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A MULTI-RISK FRAMEWORK FOR ASSESSING AND RANKING SEISMIC AND FLOOD RISKS: AN APPLICATION IN ITALY-SLOVENIA TRANSBOUNDARY REGION

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Abstract

To formulate suitable prevention and mitigation policies, risk assessment is the primary tool adopted by decision makers to understand and quantify the potential impacts resulting from hazardous events. In areas exposed to multiple hazards a joint analysis for quantifying and comparing all risks that potentially affect the territory is crucial. However, the evaluation of possible interactions among risks and their comparison could be a complex task. This paper illustrates the methodology for multi-risk assessment proposed within BORIS project (Cross BOrder RISk assessment for increased prevention and preparedness in Europe), focusing on the assessment of seismic and flood risk in the Eastern Alps cross-border area between Italy, Slovenia and Austria. Adopting a multi-layer single risk approach, the risk evaluation related to the investigated hazards is performed by independent analyses and the expected losses are compared and ranked through risk curves. To ensure the comparability of the risks, the same boundary conditions for the analysis (common area, time frame of analysis and metric to represent the risk) as well as the same methodological approach to compute the probabilistic risk curves are defined. The harmonized methodology proposed is applied to a pilot transboundary region at the Italy-Slovenia border, including 27 municipalities in Italy and 6 in Slovenia. The municipal scale is selected as a scale to represent and compare the risks and the metric to evaluate impacts is measured in terms of direct economic losses. Results in terms of Expected Annual Losses (EAL) show in which municipality the overall risk is significantly high and in which town one risk could be more relevant than the other.

Keywords: multi-risk, cross-border risk assessment, risk curves.

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1 INTRODUCTION

The analysis of risks deriving from natural hazards helps stakeholders involved in risk management to investigate disaster risk reduction issues for more resilient communities and to enhance disaster preparedness for effective response. As many regions of the world are exposed to multiple hazards, a joint analysis of risks originated from different sources potentially affecting the same area is crucial. In fact, analysis of single hazards that may hit a given area gives no indication about their relative importance or possible effects amplification due to hazards interaction and/or cascading effects. Usually, different methodologies and spatial/temporal resolutions are adopted in the quantification of single risk. The metrics adopted to measure risk could vary as well. This makes the outcomes of risk analysis related to different hazards hardly comparable.

The BORIS project (Cross BOrder RISk assessment for increased prevention and preparedness in Europe) was a project funded by Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO). The objective of this project, finalized in December 2022, was the development of a shared methodology aiming to improve the knowledge and understanding of disaster risk towards the most effective prevention and preparedness to flood and seismic events in transboundary regions. Addressing also issues related to effective cross-border single risk harmonization, within the project a shared framework to compare and rank the single risks in multi-risk perspectives was also proposed. In this paper, the multi-risk approach proposed in BORIS will be presented. Cross-border multi-risk assessment developed was also tested in two pilot sites in Italy-Slovenia and Slovenia-Austria transboundary areas. Herein, the outcomes of the pilot application in the cross-border area between Italy and Slovenia will be presented and discussed.

2 SHARED FRAMEWORK FOR MULTI-RISK COMPARISON AND RANKING

2.1 Multi-risk issues

In order to perform a sound comparison and ranking of different risks potentially hitting the same area, a complete Multi Risk Assessment (MRA) should be performed. In its complete acceptation, MRA entails the adoption of innovative approaches that allow risk comparison and should account for all the possible risk interactions, i.e., at the level of hazard and of vulnerability [1]. Considering interactions among the threats would allow to also evaluate the potential increase of risk with respect to the level estimated by considering each risk source as independent from one another. However, the path to a complete MRA accounting for these aspects is quite complex, and there is still the need to reinforce each single step towards the full MRA. As observed in [2], the risk evaluation related to different sources is generally done through independent analyses, adopting disparate procedures and time–space resolutions. Each hazard may be characterized by different return periods, intensity and impacts. Metrics adopted to measure risk may be very different as well. Such differences make risks hardly directly comparable, independently of the presence of possible hazard/vulnerability interactions. Therefore, [3] suggests adopting as first step towards a full MRA, the so-called multi-layer single-hazard/risk assessment approach, ignoring the interactions but harmonizing and standardizing the assessment procedures among the different perils. In other words, each risk can be assessed through independent analysis, but common time frame of analysis and common metrics for risk evaluation have to be established a priori. To represent and compare the outcomes of such individual analysis, [3] suggests the adoption of standardization schemes, such as risk matrices, i.e., table-graphs illustrating the hazard likelihood on one axis and its potential impact on the other, or risk curves, i.e., curves relating the yearly probability of occurrence of an earthquake with the related expected impacts. Examples or risk curves or risk matrices can be found in [4], [5], and [6].

In the BORIS project multi-layer single risk analyses are performed. Therefore, independent risk analyses are performed both for seismic and flood risks without considering any hazard or vulnerability interaction but defining a shared framework by adopting the same boundary conditions and the same methodological approach for the analysis of both hazards. Residential buildings and the population are the assets at risk considered in the analysis. Direct economic losses and population affected (e.g., victims, injured, displaced) are selected as impact indicators to evaluate each risk and risk curves are selected as standardization tool to represent and visualize results. In the following section, the procedure proposed to harmonize seismic and flood risk for the implementation of a multi-layer single risk assessment is described.

2.2 The BORIS approach

In performing multi-layer single risk assessment, the harmonization of procedure for the evaluation of seismic and flood risk is required to allow useful comparison towards risk ranking. Relevant issues for multi-risk harmonization mostly concern the spatial scale of analysis (the two risks are usually assessed at different scales as an extension of area impacted by diverse hazards can greatly vary), the type of analysis to perform, i.e., time-based or scenario-based, and the metrics used to evaluate impacts. As a matter of fact, the two risks are usually assessed at different scales. This is mostly due to the different extension of area potentially impacted: while seismic risk can be assessed at a large scale (e.g., regional, municipal), the scale required for flood analysis is generally much smaller as flood hazard may vary spatially much more significantly than seismic hazard. As a harmonized spatial scale is strictly required to present and compare the consequences of different hazards, such harmonization can be based on the principle of the common denominator. In other words, the scales adopted in the single risk assessments can differ, but they should allow the aggregation of the consequences to the same spatial units. Thus, the municipality scale is proposed to represent risk results, which is also the lowest level at which administrative decisions are taken. Seismic risk will be evaluated adopting such a scale of analysis, while flood risk results will be first estimated at a lower scale and then aggregated at the municipal level for risk comparison and ranking.

The type of analysis depends on the main aim of the assessment. Usually, a detailed scenario-based assessment of expected damage and impact distribution at a territorial scale is adopted in response-oriented applications, i.e., studies for emergency planning. The BORIS project focuses particularly on the development of cross-border risk analyses having the aim to improve the understanding of the disaster risk, i.e., to enhance the prevention and the preparedness of local communities. Therefore, a probabilistic framework for risk assessment is adopted. More specifically, analyses are performed considering the hazard curves related to the site or equally hazard maps with given probabilities of exceedance in 50 years (i.e., given return periods) as input. For each risk, the evaluation of potential impacts involves the combination of the risk component of hazard, vulnerability and exposure. As no hazard or vulnerability interaction is considered, different models can be used for the two risks. However, to obtain consistent single risk analysis results in a cross-border area, the same models for hazard, vulnerability and exposure should be employed in the confining countries. As also noted in [7], the models used in different nations to perform national risk assessment are different. As example, comparing the models for Italy ([8]) and Slovenia ([9]), it can be noted that they employ non-homogeneous hazard models, different criteria for buildings classification and methods to build fragility curves and variable granularity for building exposure assessment.

Therefore, the models for transboundary single risk assessment need to be harmonized before comparing relative results through risk curves. For instance, the 2020 Euro-Mediterranean Seismic Hazard Model (ESHM2020, [10], [11]) is adopted as the seismic hazard model, as it encompasses all cross-border countries involved in the project and allows to overcome issues related to differences in seismic hazard models of each country. Still, towards vulnerability harmonization, it is proposed to tackle this issue by using a heuristic approach in which a linear combination of vulnerability models is adopted in cross-border countries, as shown in [12] and [13]. Concerning flood risk, a procedure to generate flood hazard maps in cross-border catchments is proposed to harmonize flood hazard and generate maps for common and predefined return periods, while a common vulnerability model is adopted for evaluating flood vulnerability of residential buildings (HAZUS, [14]).

Impacts of single risks are expressed in terms of direct economic losses and affected population. For seismic risk, direct economic losses are usually associated with the physical damage of structures and calculated by defining damage-to-impact conversion criteria. Thus, for each damage level of the adopted damage scale, a cost ratio, i.e., a ratio of the reconstruction cost, is defined. Analogously, people affected by earthquakes can be calculated as a function of buildings' damage. For example, the number of displaced population could be calculated as the number of inhabitants in buildings that reach severe damage and are therefore considered long-term or short-term unusable, while the number of expected deaths can be estimated as a rate of occupants in collapsed or very heavily damaged buildings ([15]; [8]). Direct economic losses due to floods are usually expressed as physical damage to buildings and consequent repair costs as well ([16]; [17]). The counting of people possibly affected by floods should account for all people living in the flooded area. Thus, it also includes the residents of undamaged buildings who are evacuated due to warning issues or lose physical access to the property because of flooded roadways. Moreover, mortality in a flooded area could also increase due to social factors (e.g., age) and flood characteristics (e.g., flood velocity) ([18]; [19]). Therefore, a comparison between seismic and flood risk is performed only in terms of direct economic losses. Specifically, consequence functions for evaluating such losses are harmonized adopting the same replacement cost or reconstruction cost of buildings for both risks. In this way, the expected direct economic losses obtained can be represented and compared using the risk curves.

3 APPLICATION AT ITALY-SLOVENIA BORDER

An application of the proposed methodology for harmonized cross-border multi-risk assessment in the transboundary regions between Italy and Slovenia is presented herein. The area selected for this pilot application includes 27 Italian municipalities and 6 Slovenian municipalities, located close to the cities of Gorizia and Nova Gorica (Figure 1). Despite the different number of municipalities selected, the surface area covered by them is quite similar on both sides of the border.

The ESHM20 is adopted as the seismic hazard model. It provides peak ground acceleration (PGA) for six yearly exceedance probabilities corresponding to the return periods of 50, 101, 476, 976, 2500 and 5000 years. As the analyses are performed at the municipal scale, PGA values at the municipal centroid are extrapolated, starting with values at grid points considered by the model and adopting the distance-weighted average principle. Because the ESHM2020 model provides seismic hazard for rock-equivalent outcrop motion, the effects of local soil and other effects on ground motion intensity are taken into account by supplement models. Specifically, local maps with Vs30 values are used to account for the soil effects on the cross-border area analyzed. For the Italian side, the Vs30 map proposed by [20] is used. On the Slovenian side, soil classes and related Vs30 values are estimated at all locations of buildings based on the known geological characteristics and past studies ([21];[22];[9]); such values are then used to calculate the % of municipality area classified in the 5 soil classes of EC8. Based on the Vs30 values, the amplification factors are determined by considering the guidelines from the draft version of the new EC8 ([23]).

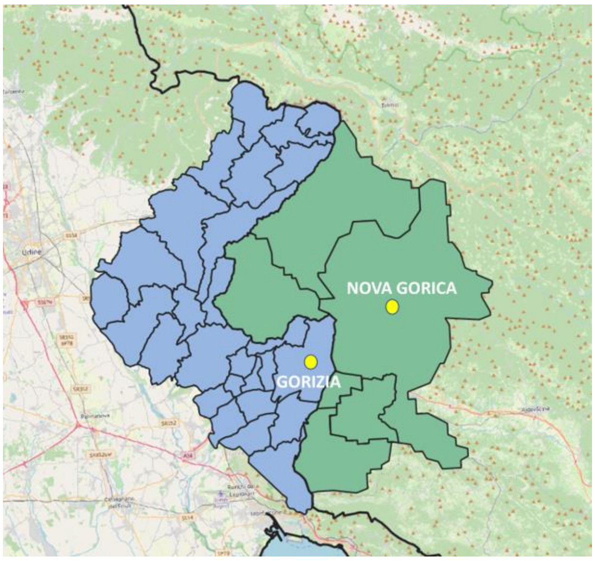


Figure 1. Italian and Slovenian municipalities included in the pilot application.

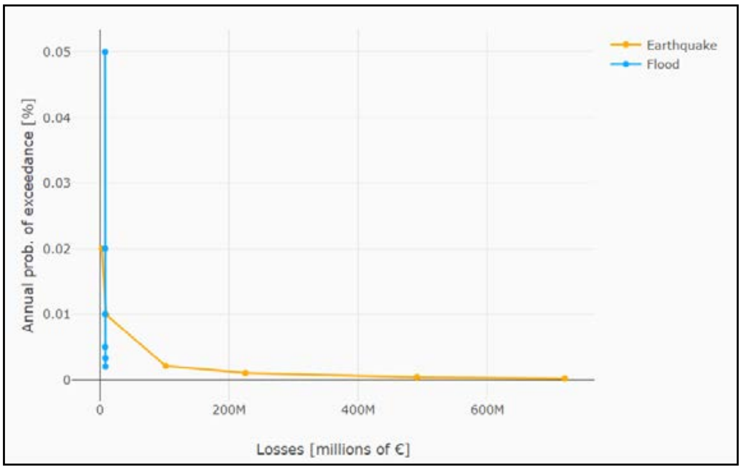
Transboundary harmonization of seismic vulnerability models is performed by adopting the heuristic approach proposed in [11]. A typology-based building classification is adopted. Six typological building classes for masonry buildings and six typological classes for RC (reinforced concrete) are considered, defined by a combination of period of construction (<1965, 1965-1982, >1982) and number of storeys (1-3, >4). Specifically, the intervals of periods of construction are defined in order to take into account the evolution of the seismic regulations in both countries. Exposure information at the municipal level is derived from census data in Italy (ISTAT, [24]) and from Real Estate Register in Slovenia. For buildings classified as “other” material are not very widespread in Italy and no vulnerability model is officially available in the Italian national risk assessment for these kinds of structures. Therefore, they are considered only in terms of exposure. This means that for each municipality buildings classified as “other” are distributed into the other building classes (i.e., masonry and RC) according to classification rules defined based on their typological features (i.e., age of construction and number of storeys) and the occurrence percentages of masonry and RC typoloties in the municipality. To develop a harmonized vulnerability model also a common damage scale for describing the damage attained by buildings needs to be established. The EMS-98 scale ([25]) is commonly used as a reference in Europe and therefore is adopted in the project. As the Slovenian model used the HAZUS scale ([26]) for describing buildings’ vulnerability, conversion rules to convert the 4 damage levels of the HAZUS scale into the 5 grades of the EMS-98 one proposed in [27] are adopted. Finally, harmonized cross-border fragility functions are derived by applying the heuristic approach. It consists of the linear combination of the national typological-based fragility curves of the two countries, aimed at obtaining a set of curves for the specific cross-border context. The coefficients used in the aggregation are calibrated based on (1) differences between building typologies on a given side of the border with respect to typologies widespread in both countries nationwide (that characterized national vulnerability models) and (2) differences in methodologies used for vulnerability assessment in both countries ([12]; [13]). For the evaluation of economic losses, harmonized earthquake-consequence functions are proposed as well. More specifically, the following percentages of cost of repair or replacement are associated with the 5 damage grades of the EMS-98 scale: 0.02, 0.1, 0.3, 0.6 and 1 of the replacement cost, respectively for damage grades from D1 to D5. It is worth mentioning that the same replacement cost is used both for seismic and flood analysis, in order to allow the comparison of the results. However, it is not possible to define a unique value of such reconstruction cost for the whole pilot area, as it is obviously country-dependent. Therefore, a replacement cost of 1350 €/m^2 and of 1250 €/m^2 is adopted for the Italian and the Slovenian side of the border, respectively. It is worth mentioning that this value in Slovenia significantly increased in the last couple of years (for about 30%).

In the flood modelling process, the proposed cross-border harmonization of flood hazard maps provided by the two countries allows to generate flood hazard maps for 20, 50, 100, 200, 300 and 500 years return periods flood scenarios. In addition to the flood extension, such maps also provide the expected flood water depth for each scenario. The latter is estimated using the FwDET algorithm ([28];[29]), a GIS (geographic information system) based tool specifically developed for evaluating the water depth using only the extension of inundated surface and the DEM (digital elevation model) ([30]). As mentioned before, for a correct evaluation flood's impact, it is necessary to consider a fine spatial resolution. Thus, detailed building-level flood exposure modelling is adopted, extrapolating buildings' footprint and their spatial distribution through a GIS software and available sources (e.g., OpenStreetMap). HAZUS vulnerability curves ([14]) are adopted for flood analysis. The curves provide the structural damage ratio (i.e., the percentage of maximum damage attainable for structures) as a function of water depth, considering as input characteristics the building type (residential and not-residential) and number of storeys. For the vulnerability characterization of exposed buildings, a logic tree approach is implemented ([30]). Starting by buildings footprint, procedure proposed in [31] is adopted to associate a building usage (residential and not residential) to each building; then, local data aggregated at municipality level for the number of storeys is adopted to associate the building's height (1 storey, 2 storeys, 3 or more storeys). After this process, in the RASOR Platform ([32]), each building is associated to a specific set of vulnerability curves and water depth value to deal with the impact assessment, obtained through the product among the damage ratio (%) (from the vulnerability curves), the replacement cost (€/m^2) and the area of the footprint (m^2) multiplied for the number of storeys.

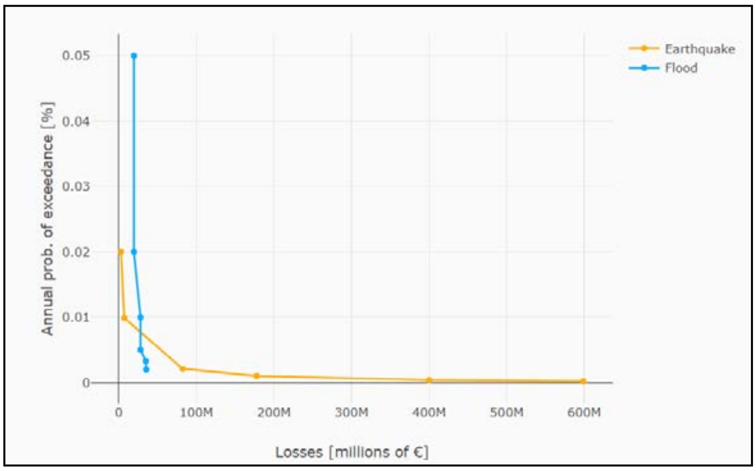
By calculating losses for different levels of hazard intensities, risk curves can be assembled. Each point on a risk curve connects the probability of exceedance of an event (e.g., a flood or an earthquake) with the expected losses from that event. A separate risk curve is generated for each considered risk and each point of the analysis (e.g., each municipality). By comparing the risk curves of different risks for the same municipality, it is possible to compare the economic losses expected at events with the same return periods. Further, by calculating the area under a risk curve, the corresponding EAL (Expected Annual Loss) can be obtained. The EAL represents the losses expected on average each year. It accounts for all return periods and is, therefore, a better point of comparison between different risks than losses at an arbitrarily selected return period. For this reason, the ranking of risks in a municipality is performed comparing EALs. However, another useful piece of information is the total EAL, which communicates the loss expected yearly due to the combined effect of all considered risks. By neglecting the potential complex interdependencies between different risks (e.g., domino effects), the total EAL can be calculated as the sum of all single risk EALs.

Figure 2 shows the risk curves obtained for the two cities of Nova Gorica and Gorizia. EAL due to earthquakes is about 844000 € for the town of Gorizia and about 984000 for Nova Gorica, with similar values also of economic losses per square meters (0.54 €/m^2 and 0.57

€/m^2, respectively). On the contrary, greater differences can be observed in the EALs due to floods: about 1138800 € for Gorizia and 394150 € for Nova Gorica (0.73 €/m^2 and 0.21 €/m^2, respectively). This means that a possible river flooding would be more relevant for the Italian municipality than for the Slovenian one. Moreover, in Gorizia flood's losses are also higher than the seismic ones, with a EAL ratio (EAL flood over EAL seismic) equal to 1.35. In other words, economic impacts due to a flood event are potentially heavier than the impacts associated with a possible earthquake for this city.



(a)



(b)

Figure 2. Risk curves for the two risks analysed for the cities of Nova Gorica (a) and Gorizia (b).

Within the project, a web GIS platform was also developed for viewing data and analysis results (https://boris.eucentre.it). The platform allows to visualize results of single and multi-risk assessment performed in BORIS, as well as input data used. For instance, it is possible to visualize models and data related to exposure modelling (e.g., number of buildings belonging to each building class at municipal level) or to vulnerability modelling (e.g., fragility curves and vulnerability curves adopted). In addition, the platform shows the results of single risk assessments, in terms of economic losses or people affected, and results of multi-risk analysis. The latter are shown both through risk curves and maps. Multi-risk maps show for each municipality in the pilot areas the values of overall EAL (as the sum of seismic and flood EALs). Also, for a better identification of the criticality of one risk over another, the ratio between the

EALs (EAL flood over EAL seismic) are also mapped. Figure 3 shows the map of such ratios as visualized in the platform.

4 CONCLUSIONS

This paper presents the results of the application of the methodology for multi-risk assessment presented in the BORIS project in the cross-border area between Italy and Slovenia. Seismic risk and flood risk are analyzed in the framework of multi-layer single risk assessment. Thus, individual analyses are performed for each risk, neglecting possible risk interactions, but harmonizing the procedure for the assessment. Proposals for the standardization of single risk assessment processes mostly concern the type of analysis, the scale of analysis and the metrics used for expressing risks. Risk curves were selected as a tool to show and compare risk results. The application presented here demonstrates that the BORIS approach allows to easily compare and rank different risks that could potentially affect the same area. The use of risk curves also allows a quantitative evaluation of risks, through the calculation of EALs. Also, the evaluation of ratios between the EALs of the two risks analyzed (flood/seismic) for each municipality in the pilot allows to identify the areas where one risk is more relevant with respect to the other. Although the application was demonstrated for the countries of Italy and Slovenia, the approach proposed can be easily adaptable to other contexts in Europe and worldwide. However, additional efforts are needed to harmonize the earthquake-based and flood-based consequence functions.

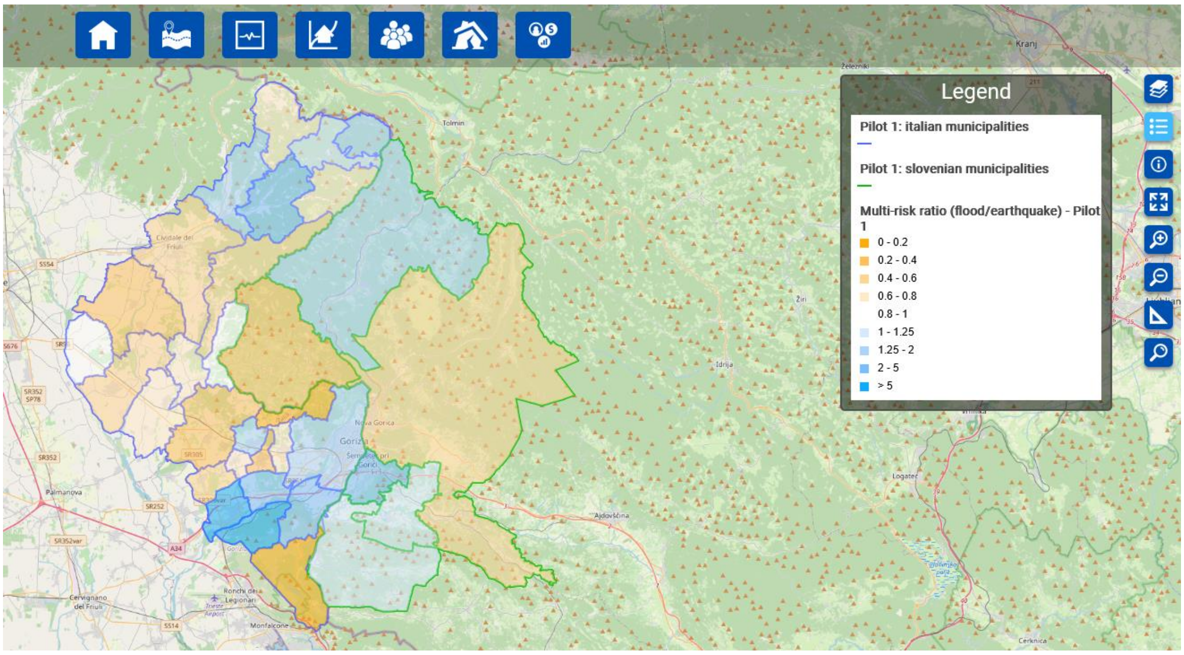


Figure 3. Maps of multi-risk ratios (EAL flood/EAL seismic) for each municipality involved in the application. Source: BORIS web platform (https://boris.eucentre.it).

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