Indexes of exposure combined flood seismic risk exposure for IT pilot site

Final Version

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Table of content

1.Introduction

Many areas worldwide and in Europe are subject to catastrophic events, the number of which has increased significantly in the last two decades; this highlighted not only a greater exposure of these territories to multi-risk events but also a greater vulnerability of societies to more complex risks.

The main culprits of these multi-risk dynamics are globalization and climate change.

Globalization means that the countries of the world are closely linked and interdependent, making communities not only vulnerable to extreme events that occur in their countries but also to those that occur outside their national territories (through markets, economies , investments, etc.); climate change determines, among others, an increase in the frequency and intensity of extreme meteorological phenomena, an increase in the hydrological and flood risk as well as an increase in the risk of fires.

The awareness of this worrying trend has determined the need for adequate supports, tools and methodologies to address these problems. [1]

The choice to adopt a multi-risk analysis approach has the potential to play a fundamental role in increasing urban resilience, an essential factor for sustainable development, enabling cities to prepare, respond and recover when hit by catastrophic events, and therefore prevent or contain economic, environmental and social losses. [2]

However, performing a multi-risk analysis with the tools and methodologies available today raises numerous challenges and difficulties.

They are mainly linked to the fact that the risk assessment is carried out through independent procedures that adopt different estimation metrics (making comparison difficult) without taking into account any correlations or cascading effects.

Therefore, it is still not very clear how to integrate the various threats into a multi-risk framework.

The objective of this work was to develop and apply a methodology for the assessment of the combined seismic-hydraulic risk of the Ferrara area which, through a study of the characteristics of the territory, and therefore of the various dangers to which it is subject, would allow to highlight the areas more vulnerable.

2. The multirisk concept

In order to understand the concept of multi-risk assessment, it is first necessary to define the concept of risk.

UNISDR defines risk as: "the combination of the probability of an event and its negative consequences". [3]

In other words, the risk is a function of three parameters: hazard, vulnerability and exposure.

The hazard represents the probability that an adverse event will occur in a specific area and in a specific time interval; vulnerability, on the other hand, is an intrinsic characteristic of a system, it represents its propensity or predisposition to suffer a certain level of damage following the occurrence of an hazard event, finally, exposure indicates the presence of "people, property, systems and much more still in hazard zones that are thereby subject to potential losses ". [3,4]

In synthetic form:

$$R = P \times V \times E \tag{1}$$

The product of the last two factors, vulnerability and exposure, represents the potential damage; it indicates the overall damage resulting from the occurrence of a hazard.

The concept of multi-risk follows, as the overall risk within a multi-hazard and multi-vulnerability perspective; the first term indicates several hazards affecting the same exposed elements (with or without space-time coincidence) or the occurrence of a hazard event that triggers another one giving rise to a domino or cascade effect, while with the term multi-vulnerability we it can refer to several sensitive elements exposed having possible different vulnerabilities towards the various hazards affecting them or vulnerabilities that vary over time. [4]

3. Aim and scope

The purpose of this project was to jointly analyse the seismic and hydraulic risks of the Ferrara province territory.

Ferrara province territory is located at the north-eastern extremity of the Pianura Padana (a flatland area in the north part of Italy), and it is bathed by the Adriatic Sea on the east side.

It is also characterised by minimum land slopes and its altimetry is mainly under the sea mean level: in specific, more than 40% of the territory is under the mean sea level (as showed in figure 1).

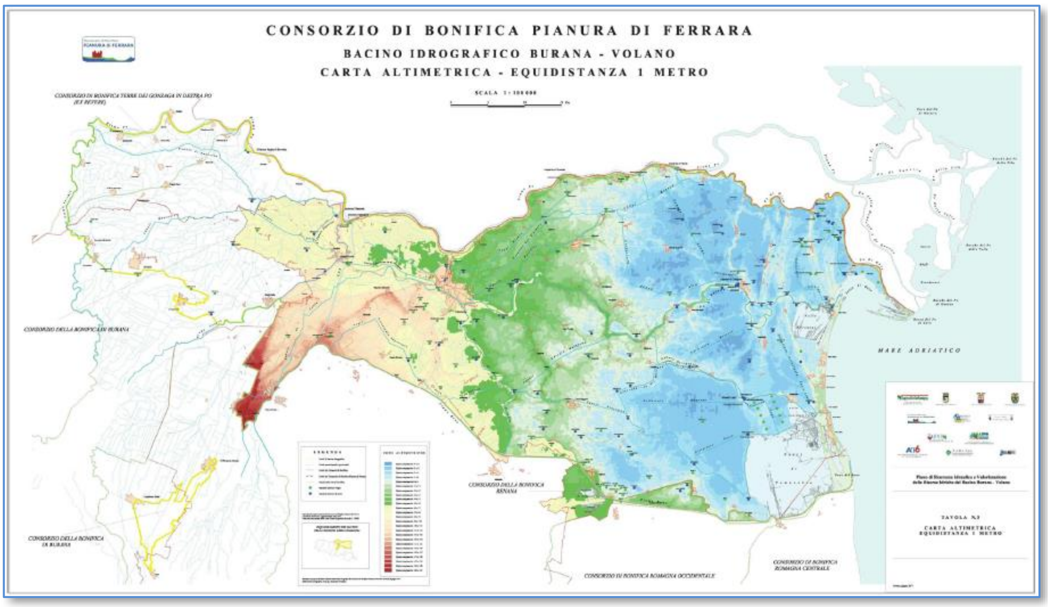

Figure 1. Ferrara territory altimetry [5].

Moreover, the eastern part of the territory is affected by ground lowering phenomena as well.

These soil modifications, caused mainly by anthropic and artificial actions, produced lowering until 2.5 m depth.

The following 23 municipalities belongs to the Ferrara province: Argenta, Berra, Bondeno, Cento, Codigoro, Comacchio, Copparo, Ferrara, Fiscaglia, Formignana, Goro, Jolanda di Savoia, Lagosanto, Masi Torello, Mesola, Mirabello, Ostellato, Poggio Renatico, Portomaggiore, Ro, Sant'Agostino, Tresigallo, Vigarano Mainarda e Voghiera.

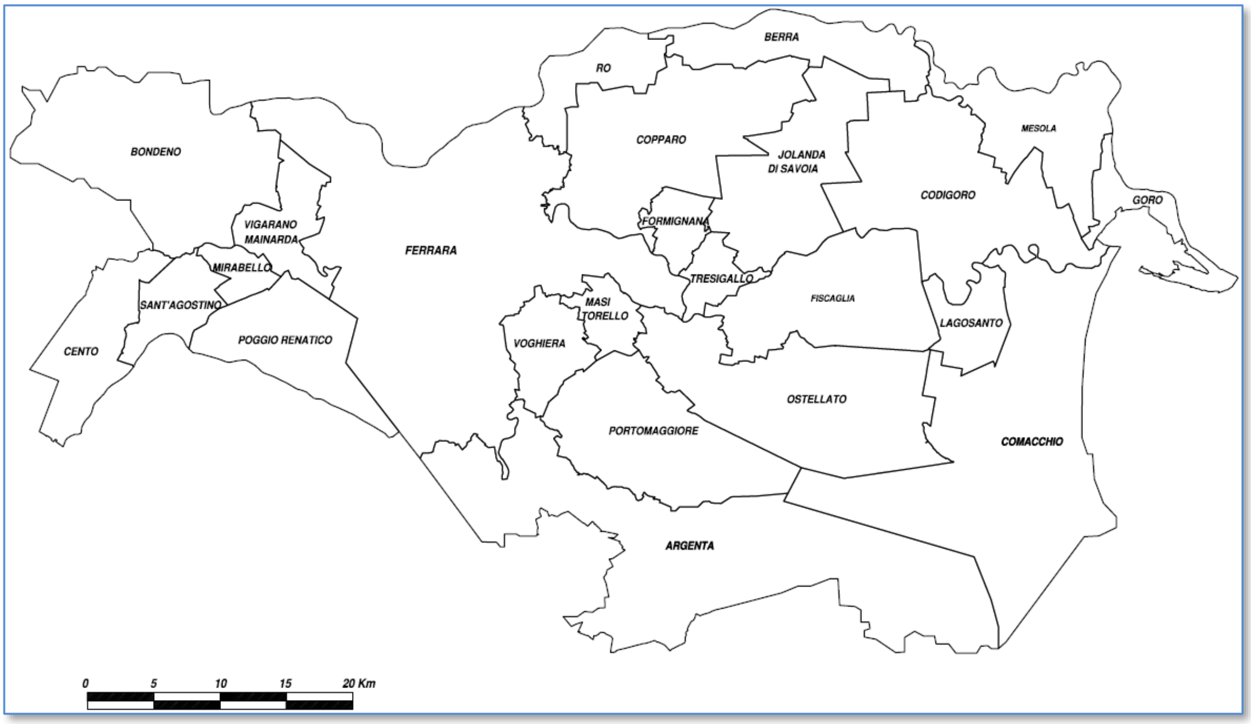

Figure 2. Municipalities that belong to the Ferrara Province.

The main water course that flow through Ferrara province is the river Po, it marks the border with the Rovigo Province, and, in the Ferrara territory, it is divided into Po of Volano, Po of Primaro and Po of Goro.

There is also Reno river, that set the southern border from Cento municipality untill Argenta municipality with some interruptions; and in the end it flows south into Lido di Spina, in the Province of Ravenna.

The Idice and Sillaro streams cross the province only in their last stretch, flowing respectively into the Campotto and Valle Santa valleys.

To the west, the Panaro river, the last tributary of the Po, crosses the municipality of Bondeno.

Furthermore, numerous artificial canals flow through the Ferrara Province, including the Cavo Napoleonico which connects the Po and Reno, and the Idrovia Ferrarese. [5]

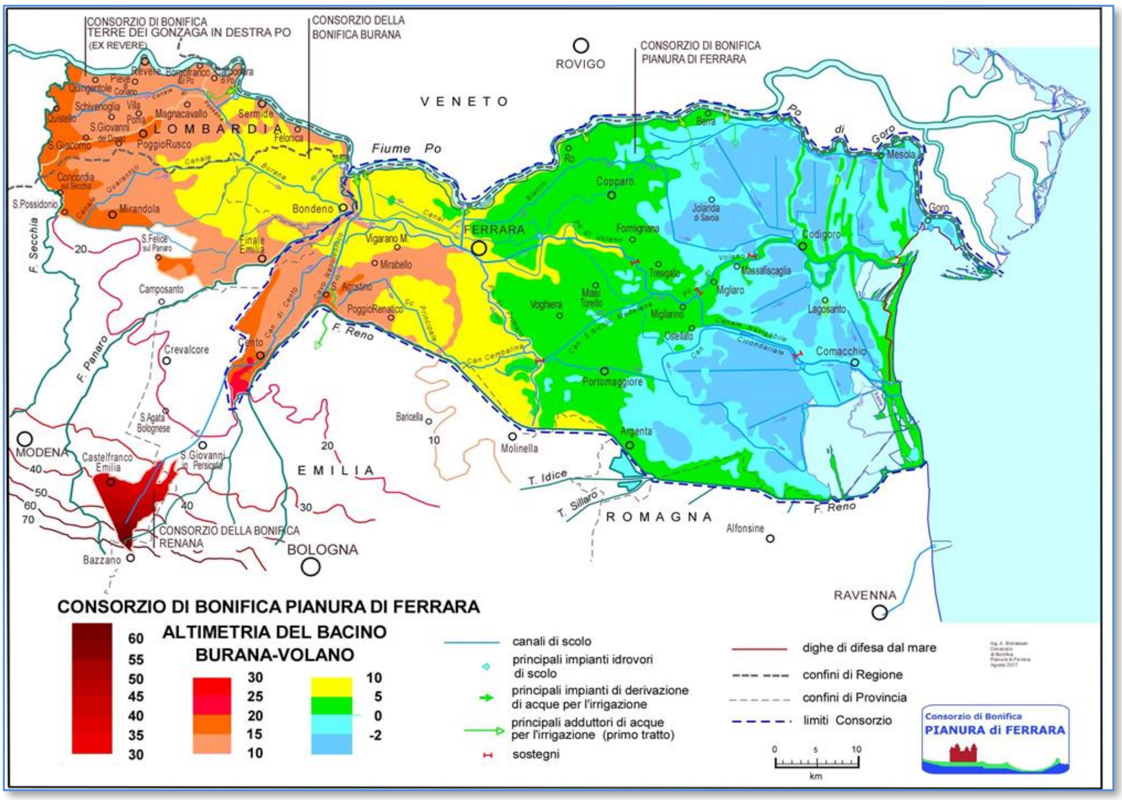

Figure 3. Peculiarity of the Ferrara territory [5].

The hydraulic and seismic characterization of the territory will be illustrated in the following sections (3.1 and 3.2).

3.1 Hydraulic risk

The hydraulic risk is estimated, from an analytical point of view, using the discrete following equation:

$$R = P \times V \times E \qquad (2)$$

Where R stands for the risk, P is the probability of occurrence of the flood with assigned intensity within a specific area and specific time interval, V is the vulnerability of the site, intended as its capacity to cope with the flood event, and E represents the exposed elements, namely people/goods/activities exposed to the flood within the specific site and the time interval.

The probability of occurrence of the flood, P, is evaluated concerning the different typologies of watercourses that flows thru the territory; in particular, within the eastern part of the flatland Pianura Padana, where Ferrara Province is located, there are identify two main types of waterstypes:

- Primary watercourses network (in Italian "Reticolo primario") consisting of the biggest watercourses whose flow-rates are not mechanically regulated, so the motion is given just by the favourable altimetry, i.e. the gravity. This network contains the Po River and its main tributaries.
- Secondary watercourses network (in Italian "Reticolo secondario"), it consists of the network of the land reclamation system managed by authorities such as Consorzio di Bonifica Pianura di Ferrara. This network comprises channels, water-lifting plants and other hydraulic objects always operating for the regulation of water heights within the network.

Between this two, it is more likely a flood occurrence due to the failure of the Secondary watercourses network.

This because the functioning of this network is based on several hydraulic infrastructures, such as weirs, syphons, hydraulic intake and drop intake systems, detention basins, floodgates and several water-lifting plans.

If only one of these latter do not work for any reason, the system would fail, affecting city centres and relevant infrastructures. [5]

3.2 Seismic Risk

Similarly to the hydraulic risk, the seismic risk is defined, synthetically, through the following expression:

$$R = P \times V \times E \qquad (3)$$

Where P represent the seismic hazard of the area, V the seismic vulnerability, and E stands for the exposure of the area.

Seismic hazard, P is defined as the probability that an earthquake that exceeds a given intensity threshold will occur in a given area and in a given period of time.

P depends on the seismicity of the area (which is a physical characteristic of the territory) i.e. on the strength (magnitude) and frequency of the earthquakes that have affected this area over time.

The seismic vulnerability, V, represents the predisposition of the system to be damaged following the occurrence of a seismic event of a given intensity.

Lastly, exposure E includes everything that can be negatively affected following the occurrence of a seismic event, i.e. people, buildings, infrastructures, economic, social, cultural and environmental assets, etc.

It follows that a densely populated area or with very old buildings (i.e. with very little safety against seismic actions) and characterized by low seismic hazard will have a high seismic risk; on the contrary, a sparsely populated area, devoid of commercial, economic, social activities but with a high seismic hazard will have a zero seismic risk.

The National Institute of Geophysics and Volcanology (INGV) provides a seismic hazard map of the national territory where the latter is divided into different areas according to the pick ground acceleration. [6]

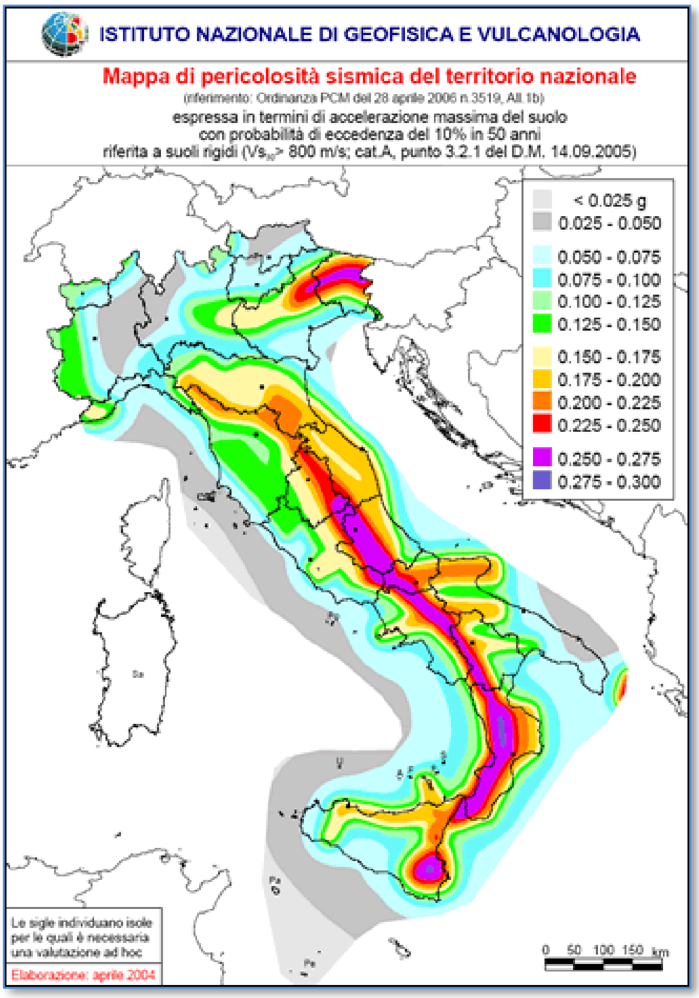

Figure 4. Seismic Hazard Map of Italy [9].

This map was created based on information such as: intensity and frequency data of historical earthquakes and geomorphological and stratigraphic soil characteristics.

Specifically, 4 seismic zones are identified, each characterized by a range of horizontal peak acceleration values on the ground, ag, with a probability of exceeding equal to 10% in 50 years.

Zone 1	It the most dangerous area, where major earthquakes may occur.
Zone 2	Municipalities in this area may be affected by quite strong earthquakes.
Zone 3	Municipalities in this area may be subject to modest shocks.
Zone 4	It is the least dangerous. Municipalities of this area have a low probability of seismic damages.

Seismic zone	***Acceleration with probability of exceeding equal to 10% in 50 years (ag)***
1	ag >0,25
2	0,15 <ag≤ 0,25
3	0,05 <ag≤ 0,15
4	ag ≤ 0,05

The entire Ferrara Province territory is classified in seismic zone 3, except for the Argenta municipality that lies in seismic zone 2.

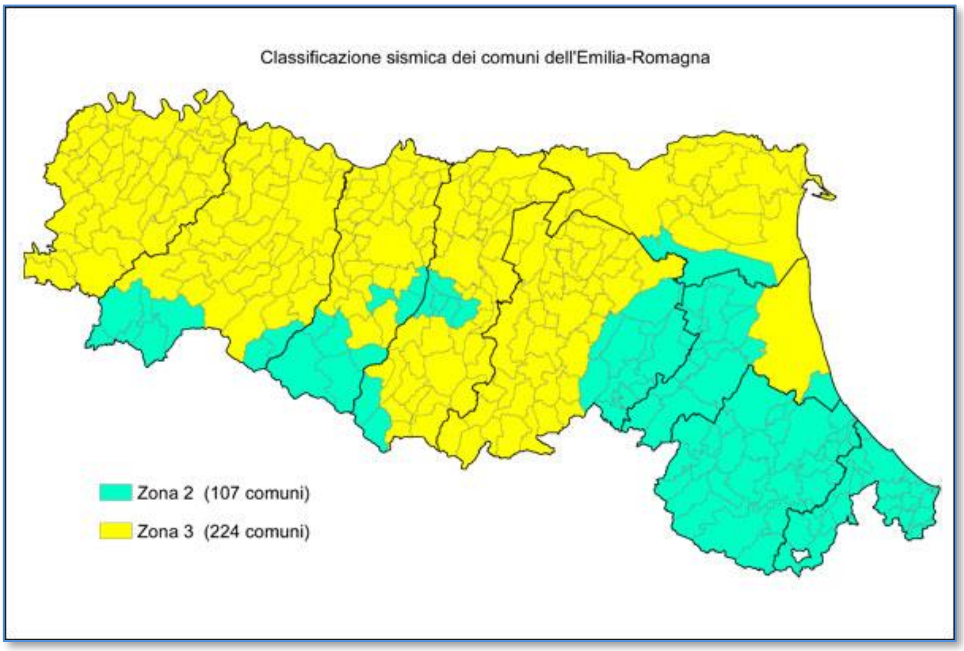

Figure 5. Seismic classification of the Emilia-Romagna municipalities [10].

4 Results

4.1 Usual

The software returns the ordering of the municipalities in the province of Ferrara, from the one most sensitive to hydraulic-seismic risk to the one that is least affected.

Basically, what is provided to the analyst is an order of priority.

The table below (figure 22) shows the final ranking of the alternatives.

Rang	***Alternatives***	***Phi***	***Phi+***	***Phi-***
1	Ferrara	0,6111	0,7302	0,119
2	Cento	0,5873	0,7222	0,1349
3	Tresigallo	0,4127	0,6111	0,1984
4	Vigarano Mainarda	0,2857	0,5873	0,3016

5	Mirabello+ Sant'Agostino	0,2698	0,5794	0,3095
6	Argenta+ Portomaggiore	0,2381	0,5238	0,2857
7	Bondeno	0,1825	0,4921	0,3095
8	Copparo	0,0238	0,4127	0,3889
9	Poggio Renatico	0,0238	0,4524	0,4286
10	Comacchio	0,0000	0,4048	0,4048
10	Formignana	0,0000	0,381	0,381
12	Voghiera	-0,0238	0,3651	0,3889
13	Lagosanto	-0,0317	0,3889	0,4206
14	Berra	-0,1587	0,3016	0,4603
15	Masi Torello	-0,1746	0,2937	0,4683
16	Ro	-0,1905	0,2857	0,4762
17	Fiscaglia	-0,2063	0,2778	0,4841
18	Mesola	-0,2857	0,2381	0,5238
19	Ostellato	-0,3571	0,1984	0,5556
20	Goro	-0,3651	0,1984	0,5635
21	Codigoro	-0,3651	0,2222	0,5873
22	Jolanda di Savoia	-0,4762	0,1429	0,619

Figure 22. Alternatives ranking.

This is not the only way to view the results, the Promethee Rainbow, figure 23, allows to highlight for each alternative the criteria that positively or negatively affect the final result.

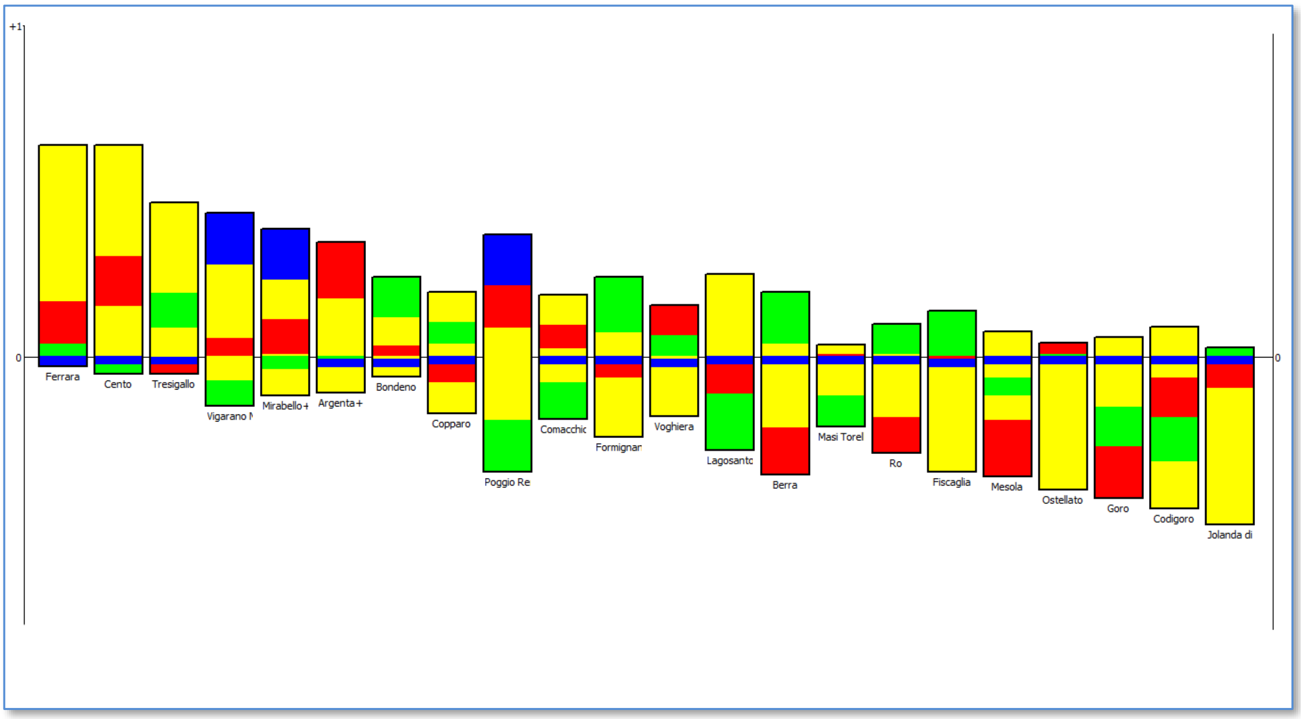

Figure 23. Promethee Rainbow.

The colours are representative of the criterion: yellow indicates the criteria relating to the exposure factor, red the seismic hazard, green the vulnerability, and blue the hydraulic hazard.

For example, for the municipality of Ferrara (first in the ranking) it can be observed that the criterion that has a negative effect is the one related to the hydraulic hazard while all the others have a positive effect; on the contrary, as regards the municipality of Jolanda di Savoia (last in the ranking), the only criterion that has a positive influence is the one related to vulnerability while all the others have a negative influence.

Returning to the orderings, in figure 24, we can observe the Promethee II Complete Ranking in which the alternatives are ordered in relation to the value of their net flow φ.

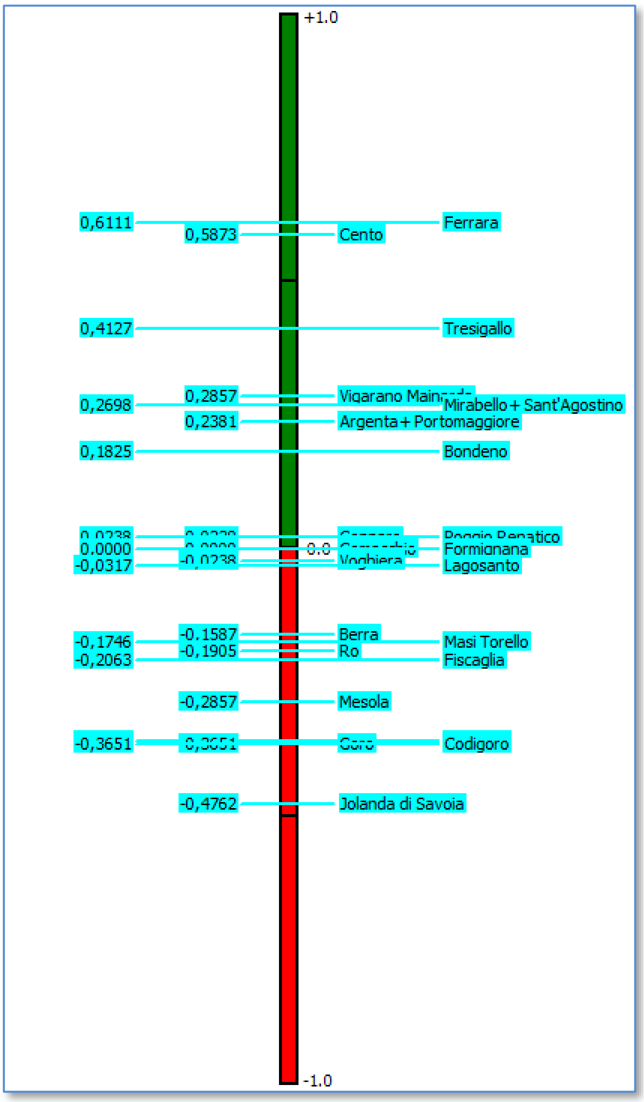

Figure 24. Promethee II Complete Ranking.

On the basis of the ranking offered by Promethee it was possible to create a risk map of the municipalities of the province of Ferrara that was able to highlight the high priority areas, i.e. those with a high level of risk, the areas characterized by a medium risk level and finally low risk areas.

This map is shown in figure 25, in it it can be seen that the three risk levels are identified by three 3 different colours: starting from red (high risk) to finally get to yellow (low risk), passing through orange (medium risk).

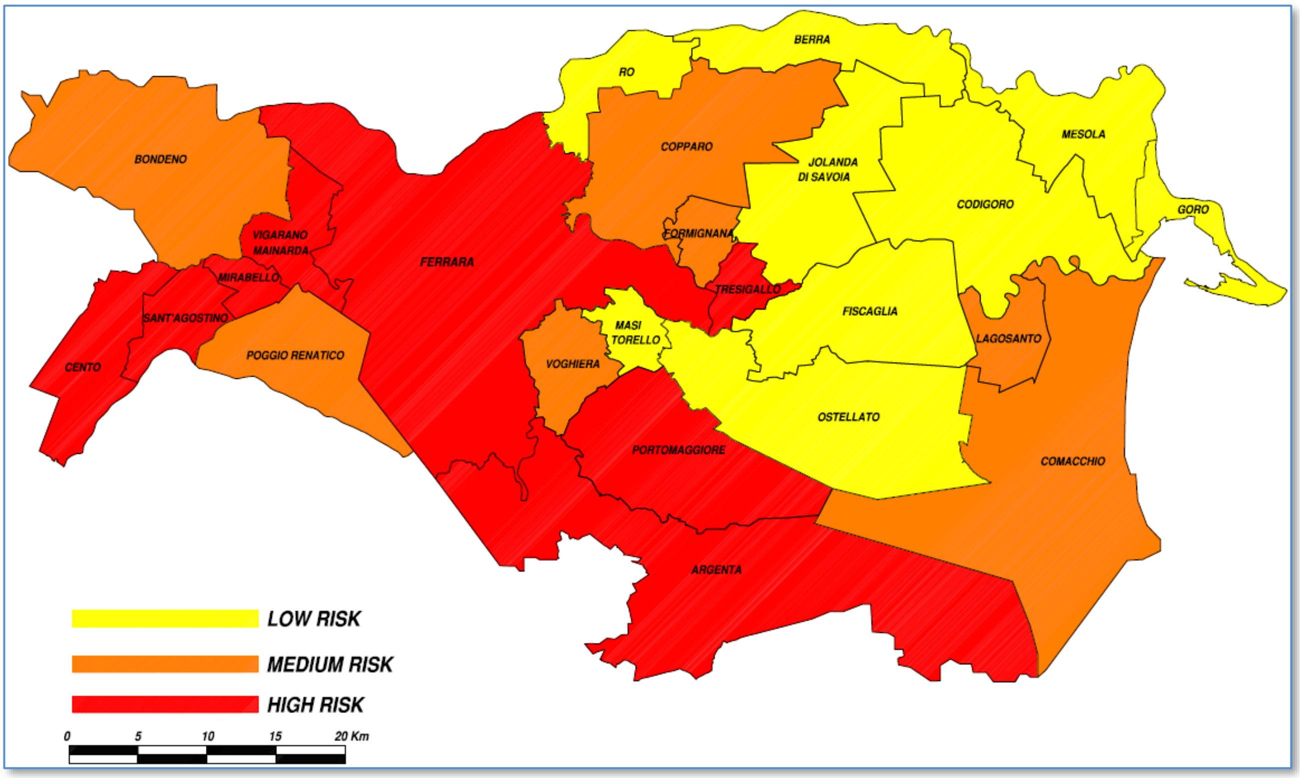

Figure 25. Multirisk map of the Ferrara province.

4.2 Sensitivity of the preference function

The results obtained when for the "quantitative" criteria, i.e. hydraulic hazard, land use, age of buildings and population density, is chosen linear function as the preference function with the thresholds Q and P determined with the 'Zero-max method 'are shown in the figures below.

Rang	***Alternatives***	***Phi***	***Phi+***	***Phi-***
1	Cento	0,459	0,5086	0,0496
2	Ferrara	0,3545	0,393	0,0385
3	Tresigallo	0,1821	0,2642	0,0821

4	Mirabello+ Sant'Agostino	0,1444	0,2622	0,1179
5	Argenta+ Portomaggiore	0,1352	0,2182	0,0829
6	Bondeno	0,1257	0,2069	0,0812
7	Vigarano Mainarda	0,112	0,255	0,143
8	Copparo	0,0505	0,1684	0,1179
9	Poggio Renatico	0,031	0,2216	0,1906
10	Comacchio	0,0224	0,1631	0,1406
10	Voghiera	-0,0422	0,0984	0,1406
12	Formignana	-0,0721	0,0937	0,1657
13	Fiscaglia	-0,0761	0,0868	0,1628
14	Lagosanto	-0,0898	0,1385	0,2283
15	Codigoro	-0,101	0,1155	0,2164
16	Ostellato	-0,1092	0,0736	0,1828
17	Ro	-0,1362	0,0589	0,195
18	Masi Torello	-0,1371	0,0557	0,1928
19	Berra	-0,1551	0,0688	0,2239
20	Jolanda di Savoia	-0,1947	0,0408	0,2355
21	Mesola	-0,2203	0,0353	0,2556
22	Goro	-0,283	0,0137	0,2968

Figure 26. Ranking of the alternatives Linear "Zero-max".

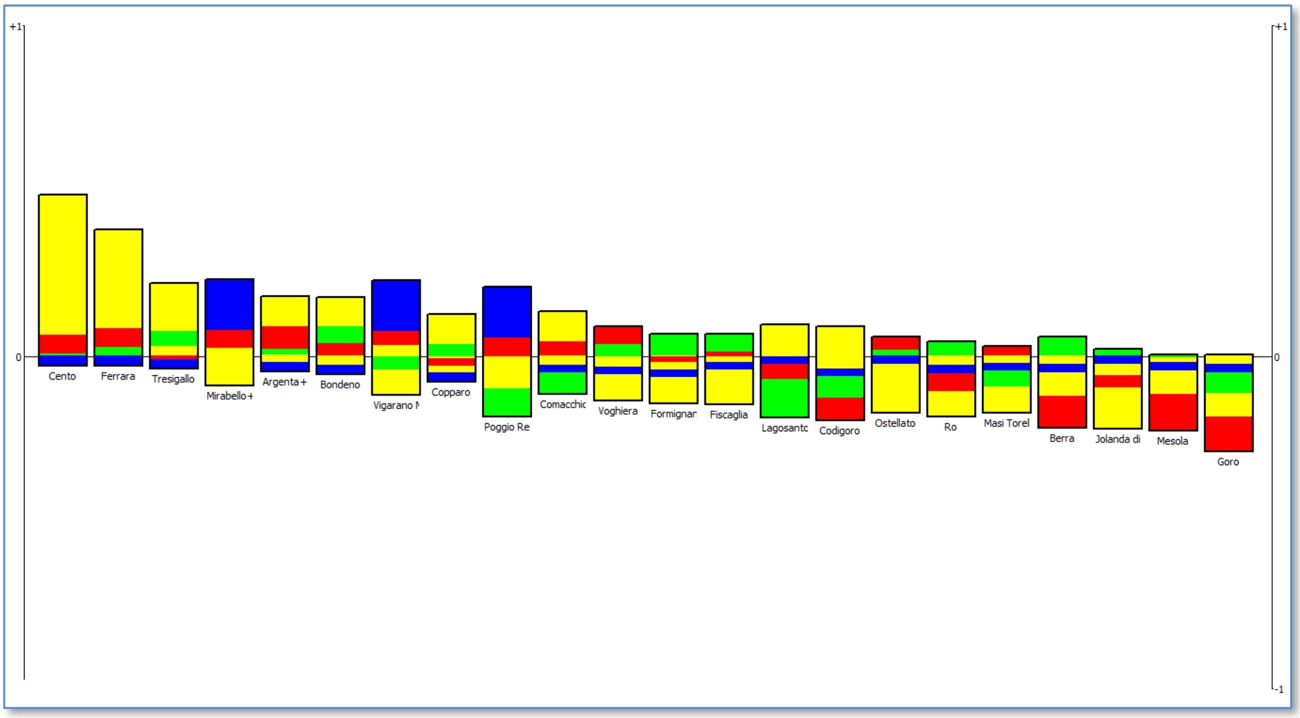

Figure 27. Promethee Rainbow Linear "Zero-max".

Observing the Promethee Rainbow it is clear that, in this case, the municipality of Cento is in the first position of the order, whose only criterion that negatively affects is the one related to the hydraulic hazard while at the last position there is the municipality of Goro for the which virtually all criteria affect negatively.

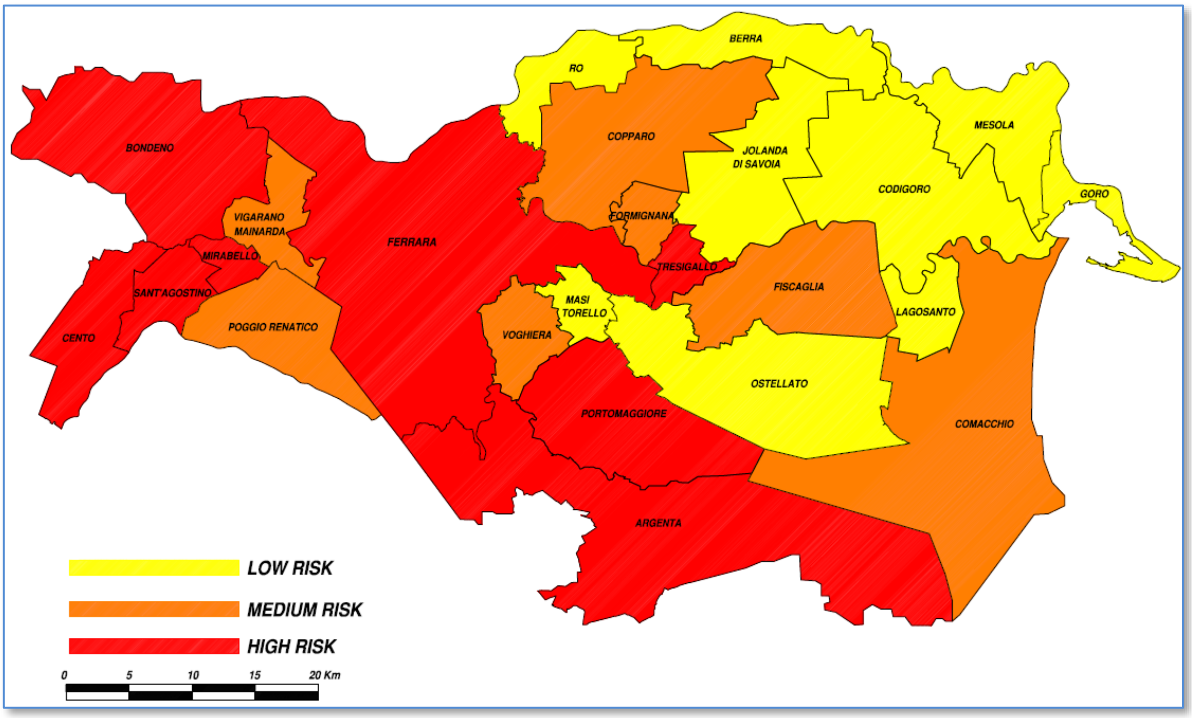

Figure 28. Multirisk map of the Ferrara province (modelling Linear "Zero-max").

When the preference function of the quantitative criteria is linear with the preference and indifference thresholds determined following the 'Mean-std' method, the following results can be observed in the figures below.

Rang	***Alternatives***	***Phi***	***Phi+***	***Phi-***
1	Cento	0,4532	0,4849	0,0317
2	Ferrara	0,3769	0,4123	0,0354
3	Tresigallo	0,2051	0,2613	0,0562
4	Vigarano Mainarda	0,1219	0,2185	0,0966
5	Mirabello+ Sant'Agostino	0,078	0,1835	0,1056
6	Lagosanto	0,0597	0,1319	0,0722
7	Poggio Renatico	0,0523	0,167	0,1147
8	Argenta+ Portomaggiore	0,0307	0,1133	0,0826
9	Copparo	0,0261	0,1107	0,0846

10	Bondeno	0,0222	0,1075	0,0853
11	Comacchio	0,0217	0,1075	0,0857
12	Codigoro	0,0125	0,1053	0,0928
13	Formignana	-0,1232	0,0146	0,1378
14	Masi Torello	-0,1275	0,0086	0,1361
15	Goro	-0,1278	0,0106	0,1384
16	Mesola	-0,1317	0,0069	0,1386
17	Berra	-0,1383	0,0046	0,1429
18	Voghiera	-0,1383	0,0041	0,1424
19	Ro	-0,1385	0,004	0,1425
20	Fiscaglia	-0,1497	0,002	0,1517
21	Ostellato	-0,1839	0	0,1839
22	Jolanda di Savoia	-0,2014	0	0,2014

Figure 29. Ranking of the alternatives Linear "Mean-std".

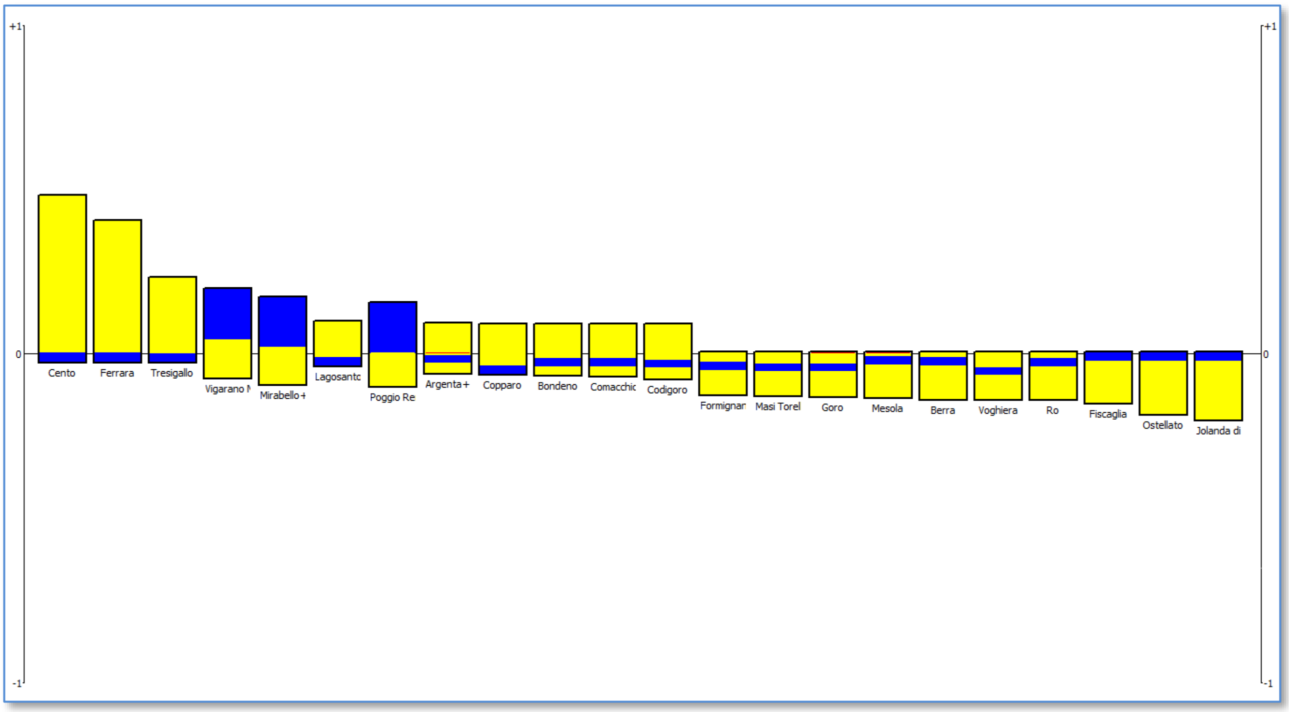

Figure 30. Promethee Rainbow Linear "Mean-std".

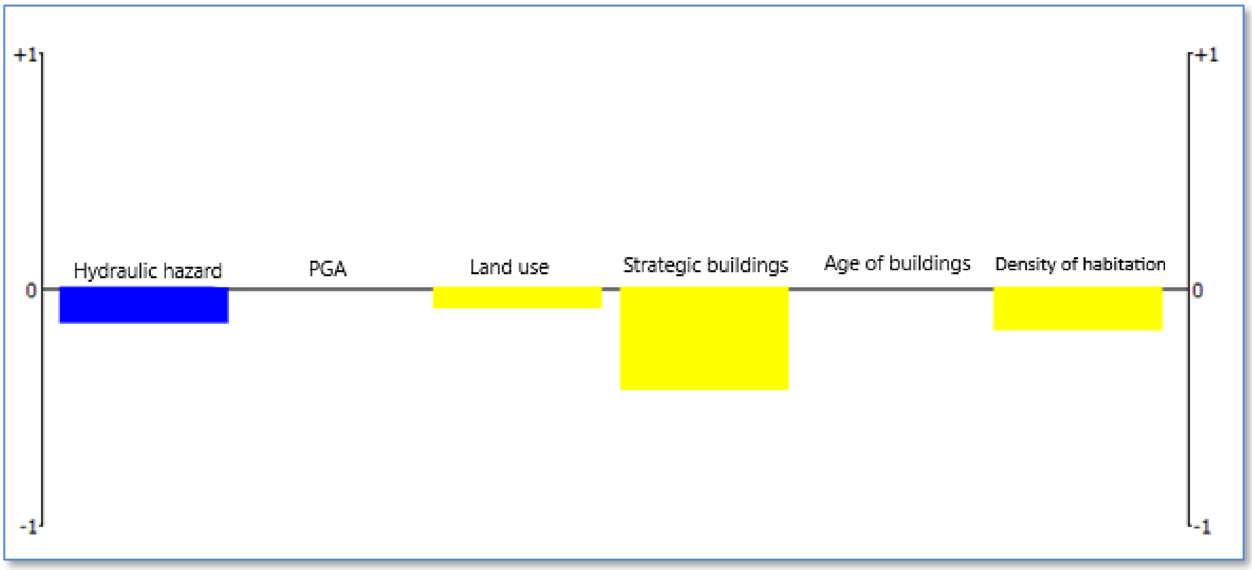

Figure 31. Promethee Profiles of alternatives, relative to the municipality of Berra.

Significantly, it can be noted that for all alternatives the criteria relating to seismic hazard and vulnerability are practically almost irrelevant for the purposes of the sorting, and even for some alternatives they are null as shown through the Profiles of alternatives; figure 31 shows the Profiles of alternatives of the municipality of Berra for which the PGA and Age of the buildings criteria are null.

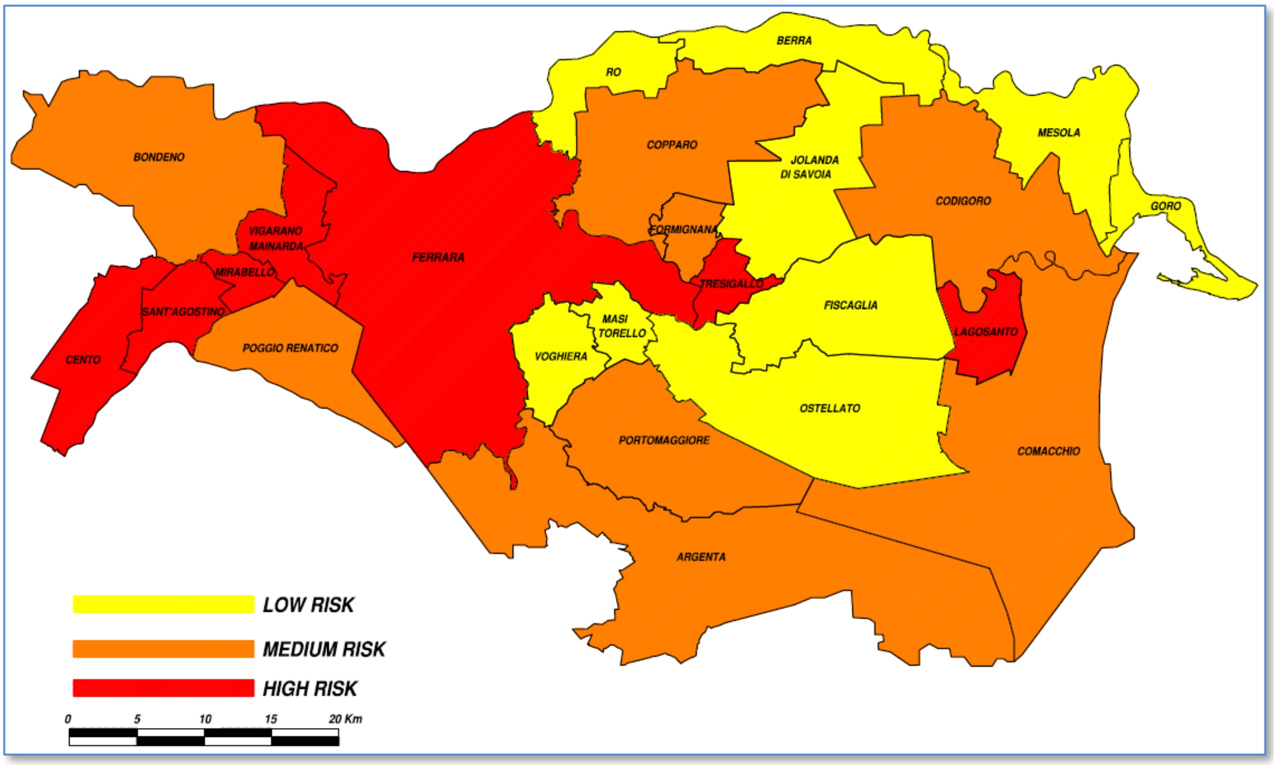

Figure 32. Multirisk map of the Ferrara province (modelling Linear "Mean-std").

What can be deduced by comparing the results obtained from the different models is that by changing the preference function adopted, there are no large variations in the final risk maps.

In particular, if we consider the map obtained from the first modelling (Usual preference function) with that of the modelling which involves the use of the "Linear 'zero-max'" preference function, the only difference is that they are inverted the risk levels of the municipalities of Vigarano Mainarda and Bondeno, and Fiscaglia and Lagosanto; ie in the "Usual" modeling Vigarano Mainarda has a high risk level and Bondeno a medium risk level, Fiscaglia a low risk level and Lagosanto a medium risk level; on the contrary, in the "Linear 'zero-max'" modelling Bondeno presents a high risk level while Vigarano Mainarda a medium risk level, Fiscaglia a medium risk level while Lagosanto a low risk level.

Some slight differences are found, however, by comparing the map obtained from the "Usual" modelling with that of the "Linear 'mean-std'" modelling.

More specifically: in the "Linear 'mean-std'" modelling the municipality of Lagosanto assumes a high level of risk (while in the Usual modelling it covered a medium level), and the municipalities of Codigoro, Argenta and Portomaggiore are colored orange assuming a level of medium risk (these, respectively, in the Usual modelling, had a low and high risk level); finally, the municipality of Voghiera which in the Usual modelling was at medium risk becomes at low risk in the Linear 'mean-std' model.

Concluding the sensitivity analysis on the preference functions, what can be said is that the choice of the preference function affects the final ranking of the alternatives, however, not to induce significant changes for the purposes of this analysis.

In fact, in general, what can be observed in all three models is that the map obtained presents a similar risk trend, i.e. the territory is divided into two parts: that of the municipalities of the Upper Ferrara area (western part of the territory of the province of Ferrara), Ferrara and Tresigallo characterized by a medium-high risk level; while the remaining part of the territory which includes the municipalities of the Lower Ferrara area, Voghiera, Ostellato and Masi Torello is characterized by a medium-low risk level.

4.3 Sensitivity of the weights

This paragraph reports the results of the sensitivity analysis on the criteria weights; as introduced in paragraph 4.2.3, first the increases in the weight of the individual criteria, one at a time, are presented, then the simultaneous increase in the weights of the three criteria relating to the "exposure" component of the risk.

To lighten the writing and facilitate the viewing of the results of the sensitivity analysis on the weights, these are reported in the form of maps.

The results are presented, with the criteria ordered as follows: hydraulic hazard, PGA, land use, strategic buildings, age of buildings, population density.

With the first increase of the hydraulic hazard, the order remains almost unchanged, determining a risk map identical to that of the zero situation (figure 25).

With the last two increase it can be noticed some variations as shown in figure 33.

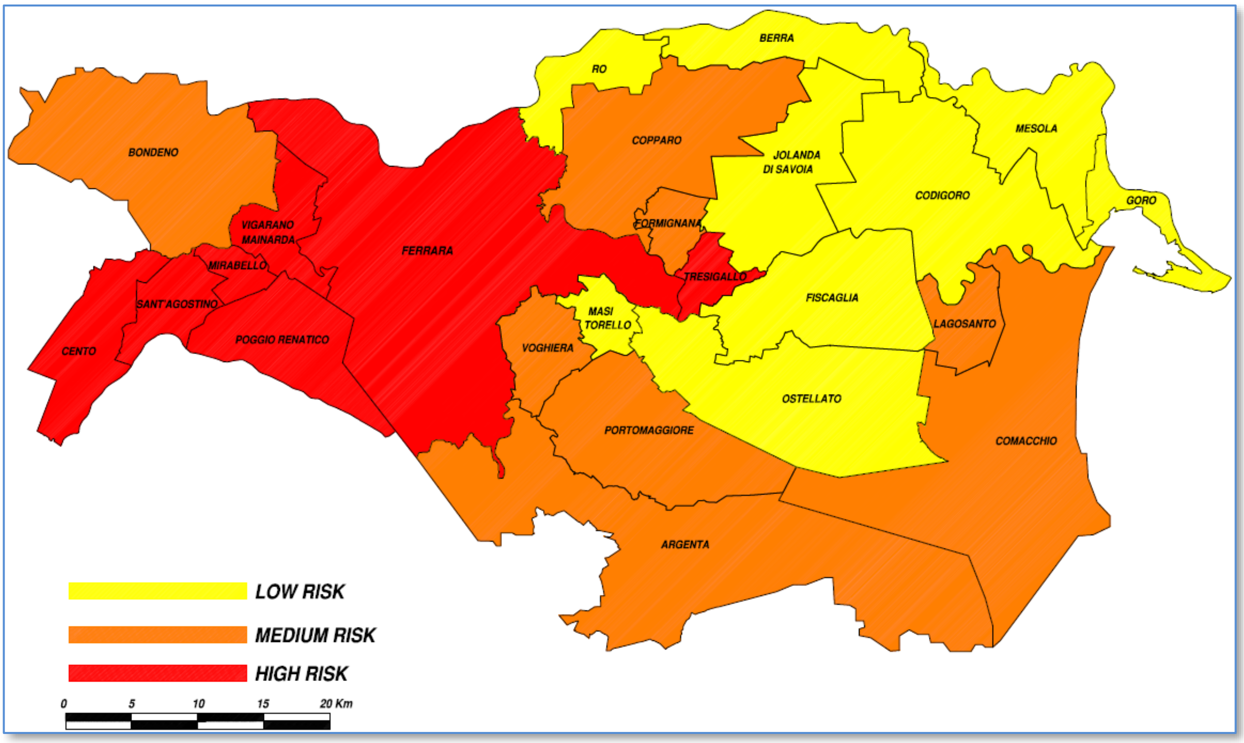

Figure 33. Multirisk map situation 2-3 hydraulic hazard weight increase.

For the PGA, the first increase the risk map remains the same as in figure 25.

More differences it can be observed with the following weight increases (figures below).

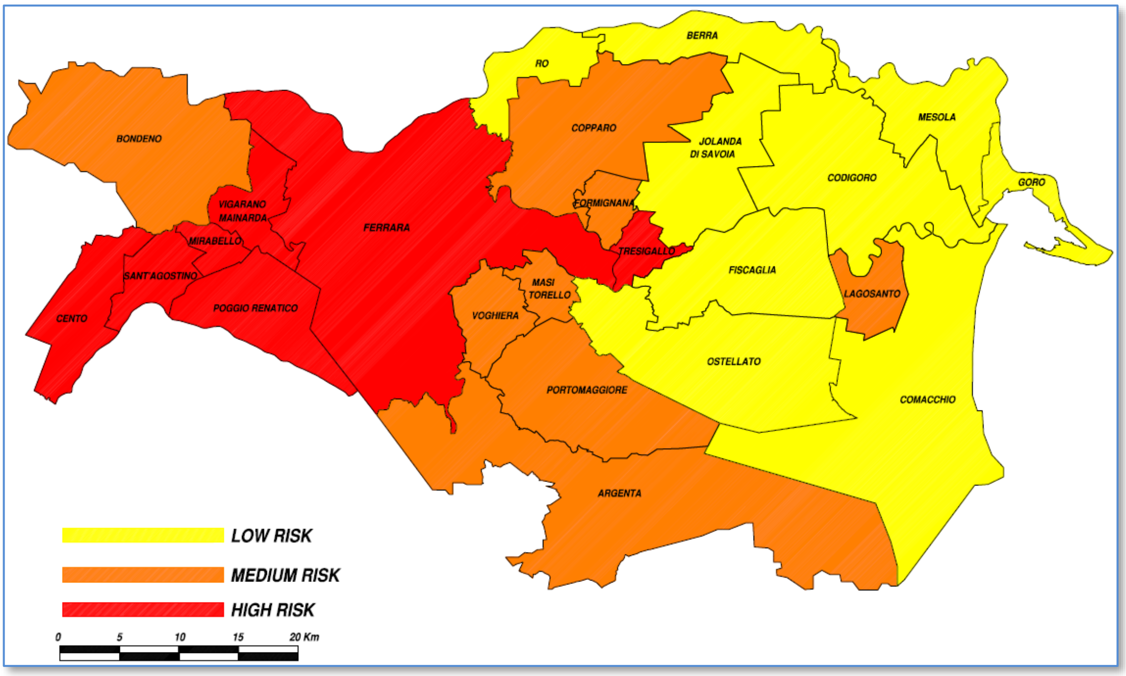

Figure 34. Multirisk map of the Ferrara province after the second increase of the PGA weight.

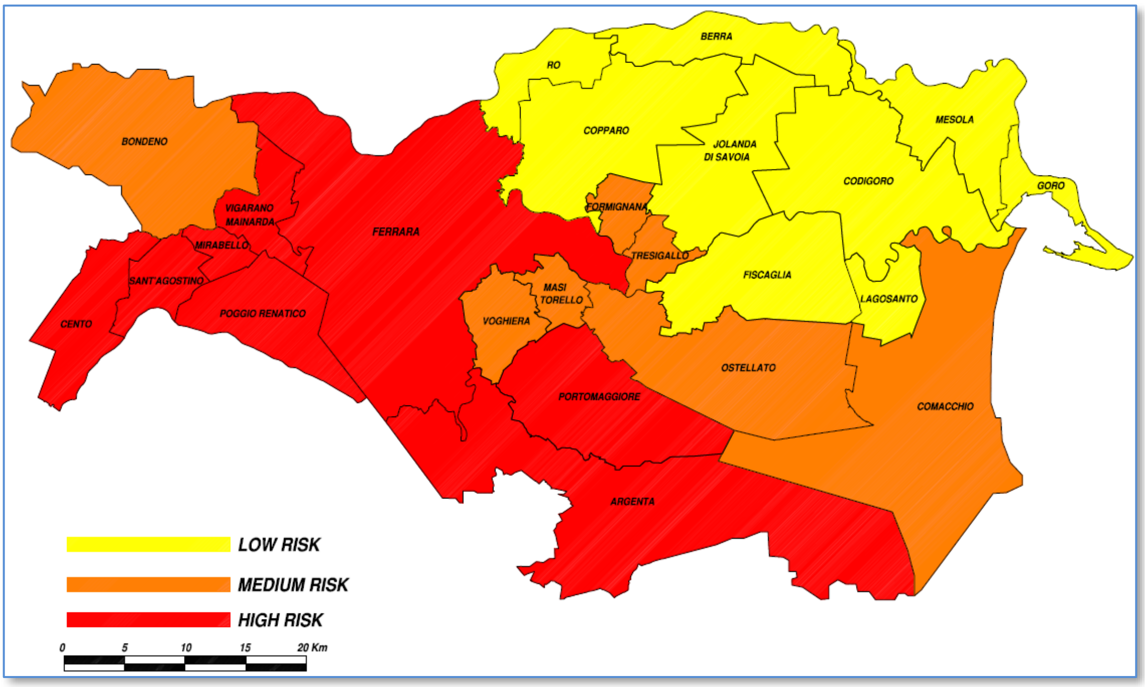

Figure 35. Multirisk map of the Ferrara province after the third increase of the PGA weight.

Continuing with the land use criterion, also in this case, the first increase leaves the risk map unchanged (figure 25); while the last two increases produce some variations on the risk map.

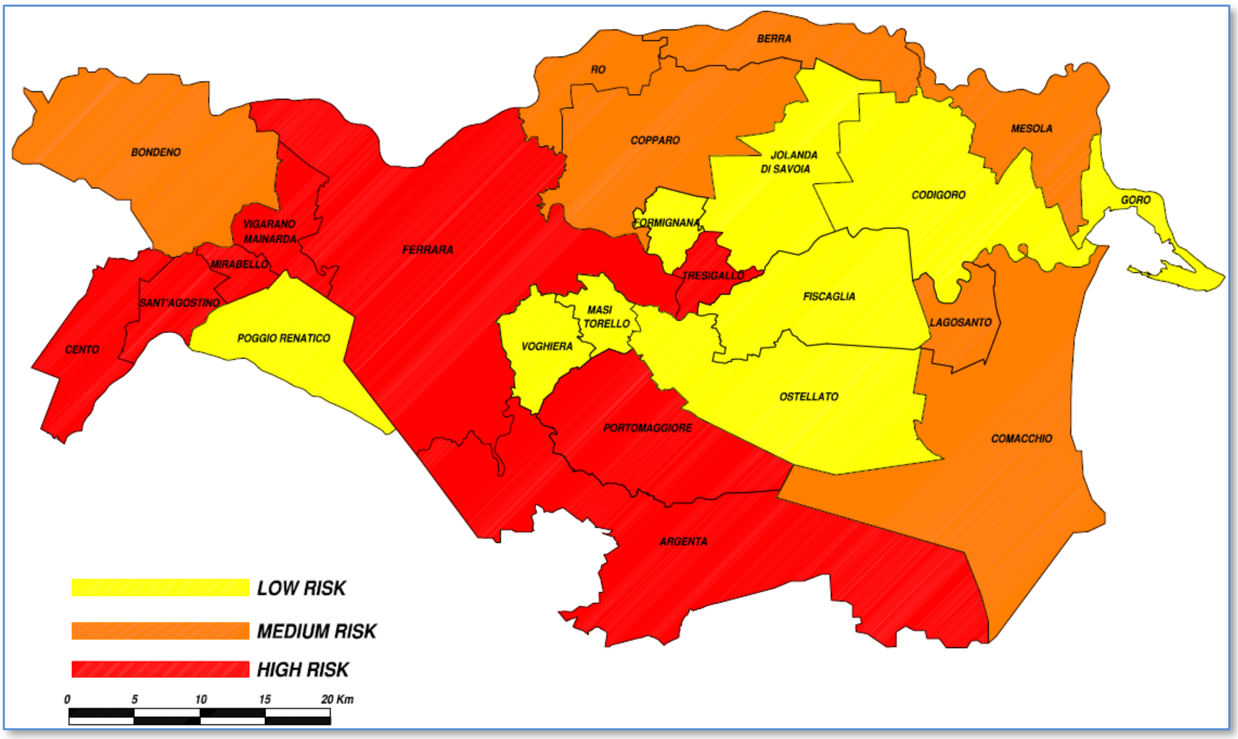

Figure 36. Multirisk map of the Ferrara province situation 2-3 land use weight increase.

Turning to the strategic buildings criterion, already with the first increase there are differences in the risk map compared to the zero situation; they are shown in figure 37.

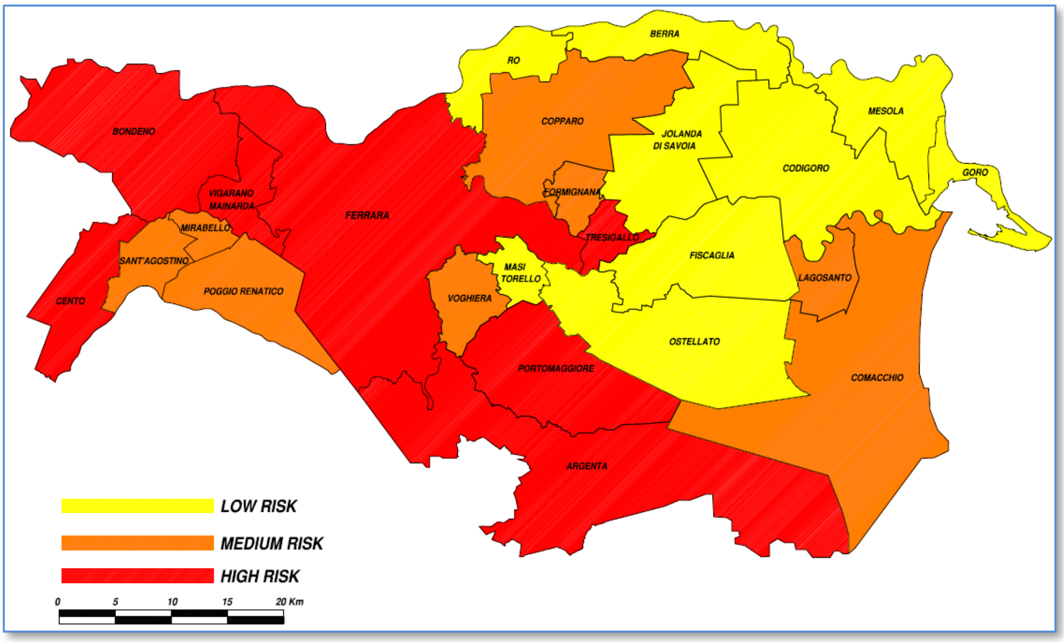

Figure 37. Multirisk map of the Ferrara province after the first weight increase of Strategic buildings criterion.

The effects of the last two weight increases are shown in figure 38.

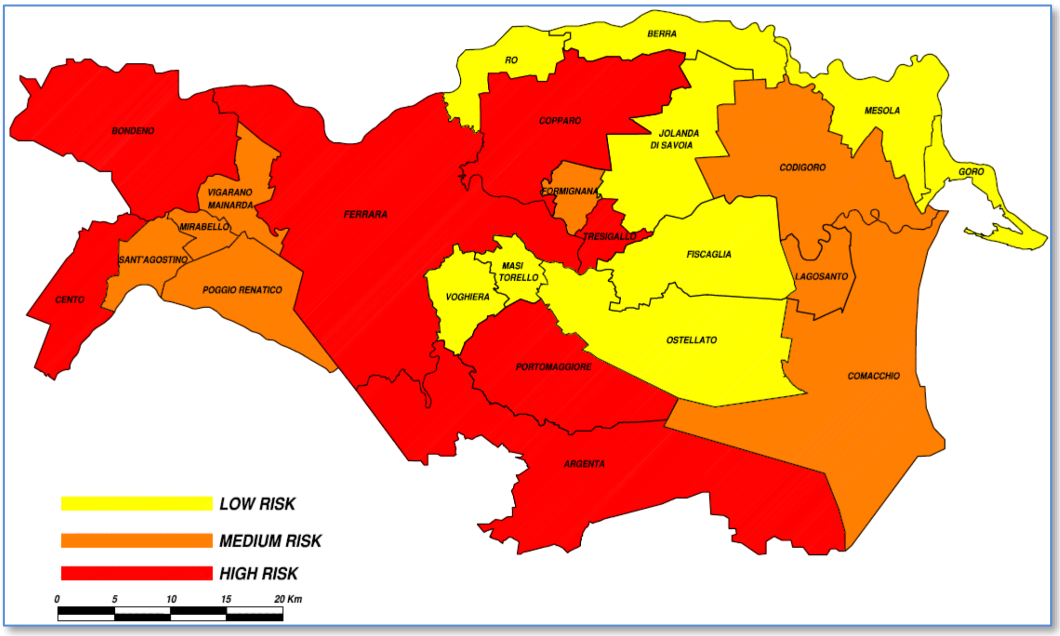

Figure 38. Multirisk map of the Ferrara province situation 2-3 Strategic buildings weight increase.

Next up is the age of buildings criterion, for it each increase of the weight leads to a different risk map.

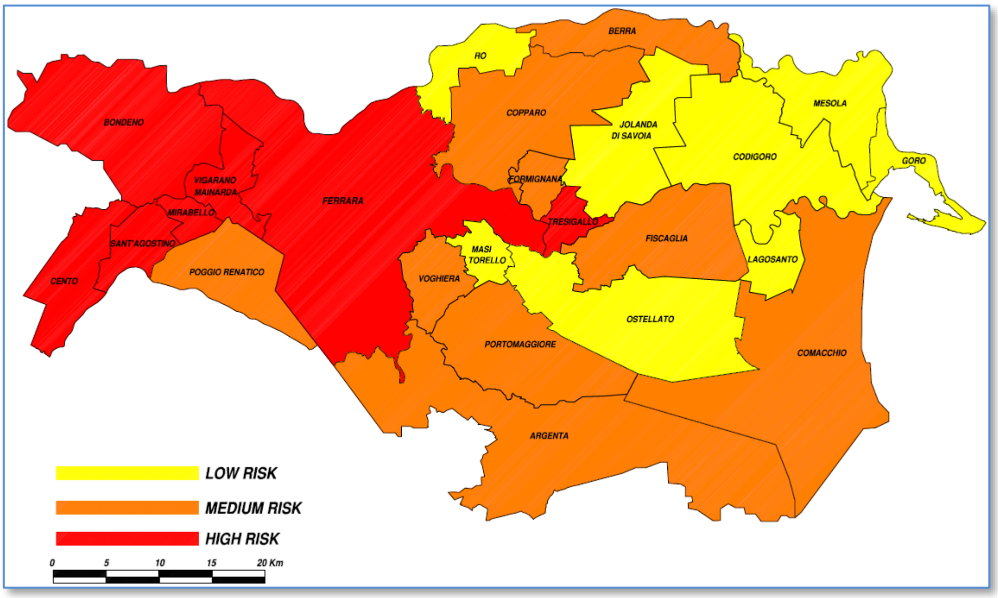

Figure 39. Multirisk map of the Ferrara province after the first weight increase of the age of buildings criterion.

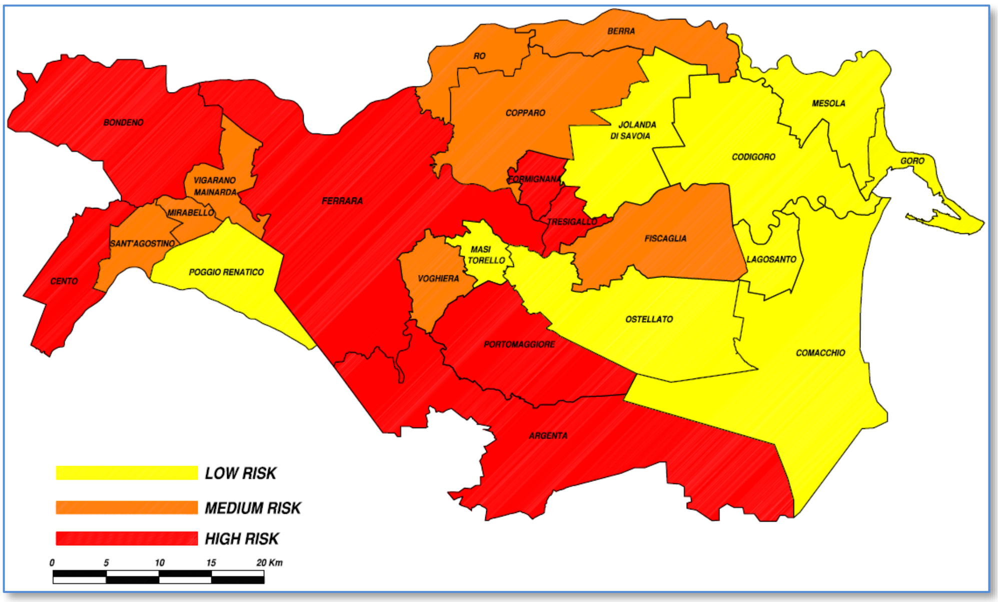

Figure 40. Multirisk map of the Ferrara province after the second weight increase of the age of buildings criterion.

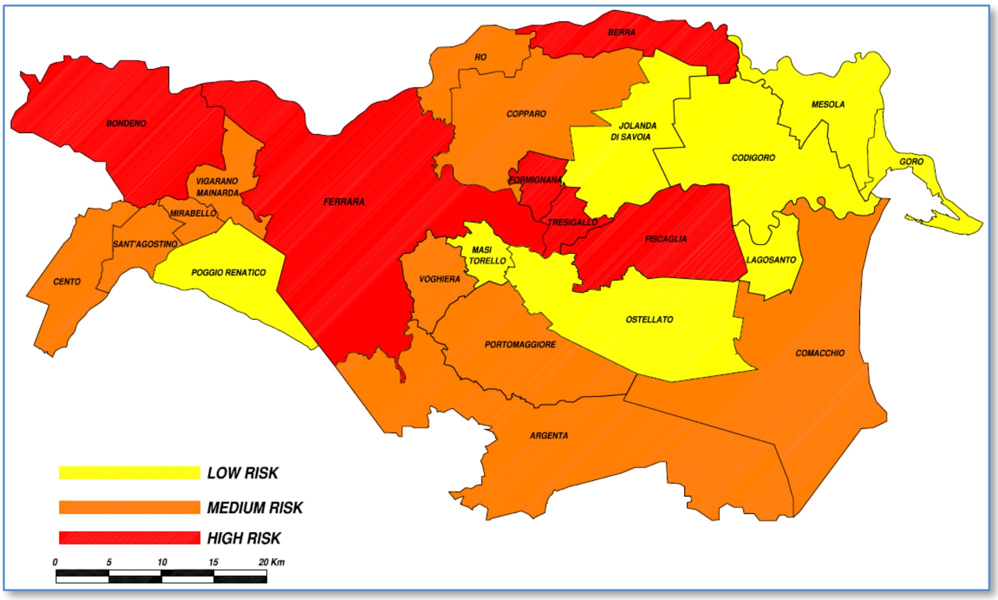

Figure 41. Multirisk map of the Ferrara province after the third weight increase of the age of buildings criterion.

The last criterion is the population density, so the first increase leaves the map unchanged (see figure 25), while the subsequent increases bring about modifications visible in the figures below.

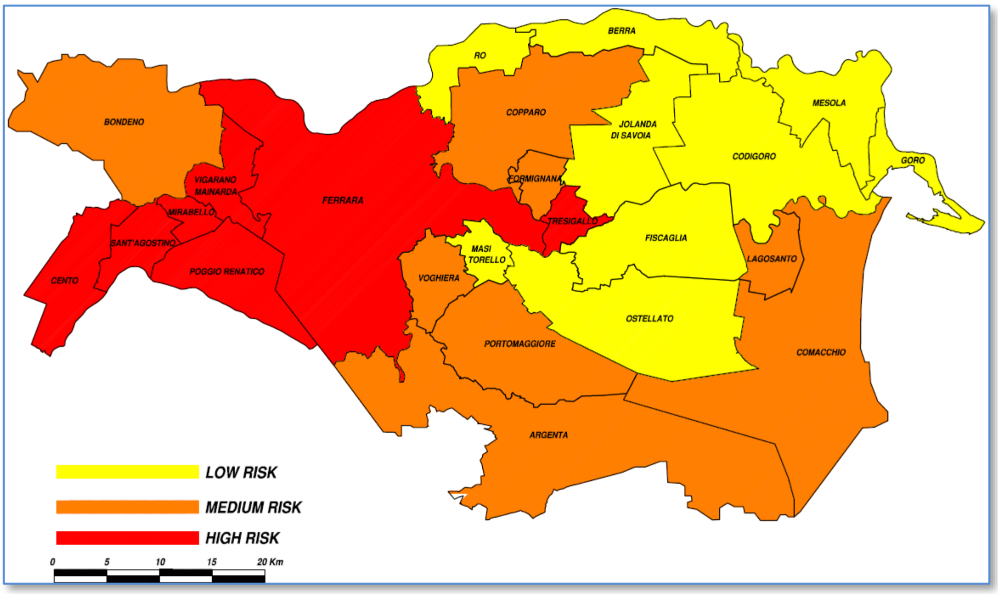

Figure 42. Multirisk map of the Ferrara province after the second weight increase of the population density criterion.

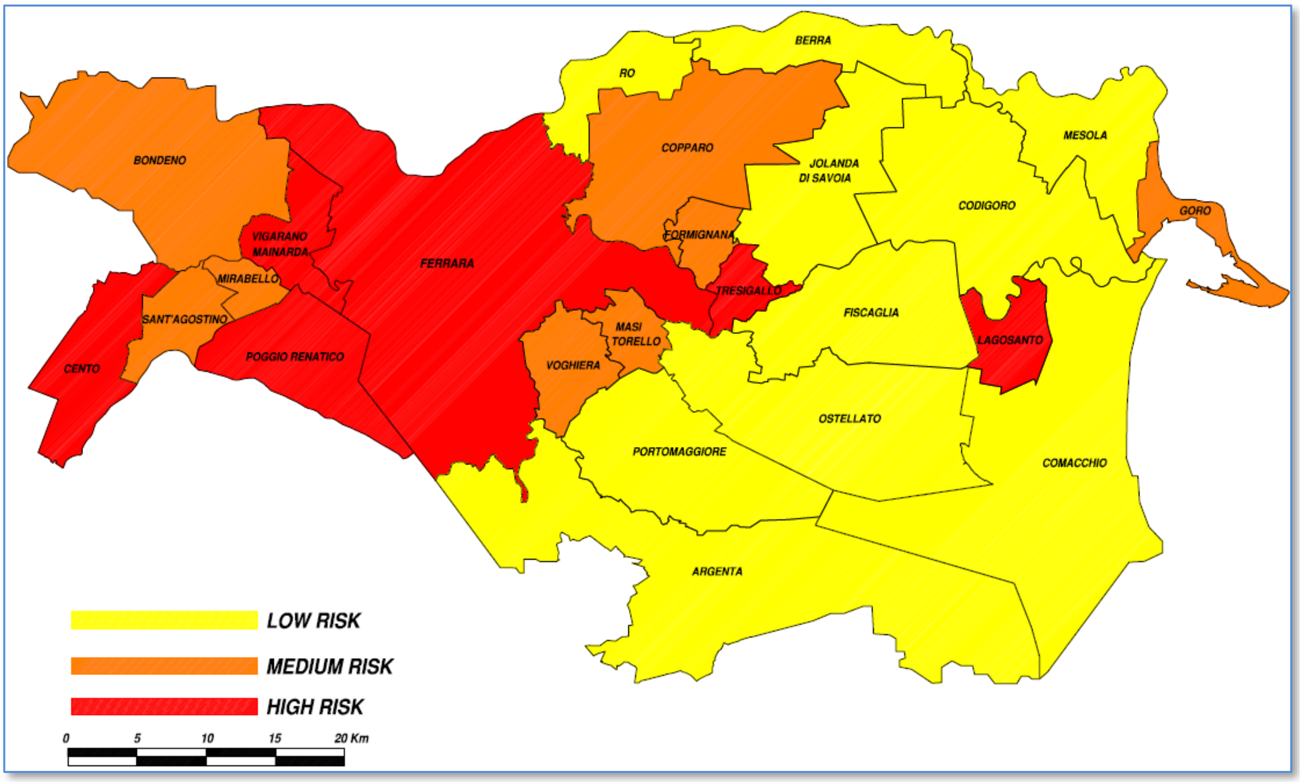

Figure 43. Multirisk map of the Ferrara province after the third weight increase of the population density criterion.

Lastly, the results of the sensitivity of the weights of the criteria relating to the exposure factor are presented.

Proceeding as illustrated in paragraph 4.3, the first increase in the weight relating to the criteria regarding the exposure factor does not change the risk map, which remains the same as in situation 0, but only to the ordering of the alternatives, while with the second increase greater variations can be observed.

The figures below show these results.

USUAL								
SITUATION 1: EXP WEIGHT= 0,22; OTHERS=0,11					**SITUATION 2**: EXP WEIGHT=0,32; OTHERS=0,01			
Rang	Alternativa	Phi	Phi+	Phi-	Alternativa	Phi	Phi+	Phi-
1	Ferrara	0,7153	0,8064	0,0911	Cento	0,9452	0,9683	0,0231
2	Cento	0,7093	0,8061	0,0968	Ferrara	0,9168	0,9538	0,037
3	Tresigallo	0,5092	0,6746	0,1654	Tresigallo	0,696	0,7975	0,1015
4	Vigarano Mainarda	0,2908	0,5771	0,2863	Lagosanto	0,4603	0,6797	0,2193
5	Argenta+ Portomaggiore	0,2279	0,534	0,306	Vigarano Mainarda	0,3006	0,5575	0,2569
6	Mirabello+ Sant'Agostino	0,219	0,5413	0,3222	Argenta+ Portomaggiore	0,2083	0,5536	0,3454
7	Bondeno	0,1597	0,4971	0,3375	Mirabello+ Sant'Agostino	0,1207	0,4675	0,3468
8	Lagosanto	0,1359	0,488	0,352	Bondeno	0,1154	0,507	0,3915
9	Copparo	0,0416	0,4381	0,3965	Comacchio	0,1044	0,5017	0,3973
10	Comacchio	0,0356	0,4378	0,4022	Copparo	0,076	0,4873	0,4113
11	Poggio Renatico	-0,0499	0,4041	0,454	Mesola	-0,0919	0,3574	0,4493
12	Formignana	-0,0661	0,3555	0,4216	Masi Torello	-0,1448	0,3309	0,4757
13	Voghiera	-0,1127	0,3295	0,4422	Goro	-0,1563	0,3252	0,4815
14	Masi Torello	-0,1644	0,3064	0,4708	Codigoro	-0,1861	0,3564	0,5426
15	Berra	-0,2045	0,2863	0,4908	Poggio Renatico	-0,1924	0,3107	0,5031
16	Mesola	-0,2197	0,2787	0,4984	Formignana	-0,1938	0,3064	0,5002
17	Ro	-0,226	0,2756	0,5016	Voghiera	-0,2848	0,2607	0,5455
18	Goro	-0,2939	0,2416	0,5355	Berra	-0,2929	0,2569	0,5498
19	Codigoro	-0,3041	0,268	0,5721	Ro	-0,2949	0,2559	0,5507
20	Fiscaglia	-0,3385	0,2193	0,5578	Fiscaglia	-0,594	0,1063	0,7003
21	Ostellato	-0,4816	0,1451	0,6267	Ostellato	-0,7225	0,0418	0,7643
22	Jolanda di Savoia	-0,5829	0,0971	0,68	Jolanda di Savoia	-0,7893	0,0087	0,798

Figure 44. Ranking of the alternatives exposure sensitivity.

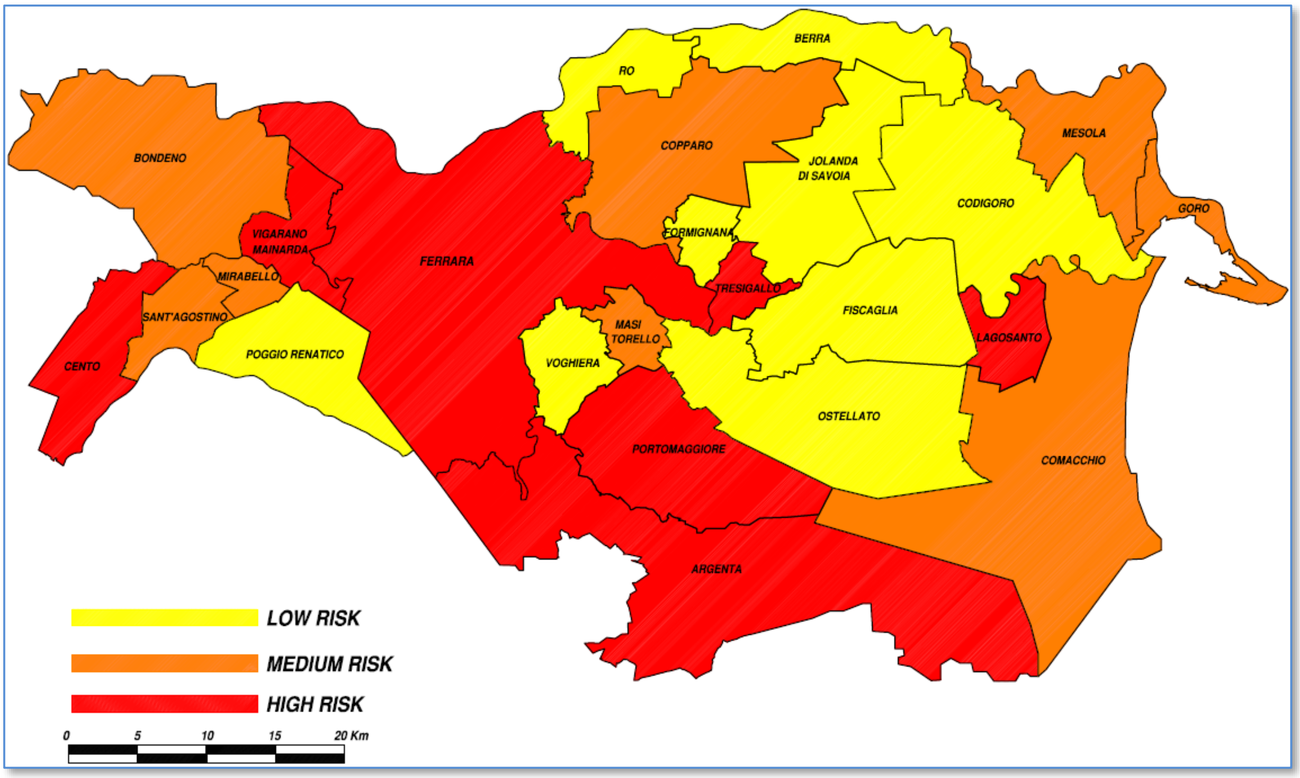

Figure 45. Multirisk map after the second increase of the weight of the exposure criteria.

Therefore, at the conclusion of the sensitivity analysis on weights it can be stated that: in general, the results are sensitive to the increase in the weights of the criteria, determining a risk map that varies from case to case, bringing the risk of some municipalities to decrease while that of others to increase.

However, these variations do not upset the general risk trend, which highlights a territory divided into two parts, that of the municipalities of the Upper Ferrara area (western part of the territory of the province of Ferrara), Ferrara and Tresigallo characterized by a medium-high risk level; while the remaining part of the territory which includes the municipalities of the Lower Ferrara area, Voghiera, Ostellato and Masi Torello is characterized by a medium-low risk level.

5 Conclusions

In order to lay the foundations for the development of an environmental and sustainable land use plan, as well as risk mitigation strategies, it is necessary the analysis, quantification and comparison of all the risks that may affect a certain territory.

To date, risk assessment is generally performed by means of independent analyses that adopt non-uniform procedures, determining in results that are difficult to compare.

The purpose of this paper was to assess jointly the hydraulic and seismic risk for the Ferrara area.

The application of the Multiple-Criteria Decision Analysis (MCDA) methodology, for this evaluation, has proved to be an innovative and promising tool.

The potential derives from the system's ability to analyse information from various sources and to systematize data expressed in different units and scales jointly.

The application of this methodology through the Visual PROMETHEE software has made it possible to highlight the areas of the Ferrara area that are most sensitive to risk and, therefore, to provide useful information for local authorities in order to define future intervention priorities.

This case study deals only with a first application within a panorama that lends itself very well to further studies and insights.

Furthermore, the proposed methodology has proved to be "flexible", i.e. it lends itself to being reapplied in similar cases while maintaining the same application schemes or slightly varying some criteria, for example, depending on the territory under study, the risks could be different, therefore, different criteria must be used to express them.

In conclusion, it is worth highlighting some limitations that were found during the analysis; they are mainly related to the availability of data, in fact, the choice of criteria was based on the availability of the relevant information which led, for some criteria, to a purely qualitative evaluation; moreover, this analysis did not include the study of the cascade effects, an aspect that could be further investigated in the future.

Therefore, greater availability, accuracy and ease of retrieval of data would lead to the creation of completer and more precise analysis, as well as a future development of tools and software in this regard.

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