\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto di produzione energia-centrale idroelettrica\'
THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto di produzione energia-centrale nucleare\' THEN 3\r\nWHEN
"def_cat_us" = \'Industriale-impianto di produzione energia-stazione/sottostazione elettrica\' THEN 3\r\nWHEN
"def_cat_us" = \'Industriale-impianto di produzione energia-stazione di trasformazione\' THEN 3\r\nWHEN "def_cat_us"
= \'Industriale-impianto di produzione energia-centrale eolica\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-impianto
tecnologico\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-depuratore\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-
inceneritore\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-stazione di telecomunicazioni\' THEN 3\r\nWHEN
"def_cat_us" = \'Industriale-edificio di teleriscaldamento\' THEN 3\r\nWHEN "def_cat_us" = \'Industriale-edificio di area
ecologica\' THEN 3\r\nWHEN "def_cat_us" = \'Agricolturale\' THEN 3\r\nWHEN "def_cat_us" = \'Agricolturale-fattoria\'
THEN 3\r\nWHEN "def_cat_us" = \'Agricolturale-stalla\' THEN 3\r\nWHEN "def_cat_us" = \'Agricolturale-fienile\'
THEN 3\r\n\r\n\r\nWHEN "def_cat_us" = \'Ricreativo\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività
culturali\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività culturali-biblioteca\' THEN 2\r\nWHEN
"def_cat_us" = \'Ricreativo-sede di attività culturali-cinema\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di
attività culturali-teatro, auditorium\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività culturali-museo\'
THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività culturali-pinacoteca\' THEN 2\r\nWHEN "def_cat_us" =
\'Ricreativo-sede di attività sportive\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività sportive-piscina
coperta\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-sede di attività sportive-palestra\' THEN 2\r\nWHEN
"def_cat_us" = \'Ricreativo-sede di attività sportive-palaghiaccio\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-altre
attività\' THEN 2\r\nWHEN "def_cat_us" = \'Ricreativo-altre attività-campeggio\' THEN 2\r\n\r\nELSE 0\r\n\r\nEND ',
        'INPUT': outputs['JoinAttributesTable']['OUTPUT'],
        'OUTPUT': parameters['Taxonomy']
    }
    outputs['FieldCalculator'] = processing.run('native:fieldcalculator', alg_params, context=context,
feedback=feedback, is_child_algorithm=True)
    results['Taxonomy'] = outputs['FieldCalculator']['OUTPUT']

    feedback.setCurrentStep(6)
    if feedback.isCanceled():
        return {}

    # Field Calculator
    alg_params = {
        'FIELD_LENGTH': 20,
        'FIELD_NAME': 'Area',
        'FIELD_PRECISION': 3,
        'FIELD_TYPE': 0,  # Reale
        'FORMULA': ' $area',
        'INPUT': outputs['FieldCalculator']['OUTPUT'],
        'OUTPUT': parameters['VectorLayerAreaField']
    }
    outputs['FieldCalculator'] = processing.run('native:fieldcalculator', alg_params, context=context,
feedback=feedback, is_child_algorithm=True)
    results['VectorLayerAreaField'] = outputs['FieldCalculator']['OUTPUT']

    feedback.setCurrentStep(7)
    if feedback.isCanceled():
        return {}
```

```
        # Field calculator
        alg_params = {
            'FIELD_LENGTH': 10,
            'FIELD_NAME': 'Max_ec_dam',
            'FIELD_PRECISION': 4,
            'FIELD_TYPE': 0,  # Reale
            'FORMULA': 'if( "Building_typology" = 1, ("Area"*739) ,if( "Building_typology" = 2, ("Area"*1028) ,if( "Building_typology" = 3, ("Area"*838) ,if( "Building_typology" = 4, ("Area"*21),0))))',
            'INPUT': outputs['FieldCalculator']['OUTPUT'],
            'OUTPUT': parameters['VectorLayerEconomicLossesField']
        }
        outputs['FieldCalculator'] = processing.run('native:fieldcalculator', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerEconomicLossesField'] = outputs['FieldCalculator']['OUTPUT']

        feedback.setCurrentStep(8)
        if feedback.isCanceled():
            return {}

        # Field calculator
        alg_params = {
            'FIELD_LENGTH': 4,
            'FIELD_NAME': 'Perc_damage',
            'FIELD_PRECISION': 3,
            'FIELD_TYPE': 0,  # Reale
            'FORMULA': 'if( "Building_typology" = 1, ((0.0006* ("WaterDepth_mean")^5)+(-0.0103* ("WaterDepth_mean")^4)+( 0.0722*("WaterDepth_mean")^3) +(-0.2528* ("WaterDepth_mean")^2)+(0.5873* ("WaterDepth_mean"))+ 0.0031) ,if( "Building_typology" = 2, ((-0.0004* ("WaterDepth_mean")^5)+(0.0054* ("WaterDepth_mean")^4)+(-0.0247*("WaterDepth_mean")^3) +(0.0184* ("WaterDepth_mean")^2)+(0.3051* ("WaterDepth_mean"))- 0.0013) ,if( "Building_typology" = 3, ((-0.0007* ("WaterDepth_mean")^5)+(0.0097* ("WaterDepth_mean")^4)+(-0.0431*("WaterDepth_mean")^3) +(0.0537* ("WaterDepth_mean")^2)+(0.255* ("WaterDepth_mean"))+ 0.0033) ,if( "Building_typology" = 4, ((-0.0007* ("WaterDepth_mean")^6)+(0.0125* ("WaterDepth_mean")^5)+(-0.0833*("WaterDepth_mean")^4) +(0.265* ("WaterDepth_mean")^3)+(-0.4939* ("WaterDepth_mean")^2)+(0.8364* ("WaterDepth_mean"))-0.0012),0))))\r\n',
            'INPUT': outputs['FieldCalculator']['OUTPUT'],
            'OUTPUT': parameters['VectorLayerDamagePercentageField']
        }
        outputs['FieldCalculator'] = processing.run('native:fieldcalculator', alg_params, context=context, feedback=feedback, is_child_algorithm=True)
        results['VectorLayerDamagePercentageField'] = outputs['FieldCalculator']['OUTPUT']
        return results

    def name(self):
        return 'Buildings_damages'

    def displayName(self):
        return 'Buildings_damages'

    def group(self):
        return 'Buildings_damages'

    def groupId(self):
        return 'Buildings_damages'

    def createInstance(self):
        return Buildings_damages()
```