BORIS

Cross BOrder RISk assessment for increased prevention and preparedness in Europe

D5.1

Seismic risk, flood risk and multi-risk assessment at pilot cross-border sites

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1. SUMMARY

Transboundary risk assessment is an essential element in developing effective prevention and planning strategies to reduce the impact of natural disasters. However, the individual national risk assessments of neighbouring countries are not directly comparable in terms of methodology, level of detail and data used. The projekt "Cross border risk assessment for increased prevention and preparedness in Europe – BORIS" (GA. 101004882), sponsored by Directorate-General for European Civil Protection and Humanitarian Aid Operations (ECHO), focuses on improving disaster preparedness and prevention in cross border areas. In WP4, a harmonisation process was therefore developed with the aim of establishing the use of common approaches that allow the impacts of flood and earthquake hazards to be identified. Moreover, different hazards and their importance for a region or individual communities may vary. Hence, WP4 also described an approach for the comparability of risks in a multi-risk framework. WP5 and this document, D5.1, aim at implementing the developed single-risk and multi-risk assessment approach in two transboundary pilot regions in order to draw conclusions on the practicability, challenges and opportunities for improvement as a basis for D5.2, entitled "Consolidated version of the guidelines for cross-border risk assessment" (BORIS, 2022).

In the following sections, the pilot application of the methodology for harmonised assessment of seismic and flood risk within a multi-risk framework for transboundary regions is presented and the results are visualised through the BORIS platform developed in WP3.

Two cross-border pilot regions were analysed in more detail – one between Italy and Slovenia (section 2) and the second between Austria and Slovenia (section 3). The main steps within the analysis were, first, the definition of the study area, i.e. the municipalities to be considered, the time window and the metric for the risk assessment, followed by the identification of the relevant risks to be studied, where the BORIS project focuses on earthquake and flood risks. The second important step was the collection of input data on the regional level, which is illustrated in sections 2.2 and 3.2. Furthermore, the identification and harmonisation of hazard information in the given pilot regions was the basis for the evaluation of hazard models for the selected risks, while no hazard interactions were considered for the following multi-layered single risk analysis. The vulnerability and exposure assessment, focusing on people and residential buildings, led to the calculation of losses through consequence functions. For both risks and pilot applications, a time-based risk assessment was performed and the time frames of 1 year and 50 years were considered. For each time frame, risk results are represented both in terms of the expected damage and in terms of impact indicators. The risk results are available in a tabular form for each municipality separately and the entire area. In addition, the results are displayed on maps by coloring each municipality depending on the value of the risk indicator the user decides to visualize. Several limitations and future needs are addressed throughout the sections and will be discussed further in deliverables D5.2 "Consolidated version of the guidelines for cross-border risk assessment" and D6.4 "Lessons Learned" (BORIS, 2022).

2. Pilot application of methodology and tool for multi-risk assessment at the Italian-Slovenian border

This section deals with the assessment of seismic risk and flood risk at the highly seismic active region where the cross-border pilot site between Italy and Slovenia is located.

2.1. Definition of cross-border area Pilot 1

The Pilot 1 area was defined at the border between Italy and Slovenia (**Figure 2.1**). Several municipalities were selected on each side of the border. The municipalities are located close to the cities of Gorizia and Nova Gorica and are presented in the following of this section.

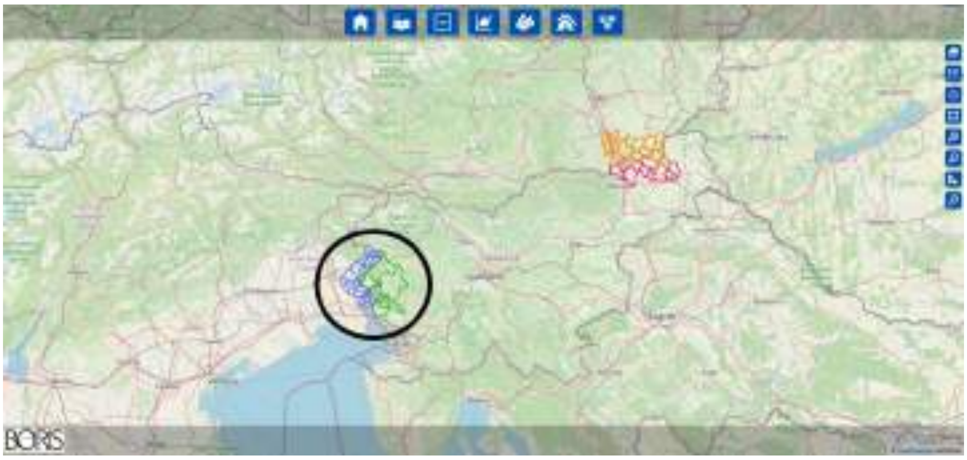


Figure 2.1: Pilot 1 area.

2.1.1. Italian Region

The Italian municipalities defined in the Pilot 1 area are the following 27, also shown in **Figure 2.2**: Gorizia, Savogna d'Isonzo, Doberdò del Lago, Sagrado, San Floriano del Collio, Farra d'Isonzo, Gradisca d'Isonzo, Mariano del Friuli, Moraro, Capriva del Friuli, Mossa, San Lorenzo Isontino, Cormons, San Giovanni al Natisone, Corno di Rosazzo, Dolegna del Collio, Manzano, Buttrio, Premariacco, Cividale del Friuli, Prepotto, San Pietro al Natisone, San Leonardo, Stregna, Savogna, Grimacco, Drenchia.

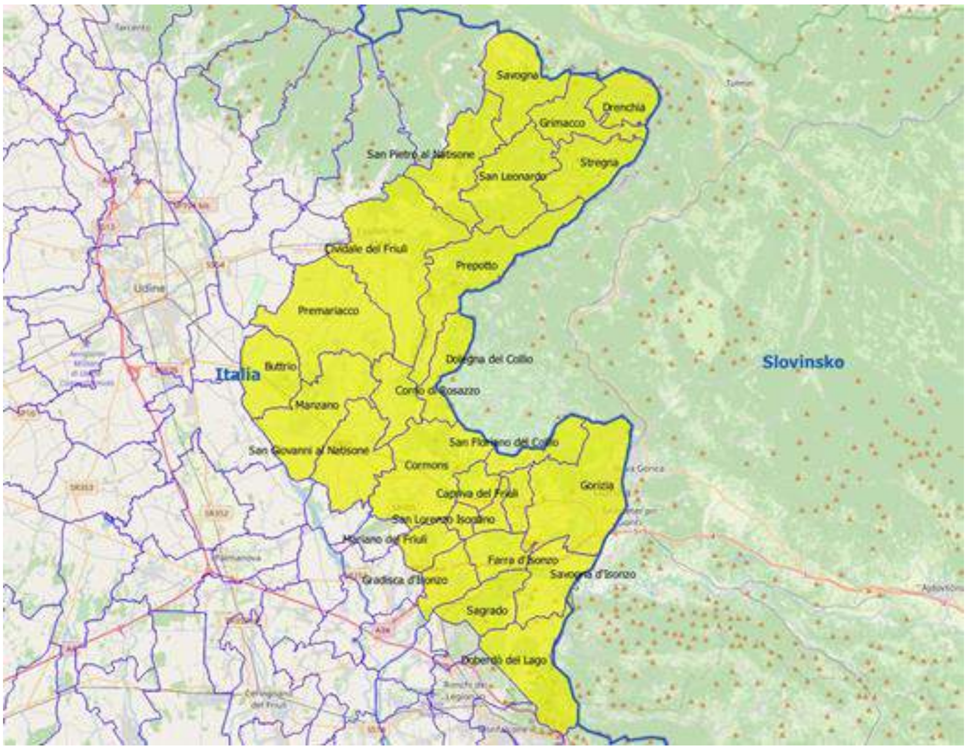


Figure 2.2: Italian municipalities in Pilot 1 area.

The selection of these municipalities was made on the basis of two criteria: the path of the rivers and the seismic hazard of the area, since the risks considered in the BORIS project are flood and earthquake. In particular, in relation to the presence of rivers in the area, the relevant role of the Isonzo River, which passes through the largest city on the Italian side of the pilot area, Gorizia, and also in Slovenia, should be highlighted. In addition, among the selected municipalities there are some affected by the passage of the Natisone, the Vipacco and the Torre river, as well as the passage of several canals. Regarding to seismic hazard, the northernmost municipalities in the selected area have a higher seismic hazard, we are in fact in the area affected in 1976 by the devastating earthquake of Friuli of Magnitude 6.5. For example, for an event with a return period of 476 years, the European Seismic Hazard Map adopted in the project (ESHM20, Danciu et al. 2021) shows PGA of 0.193 g in Buttrio and 0.184 g in the municipalities of Cividale del Friuli, Premariacco and Savogna. The municipalities located in the southernmost area around Gorizia show a lower seismic hazard e.g. 0.148 g in Gorizia for the same event with a return period of 476 years.

2.1.2. Slovenian Region

At the Slovenian side of the Pilot 1 region, the following six municipalities were selected: Kanal, Brda, Nova Gorica, Šempeter-Vrtojba, Renče-Vogrsko, Miren-Kostanjevica (**Figure 2.3**). The total study areas of the Slovenian and Italian side are comparable; however, Slovenian municipalities are larger in view of the area size, therefore the number of municipalities in the region is lower. The versatile topography of the region strongly influences spatial distribution of settlements which are highly spatially distributed. Only the city of Nova Gorica with several surrounding settlements present larger urban area.

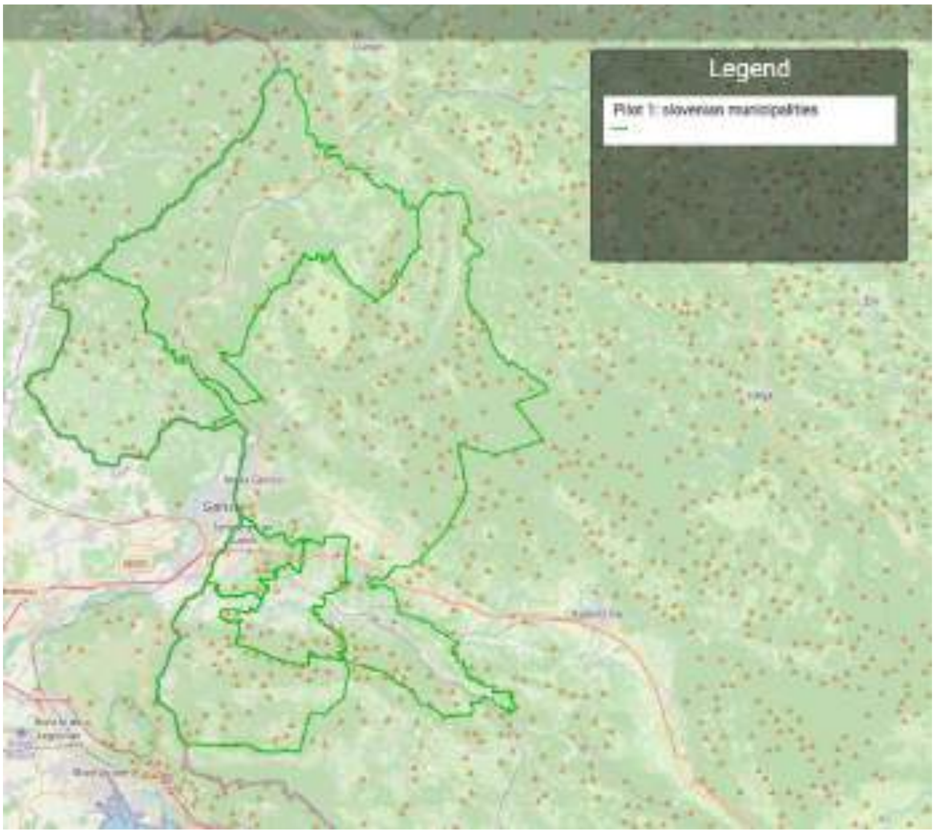


Figure 2.3: Slovenian municipalities in Pilot 1 area.

Decision on municipality inclusion in the Pilot 1 cross-border area was made similarly as described in the previous section (Italian region). More specifically, presence of historical events including both hazards (i.e. floods and earthquakes) was analysed and some data on past events were collected. The main rivers in the Slovenian part of the pilot region are Soča and Vipava River, with its tributaries. Soča River is an alpine torrential River with snow-river regime, generally the river has high discharges in late spring and autumn. The maximum discharges on Soča river exceed 2000 m^3/s while the minimal are as low as 10 m^3/s (for the hydrological station Solkan I).

Vipava River is a river with a Karst hinterland, has a rainfall-snow regime, maximum discharges are generally in late autumn and early spring. Vipava River has also torrential character, with maximum discharges over 300 m3/s and minimal less than 2 m^3/s (Hydrological station Miren I).

Recorded flood events by Slovenian Slovenian Environment Agency in the area after 2000 are: 27.-28. 10. 2012; 5. 11. 2012; 18.-20. 9. 2010; 25. 12. 2010, and 30. 3. 2009. Regarding the floods, regions along rivers Vipava and Vrtojbica are defined as areas of potential significant flood risk.

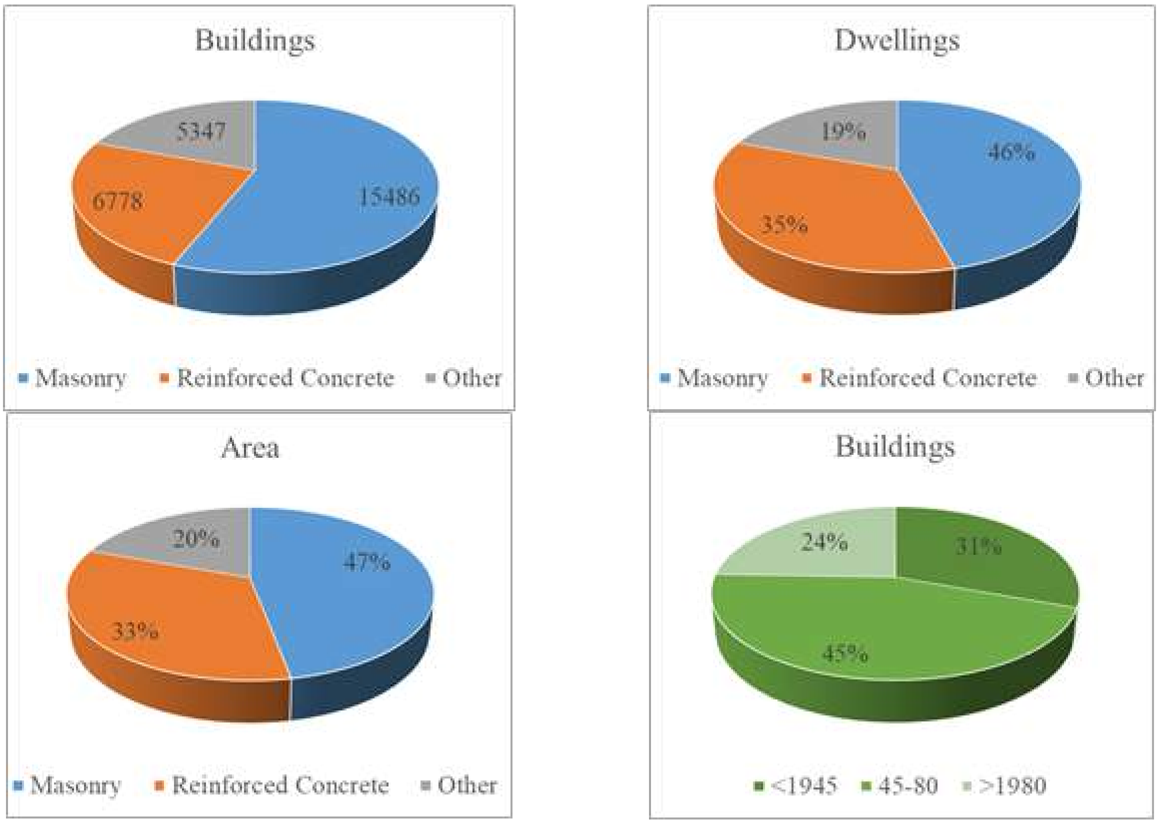
The area is also prone to earthquakes. The maximum PGA on rock or rock-equivalent sites for the return period of 475 years ranges from 0.14 g to 0.17 g, which refers to the moderate seismicity level.

2.2. Collection on input data on the regional level

2.2.1. Assets at risk - building stock

In **Italy**, exposure data are provided by ISTAT (National Institute of Statistics). The last census database (ISTAT 2011) includes buildings' information on construction material (masonry, reinforced concrete or other), number of storeys (1, 2, 3, 4 or more) and construction period (>1919, 1919–1945, 1946–1960, 1961–1970, 1971–1980, 1981–1990, 1991-2000, 2001-2005, >2005). The footprint of residential Italian buildings, relevant to flood risk assessments, comes from OpenStreetMap. Each building is also associated with a weight related to the building use "residential" and "not-residential" that derives from the GHS-BUILT-S R2022A - GHS built-up surface grid (Pesaresi and Politis, 2022).

There are a total of 27611 buildings in Italian municipalities in Pilot 1 area, subdivided into 15486 masonry (56%), 6778 reinforced concrete (25%) and 5347 other structural type (19%). The average number of stories is 2 storeys for all structural types. In relation to construction period, there are 31% buildings constructed before 1945, 45% between 45 and 1980, and the remaining 24% after 1980. The graphs shown in **Figure 2.4** show distributions of materials, construction periods and stories per buildings, dwellings and areas (m^2).



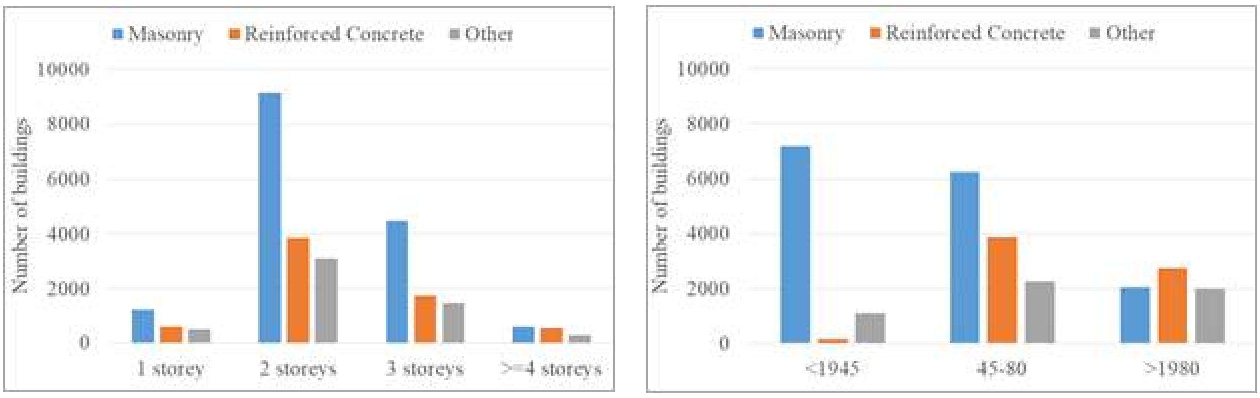
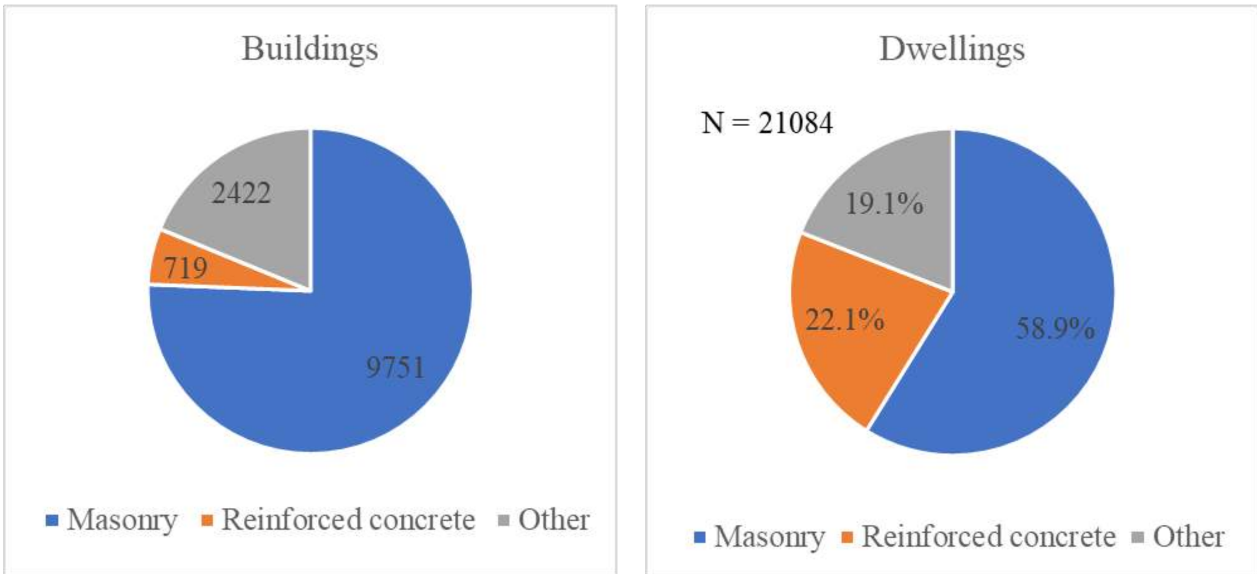


Figure 2.4: Characteristics of the building stock distribution in the Italian pilot area

On the **Slovenian** side of the Pilot 1 region, there are 12892 buildings located according to the census database (MOP, 2020). The census database includes also information about number of storeys, number of dwellings, population, and building material. More than 75% of the buildings is classified as masonry, other shares, namely 5.6% and 18.8% correspond to reinforced concrete buildings and other buildings, respectively. Most of the buildings have two storeys. In the region, almost 20% of the buildings were built before 1919 and almost 20% between 1919 and 1945. Between 1945 and 2000 more than 50% of the buildings were built. The **Figure 2.5** below shows information about buildings in the region, more specifically, the number of buildings according to the construction material, number of dwellings in individual type of the building, area of the buildings in m^2, period of construction, number of storeys according to the construction material, and period of construction according to the construction material.



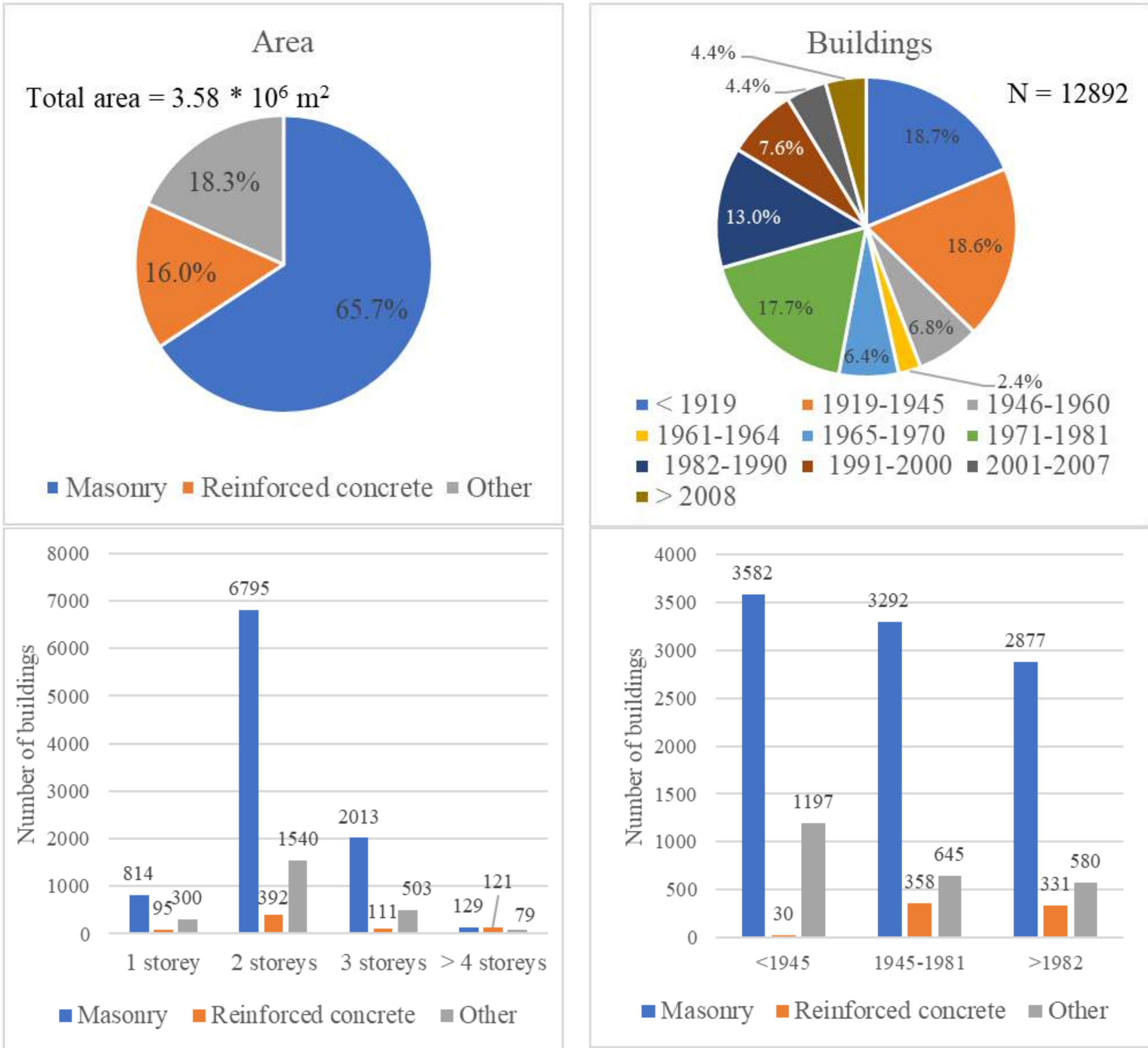


Figure 2.5: Building stock distribution on the Slovenian side of Pilot 1 region (border with Italy)

2.2.2. Assets at risk – population

Italian population data are derived, like those for buildings, from the ISTAT 2011 census. The total population in the Italian municipalities of Pilot 1 area is 104628 people, 45% (47575) of whom live in masonry buildings, 35% (36758) in reinforced concrete buildings, and 20% (20295) in buildings of other structural type. Most of the population (47%) live in buildings constructed between 1945 and 1980, 31% in newer buildings (constructed after 1980), and the remaining 22% in older buildings (constructed before 1945). Finally, in relation to the distribution of the population in buildings of different heights (and thus number of floors), the majority of the population living in masonry buildings are in low buildings (1 or 2 storeys) while the majority of the population living in reinforced concrete buildings are in buildings that have 3 or more storeys. The graphs shown in **Figure 2.6** show the distributions just described.

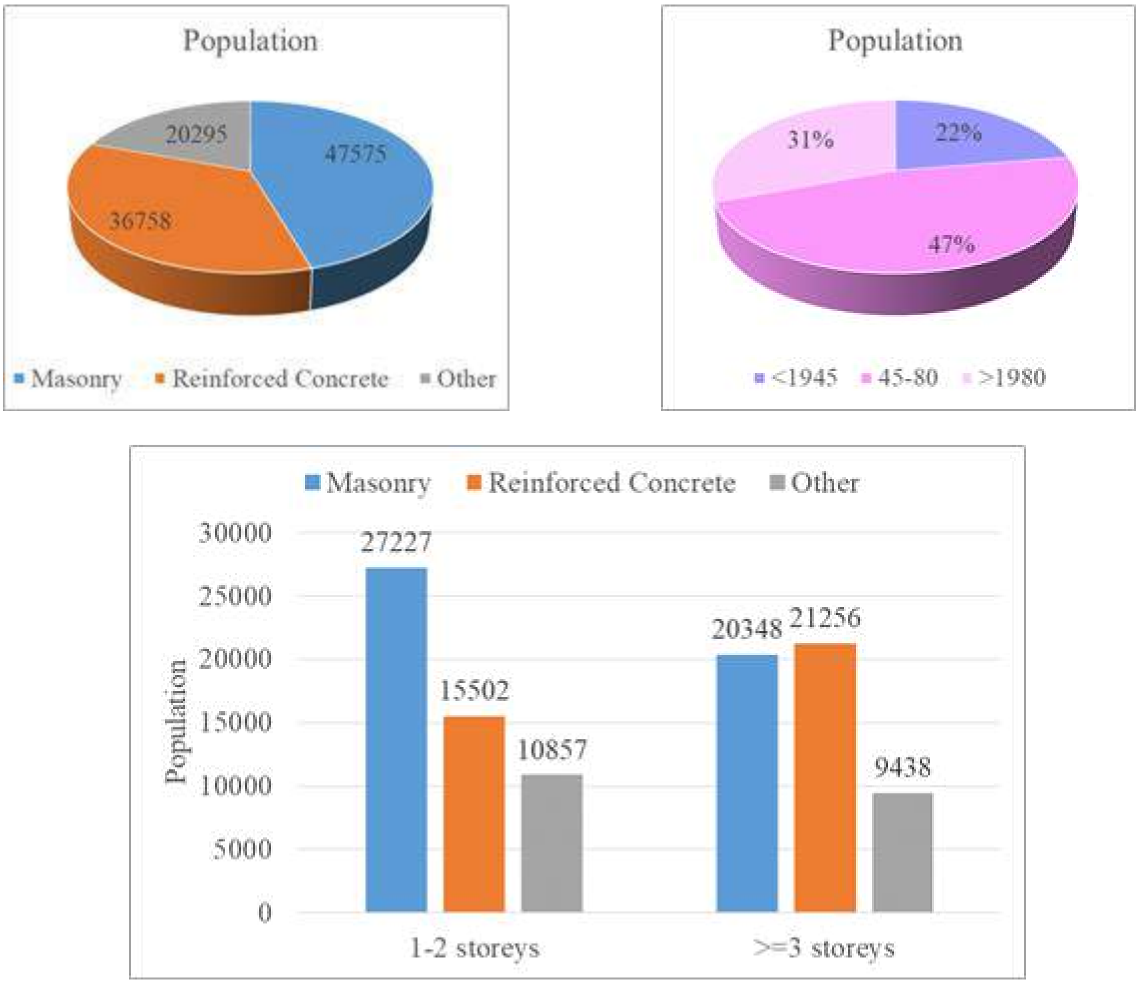


Figure 2.6: Italian population distribution

In the **Slovenian** region of Pilot 1, according to the census data from year 2020, 56437 people was living. Around 64% of the people live in masonry buildings, while in buildings classified as reinforced concrete and other, live 17.2% and 18.6% of the people, respectively. The majority of the population lives in buildings that were built after year 1945 (71%). Additionally, most of the population in the region (46%) lives in masonry buildings with one or two storeys. 18.5% of the people live in masonry buildings with three or more storeys. Some additional information about relation between number of population and construction type of the building in the region can be found on the **Figure 2.7**.

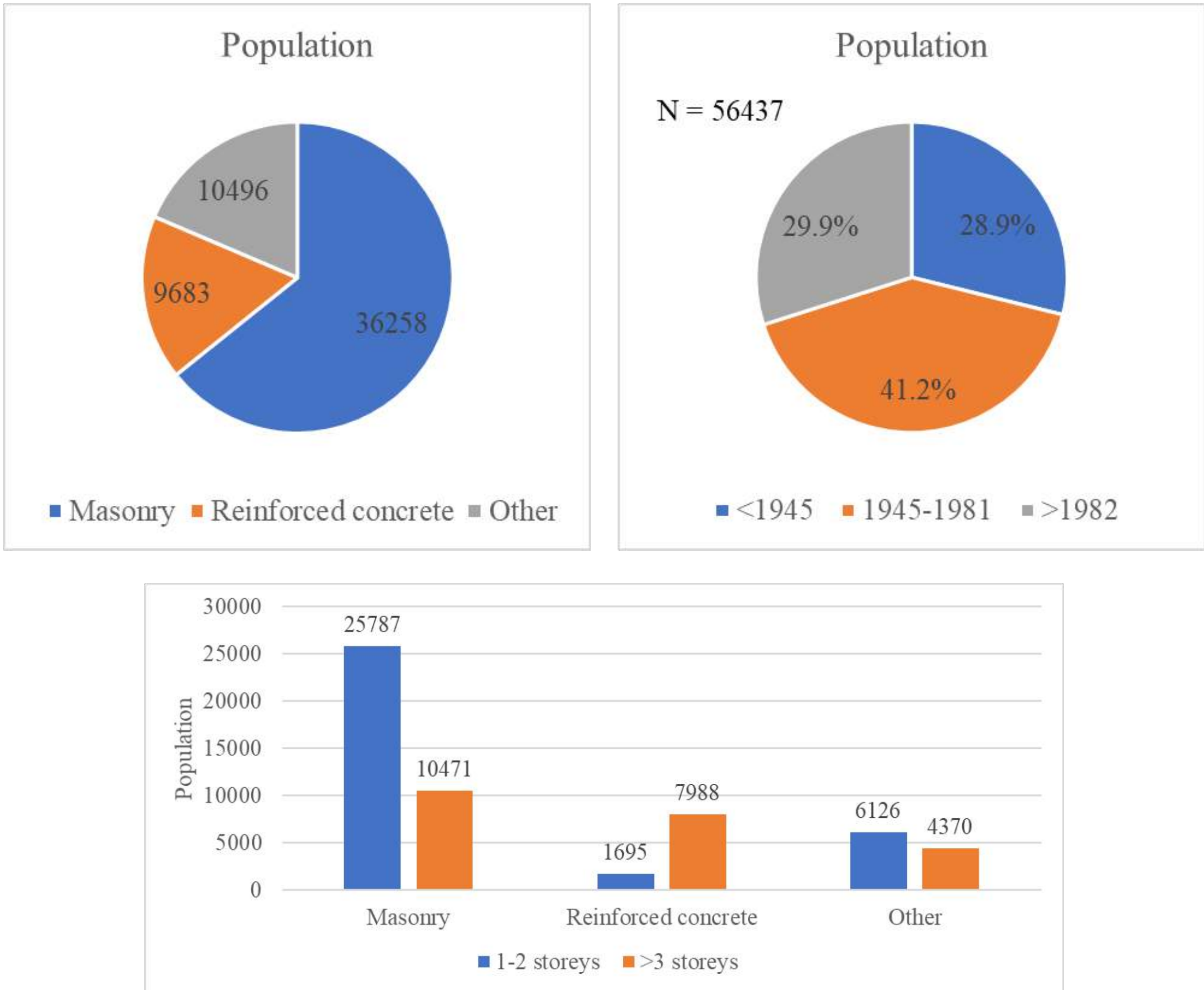


Figure 2.7: Distribution of Slovenian population in Pilot 1 region (border with Italy)

2.3. Cross-border seismic risk assessment

The seismic risk assessment was performed adopting the methodology described in section 3.2 of deliverable D4.1 (BORIS, 2022). In particular, shared or harmonized models for seismic hazard, vulnerability and exposure were adopted, allowing for consistent risk assessment in transboundary areas.

2.3.1. Seismic hazard, vulnerability and exposure

Concerning seismic hazard, the 2020 Euro-Mediterranean Seismic Hazard Model (ESHM2020), was adopted (Weatheril et al., 2020). The PGA values at geographic points corresponding to the barycentre of each municipality of the pilot are reported for six return periods (Tr=50, 101, 476, 976, 2500 and 5000), as derived from the ESHM2020 model. **Figure 2.8** shows the hazard map for earthquake considering an event with a return period of 2500 years. Similarly, other hazard maps for the remaining return periods can be viewed on the platform. hazard map for earthquake considering an event with a return period of 2500 years. Similarly, other hazard maps for the remaining return periods can be viewed on the platform.

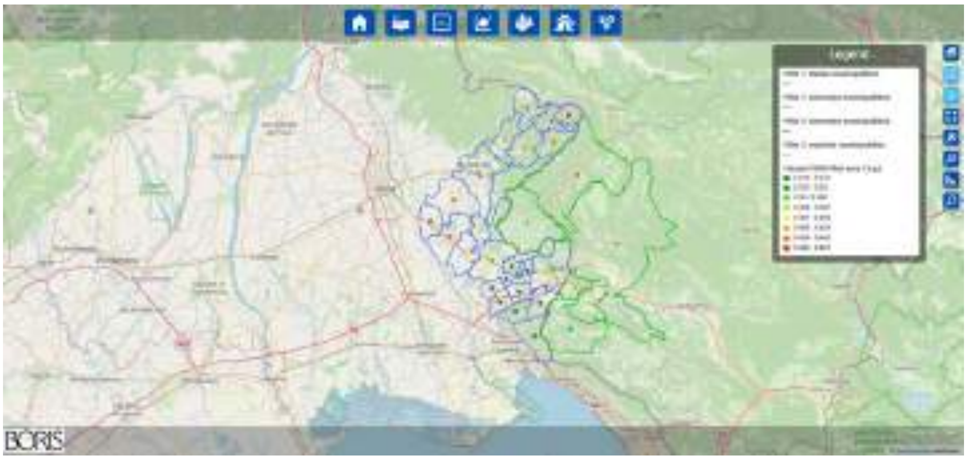


Figure 2.8: Seismic hazard map for Pilot 1 considering an event with a return period of 2500 years.

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. In particular, the local maps with Vs30 values are used to account for the soil effects on the cross-border area analysed. Based on the Vs30 values, the amplification factors are determined by considering the guidelines from the draft version of the new EC8 (CEN, 2022). In **Figure 2.9** the soil classes map for Pilot 1 is reported: it shows for each municipality the value of Vs30 (shear wave velocity at 30 m depth) calculated at the barycentre of the municipality. It is also possible to display in pop-up windows the distribution of soils within each municipality, i.e. % of soil A, B, etc.

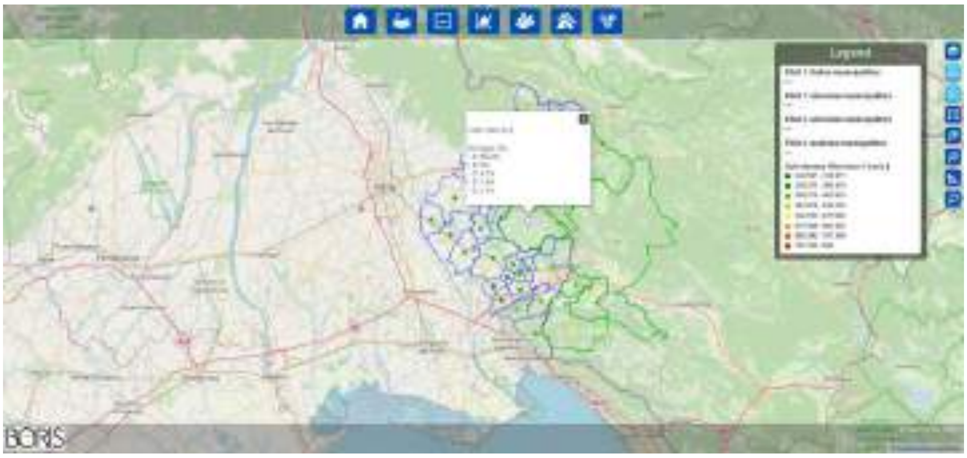


Figure 2.9: Soil classes map for Pilot 1.

Concerning exposure, according to the methodology proposed in D4.1, the buildings are subdivided in typologies based on construction material (masonry, reinforced concrete and other), number of storeys (1-3, >=4) and age (in the suitable age ranges intervals, e.g. <1965; 1965-1982; >1982). The exposure tab allows to display the number of buildings belonging to each typology characterized by these three variables (material+age+storey number), in each municipality. **Figure 2.10** shows an example of how the exposure is displayed on the BORIS platform for a selected municipality: for the taxonomies identified according to material, period, and number of storeys, the table shows, in addition to the number of buildings, also, the number of dwellings, the surface area, and the population.

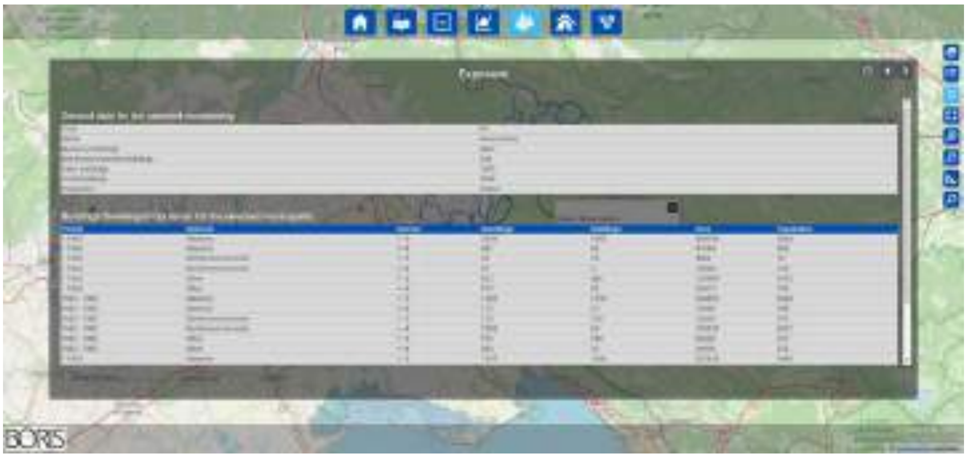
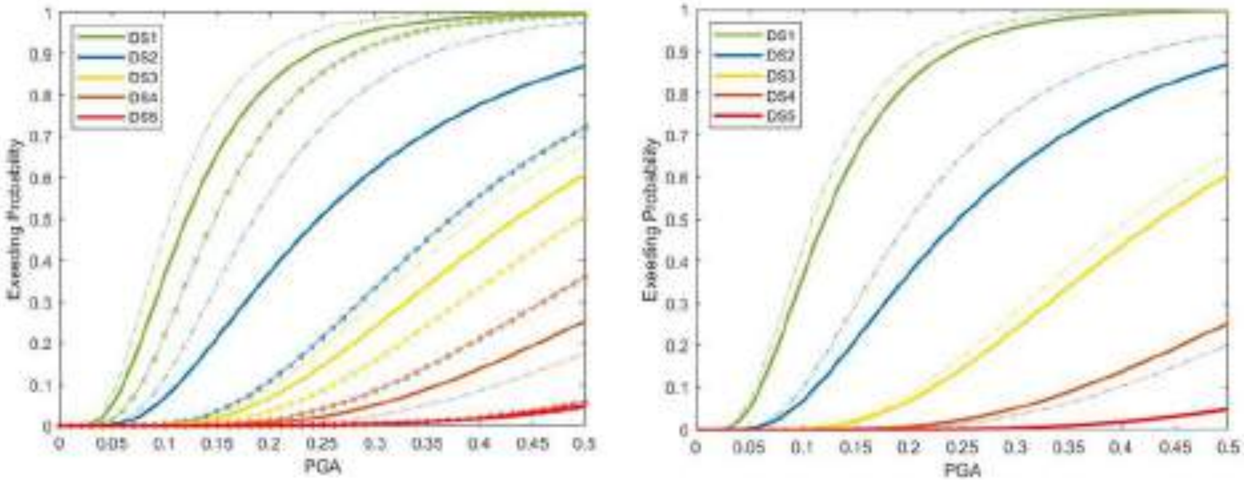


Figure 2.10: Exposure for Nova Gorica in terms of dwellings, buildings, surface area and population.

For each building typology the fragility curves are built adopting the methodology described in section 3.2.3 of D4.1. According to the method, for the same building typology it is possible to obtain different fragility curves depending on the side of the border for which they are calculated. Hence, it is possible to visualize in the web-platform the fragility curves calculated for classes in each side of the border (in this case for Italy and Slovenia); for comparison purposes it is also possible to see contemporarily both curves. The practical application of the heuristic method to the Pilot 1 shows that most of the fragility curves are very similar. However, there may be some relevant differences, as shown in **Figure 2.11**. In particular, **Figure 2.11(a)** shows the fragility curves obtained by the Italian side of the border for Low RC buildings built before 1965; in the same figure also the original fragility curves for the same typology used in Italy and Slovenia are shown. For comparison, **Figure 2.11(b)** shows the fragility curves obtained by application of the heuristic method by the Italian side of the border and by the Slovenian side of the border. From **Figure 2.11(b)** it can be seen that a certain difference of curves is obtained; this is due to the different weights assigned to Italian and Slovenian model in the heuristic combination depending on the incidence of the considered typology in the cross-border area (see definition and application of the typological weights in D4.1 for more details).



(a) (b)

Figure 2.11: Fragility curves for RC buildings, Low class of height, built before 1965. (a) fragility curves obtained by the Italian side of the border compared to the original fragility curves for Italian and Slovenian model; (b) fragility curves obtained by the Italian side of the border compared to fragility curves obtained by the Slovenian side of the border

The platform allows also to visualize the seismic fragility curves: in **Figure 2.12** an example is reported for buildings in reinforced concrete, built before 1965 with a number of storeys between 1 and 3 (in figure it is shown the case where both curves for Italy and Slovenia are shown contemporarily).

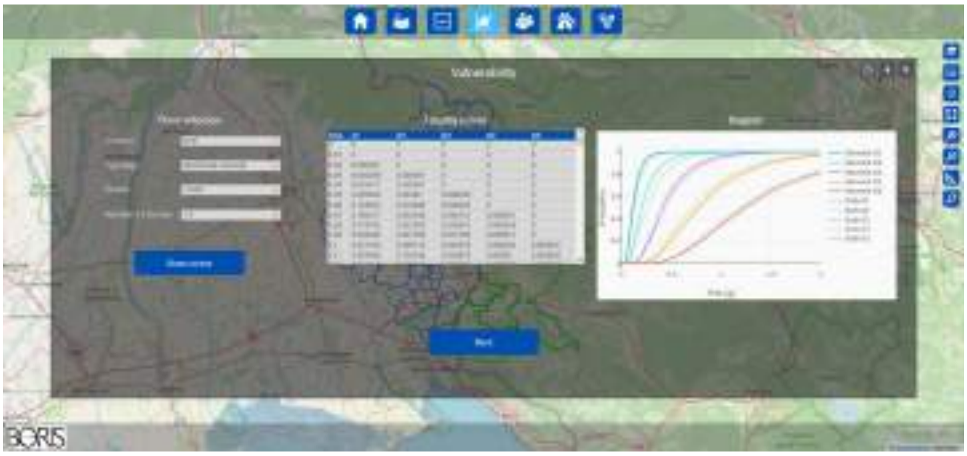


Figure 2.12: Visualization of the seismic fragility curves on the BORIS platform.

2.3.2. Risk Results

As discussed in D4.1 (BORIS, 2022), a time-based risk assessment is performed and for both pilot applications the time frames of 1 year and 50 years are considered. For each time frame, risk results are represented both in terms of expected damage and in terms of impact indicators. Concerning damage, results may be visualized both in terms of Table (the tabular visualization reports for each municipality, and then for whole municipalities taken into account, the number and percentage of buildings that reach the 5 damage levels of the EMS98 scale (Grünthal 1998)), and Map. Visualization on a map consists of colouring each municipality in function to the damage value the user decides to visualize. For example, each municipality could be coloured according to the number of buildings reaching damage level D2 in the 50-year time window.

The table in **Figure 2.13** shows how the damage results for seismic risk are visualized on the BORIS platform: for each municipalities the number and the percentage of buildings in the five damage levels (from D1 to D5) are reported.

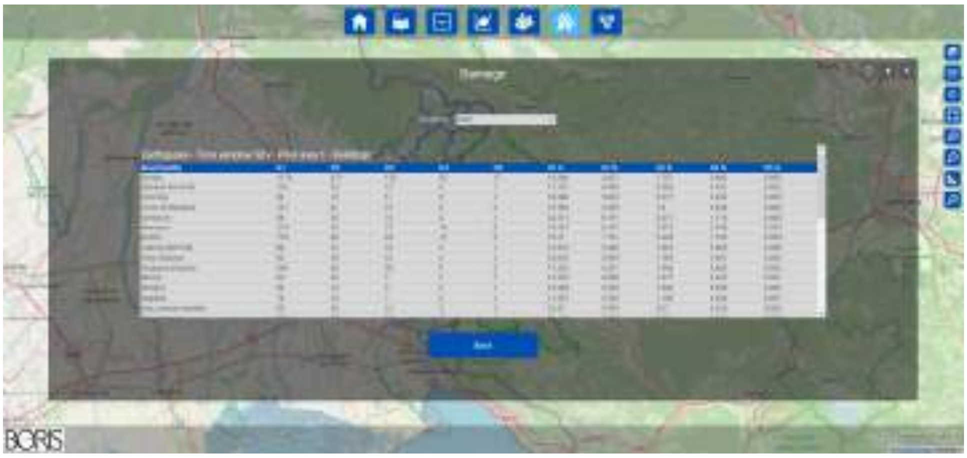


Figure 2.13: Damage results for seismic risk in Pilot 1 in tabular form.

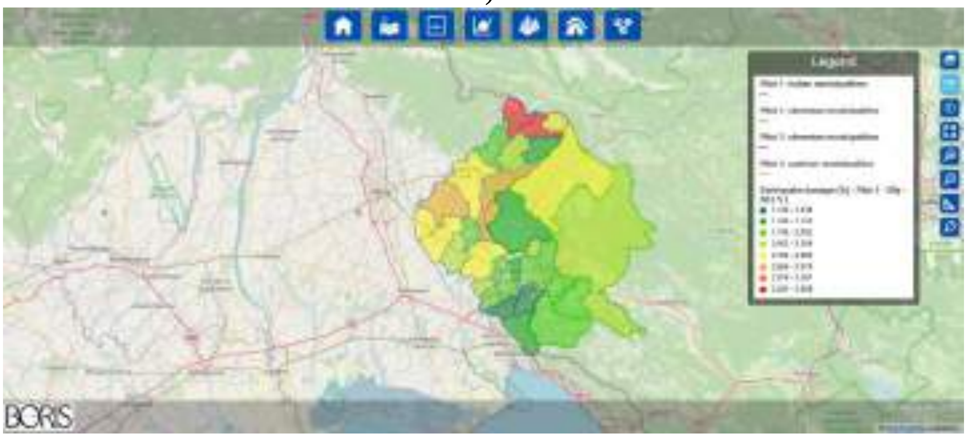
Figure 2.14, **Figure 2.15** and **Figure 2.16** (a and b) show the maps obtained for damage levels D1, D3 and D5 for time frames 1 year and 50 years respectively (representation in terms of % damage).

a)

b)

Figure 2.14: Percentage of buildings in D1 for seismic risk in Pilot 1: a) in 1 year; b) in 50 years.

a)



b)

Figure 2.15: Percentage of buildings in D3 for seismic risk in Pilot 1: a) in 1 year; b) in 50 years.

a)

b)

Figure 2.16: Percentage of buildings in D5 for seismic risk in Pilot 1: a) in 1 year; b) in 50 years.

As it can be noted, the seismic risk in Pilot 1 area has higher values in municipalities located in Italy than in those located in Slovenia, which in any case for damage level D3 in 50 years do not exceed 25 %. The greatest risk is in the municipalities located to the north and particularly in the municipalities of Savogna, Grimacco and Dolegna del Collio. The two largest cities in the area under study, Gorizia in Italy and Nova Gorica in Slovenia, show risk values for D1 in 50 years of 15 % and 13 % respectively, meaning that from a statistical point of view only 15 of 100 buildings, for example, reach the level of light damage in a 50-year time window. The proportion of buildings in a municipality reaching the D1 damage states in 50 years is expected to range between 11.5 % and 23.2 %. For the D2 damage state, this proportion is expected to be between 3.4 % and 9.1 %, for the D3 damage state between 1.1 % and 3.6 %, for the D4 damage state between 0.4 % and 1.2 % and for the D5 damage state between 0.1 % and 0.5 %.

The following **Figure 2.17** shows the table with the losses calculated in a time window of 50 years for seismic risk in the Slovenian municipalities in Pilot 1. These losses can also be shown on a map: **Figure 2.18** shows, for example, the map with the unusable buildings in long term for seismic risk in Pilot 1.

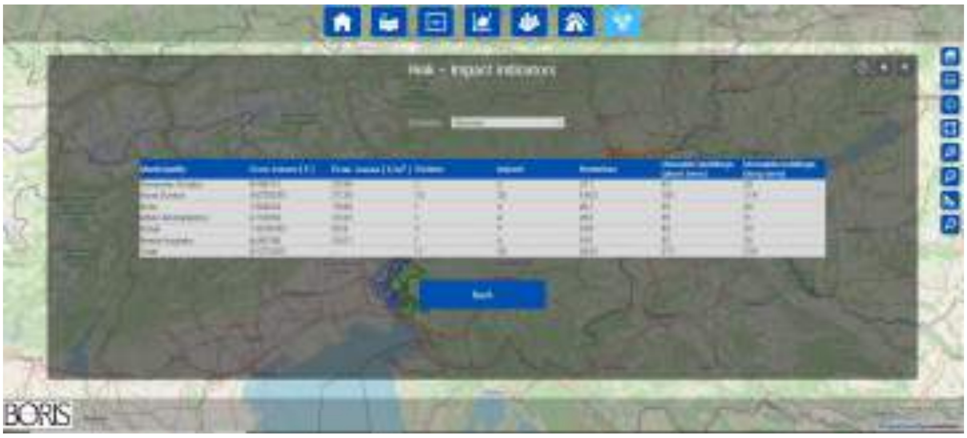


Figure 2.17: Losses in a time window of 50 years for seismic analysis in Pilot 1.

Figure 2.18: Map of unusable buildings (long term) in a time window of 50 years for seismic risk in Pilot 1.

Concerning risk-impact indicators, they are calculated adopting the consequence functions described in section 3.2.4 of D4.1. In particular, the direct Economic losses, (total losses in Euro and Euro/m2), the Injured and Victims, Displaced people and Unusable buildings in the short and long term are calculated. As for damage results, also the impact indicators refer to time windows of 1 or 50 years. The economic losses due to earthquakes in the next 50 years are expected to be between 17.7 € and 51 € per 1 m^2 of a municipality's residential floor area, with the highest values in the municipalities of Savogna and Grimacco, in Italy. The number of buildings in a municipality that are expected to be short-term unusable due to earthquakes in the next 50 years ranges from 7 to 206. For the long-term unusable buildings, the number of buildings ranges from 4 to 134. Furthermore, it is expected that earthquakes in a 50-year window will be fatal for not more than 10 residents, where the highest values are obviously found in the most populous municipalities that are Gorizia and Nova Gorica. It is also expected in a 50-year time window to have a maximum of 33 injured and a range from 8 to 1468 of displaced people. The variation in seismic risk in Pilot Area 1 is mainly influenced by the vulnerability of buildings. In fact, the Italian municipalities located in the north and two Slovenian cities, Nova Gorica and Kanal, have the highest seismic hazard values and are similar to each other, however, the two Slovenian municipalities mentioned above show lower damage and loss per square meter than the Italian municipalities, despite being very populous. In fact, comparing the fragility curves adopted for risk calculation it can be observed that averagely the curves for Italian buildings are more sloping than those for Slovenian buildings, which indicates more vulnerable buildings.

2.3.3. Limitations and Future needs

The seismic risk assessment for the Pilot 1 area contains several limitations. One of them is the ESHM2020 model, which was used in the BORIS project because it provides hazard values that change smoothly over country borders. The ESHM2020 model provides PGA values only for return periods up to 5000 years. For higher return periods that also affect the risk calculation, the PGA values were obtained by extrapolating the hazard curves, which may result in a slight bias in the risk estimates. Future studies could focus on developing a hazard model specifically for the cross-border area under consideration. Such a model could take into account the region-specific systematic effects, including the local soil effect, other site effects, source effects and path effects. A possible strategy to include such effects is to utilize non-ergodic ground-motion models (e.g., Lavrentiadis et al. 2022) in the hazard analysis.

Limitations were also found in the exposure model. The latter considered only residential buildings and population, while other assets (e.g. buildings and infrastructures) were disregarded. These assets can have a considerable impact on the overall seismic risk. Moreover, it should be noted that seismic exposure varies over time, which further causes variation in risk. Some exposure parameters evolve slowly, while others can change rapidly. One such parameter is the building replacement cost, which is impacted by construction costs. This limitation can be addressed by periodically repeating the risk assessment.

Improvements can also be made to the vulnerability model. The vulnerability models developed for the entire Italian and Slovenian territories were used as the basis for the vulnerability assessment in the current application. These vulnerability models may be biased if applied to a specific region and not to the countries as a whole. The development of a region-specific vulnerability model could address this limitation. However, it should be emphasized that developing a building vulnerability model is not straightforward. In the future, more effort should be made to develop a harmonized European methodology for seismic vulnerability assessment, analogously to that addressing the seismic hazard, as discussed in Deliverable 4.1.

2.4. Cross-border flood risk assessment

For the flood risk assessment of the Pilot 1, the area of interest is the hydrological basin of Isonzo river. The Isonzo river originates in Val di Trenta (Slovenia) from springs located at an altitude of 935 and initially develops in the Slovenian territory for about 100 km; near Gorizia it enters Friuli Venezia Giulia and then heads south until it flows into the Adriatic Sea after having traveled a total of 140 km. Its hydrographic basin develops for about 2/3 in the Slovenian territory and the remainder in the regional territory, for a total of 3416 sq km. The main tributaries are the Coritenza and the Idria in Slovenian territory, the Torre and the Vipacco in the regional territory. Important tributaries in the sub-basin of the Tower are the Natisone and the Judrio.

According to the methodology proposed in D4.1, the harmonized approach for the cross-border flood risk analyses is based on the following steps:

- ***For the hazard component***: for each flood map with assigned return period the corresponding flood depth will be calculated and then interpolated for more flood hazard maps for different return periods.

Needed Data are at least one flood extension map (from EU floods Directive) and high-resolution DTM (at least 5mx5m);

- ***For the exposure component***: the procedure for the definition of the harmonized spatial scale and exposure model consists of the integration of information on built-up area and population at global level, additional data available at local scale and downscaling methodology to implement the global information on the building footprints;
- ***For the vulnerability component:*** The library selected for describing the relationship between the state variables describing the forcing affecting a specific asset in case of flood event and the damage suffered is the HAZUS (FEMA, 2009). They are function of occupancy and number of floors, and they are provided separately for structure and for content;
- ***For the consequence component:*** in the shared methodology the indicative number of inhabitants potentially affected and the economic consequences in terms of AAL and PML are considered.

These steps are proposed to carry out ***a baseline assessment***, based on the same information on each element of risk analysis (above all the exposure one) among the different countries. It should be a more easily replicable and simpler procedure. In this way the uncertainty due to different input data could be reduced.

2.4.1. Flood hazard, vulnerability and exposure

The methodology described before has been implemented in detail for pilot project 1 as follows. The result representing the ***hazard element*** in a risk analysis is the flood hazard map. Hazard flood maps are maps of flood extension and depth for a specific probability of occurrence (return period). **Figure 2.19** shows an example of flood hazard map available for consultation from the BORIS platform for Pilot 1, considering an event with a return period of 500 years: the five colors correspond to different depth values.

For the cross-border flood risk assessment, the first activity was to obtain homogeneous hazard maps (for the same return periods) that can be used for risk mapping having as input not homogenous maps of flood prone areas (different return period and without the associated flood depth). In particular, a simplified approach to assess flood harmonized hazard curves in cross-border basins is proposed and starts from the results of the EU Floods Directive. Moreover, the method allows to further elaborate the flood hazard maps by defining flood scenarios (flood extension and depth) with return periods from 10/30 years to 300/500 years with a pre-defined timestep (e.g. 10 years). In this way, a flood hazard curve can be easily defined for each point (5m resolution) of the cross-border catchments considered.

Figure 2.19: Flood hazard map for Pilot 1 considering an event with a return period of 500 years.

In the following is further detailed the procedure applied for obtaining homogeneous Flood hazard maps (flood extension) in terms of return period, also adding the associated flood depth. The Flood hazard maps available for the EU Floods Directive are easily available only as maps representing the flooded area for assigned return time T. However, in order to use the maps produced in response of the EU Floods Directive for risk evaluation we need at least the flood water depth associated to the flood extension available for assigned return period. To achieve this goal, as we apply the FwDET algorithm able to associate to the flood extension (in input) the flood water depth by considering the level reached by the water when covering the input extension. For applying FwDET we start from: DTM available from Austria and Slovenia and the two flood prone areas in the two countries from the EU Floods Directive. In order to solve possible local mismatch between DTM and flood-prone areas or local anomalies we use a post processing tool available in GRASS GIS. And we harmonize them in order not to have discontinuities in both pilot areas 1 (Italy-Slovenia) and 2 (Austria-Slovenia) along the borders. With this approach can associate flood water depth to flood hazard extension but in order to obtain the same probability of occurrence (in the two sides of the cross-border areas) and to increase the number of flood hazard maps available (for better estimating to flood hazard), we used an ad hoc algorithm that "interpolate" flood hazard maps between two different return periods, starting from specific curves that associate a specific flood volume to a specific return period. For this region we produced flood hazard maps (water depth and extension) for T ranging from 20 to 300 years.

The availability of reliable and accurate information is a fundamental pre-requisite for deriving an acceptable ***exposure model***, and consequently a useful and reliable risk profile. For this reason, the phase of collection and comparative analysis of available data lasted some months during the project.

The exposure model has been defined starting from the following available data:

- Statistical data;
- Available exposure models;
- Global datasets on population distribution, settlement identification and land use/land cover. These datasets have the great advantage to have a global coverage and therefore to ensure a minimum background exposure knowledge to perform acceptable risk analyses;
- Building footprints, that is the reference layer for the flood risk.

The first statistical information that has been considered is the Census for the population of Italy that provides publicly accessible information on buildings, dwellings and population at census tract level. As mentioned, in the §2.2.2, the Italian population data are derived, from the ISTAT 2011 Census. While for Slovenia, the average number of people per housing unit in each municipality is provided by Central Population Register §2.2.2

Two exposure models have been analyzed in order to derive information useful for defining the specific model to be adopted in this study. Firstly, the exposure model from GAR (Global Assessment Report, UNDRR 2019) is used as a minimum level of description, it is a shape points layer, representing a 5x5 km area, reports information on the economic value and the population associated to each typology of building, in terms of both occupancy (socio-economic sector) and main constructive typology. Secondly, the model developed by the ESRM20 (European Seismic Risk Model, Crowley et al. 2021) exposure model that represents the spatial distribution of the residential, commercial, and industrial building count, population, replacement cost, construction type, number of dwellings (dwellings per building and area per dwelling), floor area and number of storeys. These layers were analyzed but not adopted for the construction of Boris exposure model, since the information was grouped in specific non-homogeneous points on the territory and among the different countries involved.

To have information spread evenly throughout the territory, the adoption of global products was preferred. In this category falls into the GHSL (Global Human Settlement Layer), GHS-BUILT-S R2022A - built-up surface grid, derived from Sentinel2 composite and Landsat, multitemporal (1975-2030) (Pesaresi and Politis, 2022). This spatial raster dataset depicts the distribution of built-up surfaces, expressed as number of square meters. The data reports about the total built-up surface and the built-up surface allocated to dominant non-residential (NRES) uses that has been implemented to associate a vulnerability characteristic, as the building usage (residential and not-residential) to each building. This association has been developed in GIS through a statistical zonation and it represents the probability of being residential and non-residential building to each asset.

OpenStreetMap (OSM) layer of building footprints updated to the 2020 has been adopted (**Figure 2.20**).

From the global data a downscaling methodology to implement the global information on the building footprints has been adopted to determine a spatial distribution of the following indicators: residential population and the factors describing the vulnerability of the built-up as the building usage and number of storeys. When possible, the downscaling procedure is controlled with the data deriving from census or local data. This buildings characterization is obtained merging in the GIS environment these several sources.

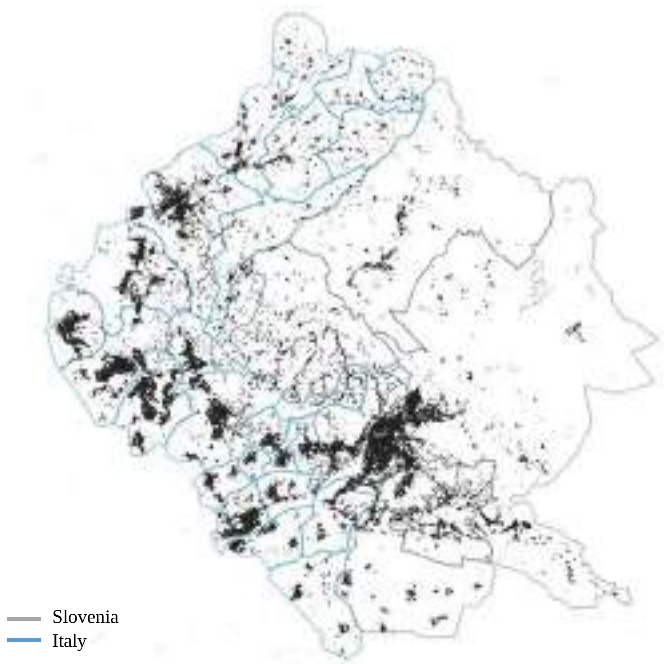


Figure 2.20: Open Street Map Building Layer – PILOT 1

Figure 2.21 below shows the buildings footprint layers for the Italian and Slovenian municipalities in pilot 1 uploaded into the platform: by clicking on a building, it is possible to see the percentage of residential and non-residential surface.

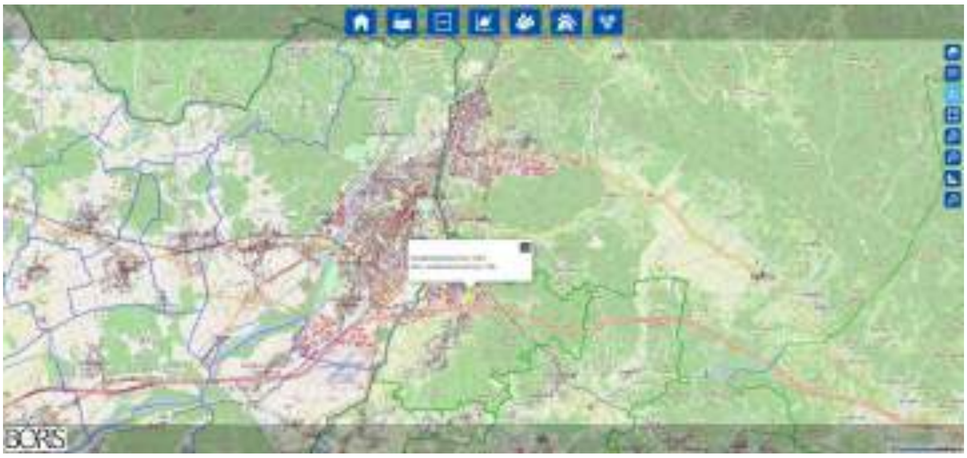


Figure 2.21: Buildings footprint for Pilot 1.

The ***residential population*** corresponds to the number of people associated to each house. The population figures come from the Census, available at Municipalities level. Within each administrative unit, the corresponding population is assigned to the buildings weighting with the overall available surface, thus also considering the number of floors. These data are used to evaluate affected people.
For the exposure characterization in terms of the ***vulnerability characteristics***, that are building use and number of storeys a logic tree approach has been implemented (**Figure 2.22**). Logic-trees were made to assign

the vulnerability characteristics to each building. Weights of discrete branches that represent alternative hypotheses and interpretations were determined by: 1) the abovementioned GHS-BUILT-S R2022A (Pesaresi and Politis, 2022) for the building use (in figure GHS-W_{RES} and GHS-$W_{NOT-RES}$); 2) local data aggregated at municipality level for the number of storeys (adopted also in the seismic analysis, MUN-W_{NoS}). After this process each building has to be associated to four vulnerability curves.

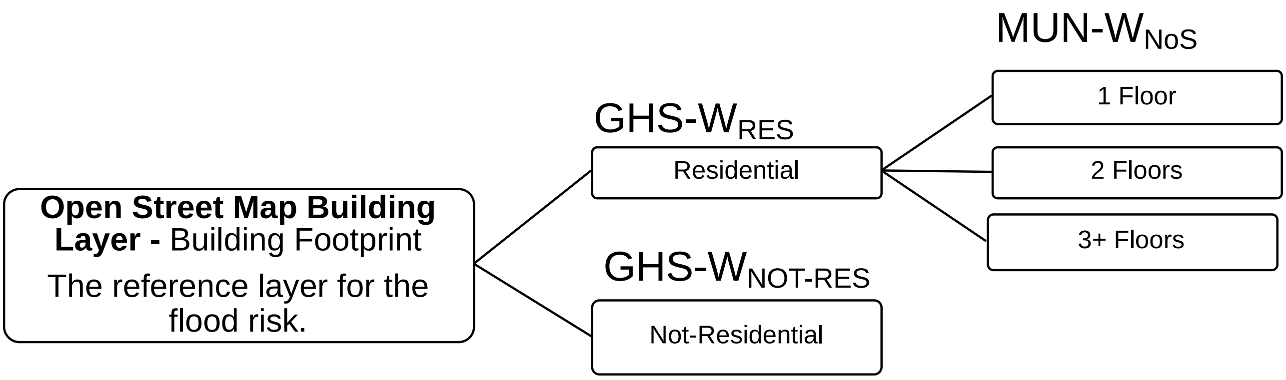


Figure 2.22: The logic tree approach for the construction of the exposure model in the Boris Project

For the ***vulnerability element,*** only the physical vulnerability is considered. For which a hazardous conditions generate a certain degree of physical damage [%], loss and population affected. As mentioned before, the vulnerability curves consider in the analyses of this project are the HAZUS curves, developed by the Federal Emergency Management Agency (FEMA, 2009). They are water depth–damage functions for buildings developed on the basis of 20yr of empirical damage data, as well as separate functions developed by the US Army Corps of Engineers (USACE). In the present work, the curves consider as input characteristics the building type (residential and not-residential) and number of storeys, only for residential buildings (**Figure** 2.**23**).

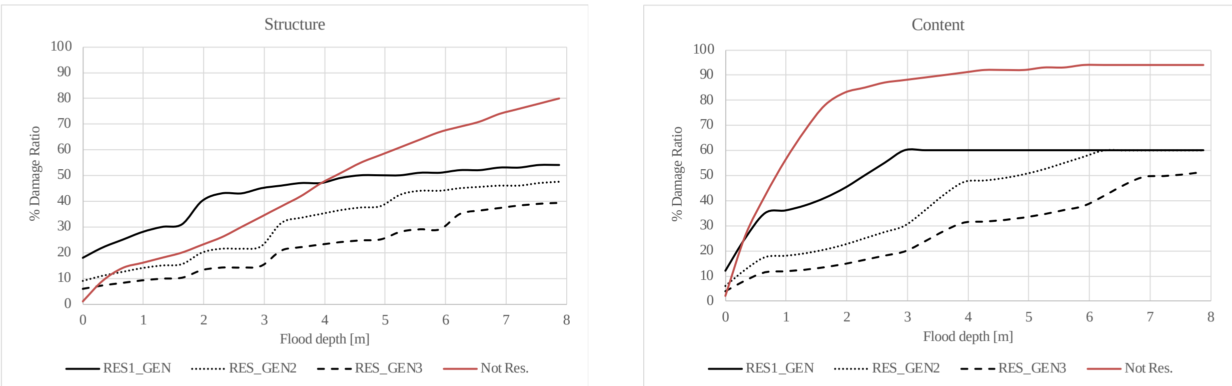


Figure 2.23: HAZUS curves function of building use and number of storeys for the residential ones (FEMA, 2009).

Figure 2.24 shows how the vulnerability curves for flood are displayed on the BORIS platform: the image reports the curves for 2-storey residential buildings, the blue line is related to structure damage and the green line is related to content damage.

Figure 2.24: Visualization of the flood vulnerability curves on the BORIS platform.

To evaluate the sensitivity of the results on the choice of the vulnerability curves, a comparison with the JRC (Joint Research Centre) curves (Huizinga et al. 2017) has been executed (**Figure 2.25**). Huizinga et al. (2017) have developed a globally consistent database of depth damage curves. This dataset contains damage curves representing damage as a function of water depth and the corresponding maximum damage values for a variety of assets and land use classes. The damage curves have been produced per damage class: residential, commerce, industry, agriculture, infrastructure, transport for each continent separately (Africa, Asia, North-America, South/Central-America, Oceania and Europe). The present application has adopted the curve proposed for the Europe. The curves have been normalized to 0.6 because what they consider total damage is 60% of the structure. So to be compared with HAZUS (FEMA, 2009) which does not have this assumption it was multiplied to 0.6. Apart from the first few centimeters (the grey line is 20 cm with respect to which we assume zero damage and unaffected population), the curves that we consider in Boris practically includes the JRC curves.

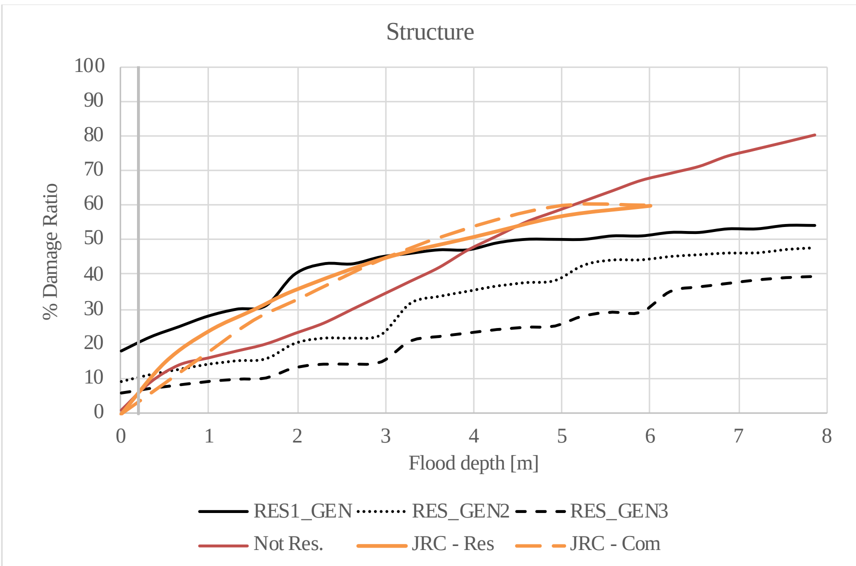


Figure 2.25: Comparison of vulnerability curves available in literature.

2.4.2. Risk Results

Each hazard map was used as input for the evaluation of impacts in terms of **potentially affected people, expected damage ratio** and **economic losses**; to this end, the following actions were performed and applied to each hazard map, also by adopting the RASOR Platform (Arrighi et al. 2018):

- A value of water depth – obtained through the overlaying with the hazard map – was assigned to each feature in the exposure model;
- By using specific physical vulnerability functions – depending on the physical characteristics of the assets – the expected damage ratio was evaluated;
- A set of performance criteria (damage states) for buildings subjected to flood hazards developed by Nofal et al. (2020) has been adopted. These performance criteria describe flood damage to buildings in terms of five damage states (DSs) ranging from insignificant damage (DS0) up to complete damage (DS4);
- Such impacts are then used to obtain the Average Annual Losses (AAL) and the Probable Maximum Losses (PML) values for each return period, for each country, considering the product among the damage ratio [%], the replacement cost [€/m2] (adopted the same for the seismic analysis), the area of the footprint [m2] and the number of storeys;
- The number of people potentially affected, considering a water depth greater than 20 cm.

Results are produced for each municipality of the Pilot 1. **Figure 2.26** shows in tabular form the results in terms of damage for the municipalities in Pilot 1. On the other hand, the **Figure 2.27Fehler! Verweisquelle konnte nicht gefunden werden.** shows the economic losses and the affected population. All these results can also be displayed on the BORIS platform as a map, as is shown in **Figure 2.28**

Considering the time frame of 1 year, the value of direct economic losses in terms of AAL amounts to € 4 million for Italy, or roughly 0.02% of the total exposure value, while for Slovenia amounts to € 2 million, 0.004% of the total exposure value.

In Italy, at municipality level, the most affected city is Gradisca d'Isonzo, in terms of ratio between AAL and the total exposure value, equal to 0.25%. It is followed by Farra d'Isonzo and Sagrado, for which the previous ratio is equal to 0.15%. In absolute terms the most affected cities are Gorizia and Gradisca d'Isonzo where AAL is about € 1 million. The same cities are those that have the most population in the affected area, approximately 100 people.

In Slovenia, at municipality level, the most affected city is Šempeter-Vrtojba, in terms of ratio between AAL and the total exposure value, equal to 2%. It is followed by Kanal, for which the previous ratio is equal to 1%. In absolute terms the most affected city is always Šempeter-Vrtojba where AAL is about € 0.8 million. It is followed by Kanal and Nova Gorica, for which AAL is about € 0.4 million. The city with the most affected population results Nova Gorica with 40 people.

Figure 2.26: Damage results for flood in Pilot 1.

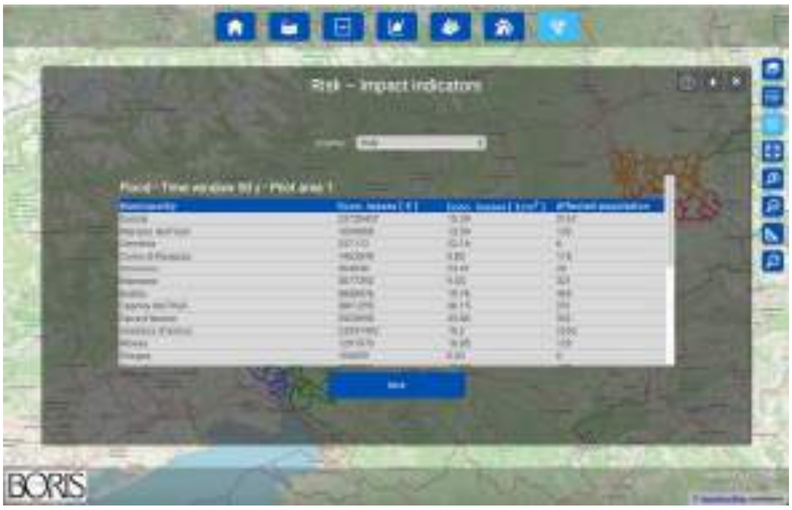


Figure 2.27: Economic losses and affected population for flood analysis in Pilot 1.

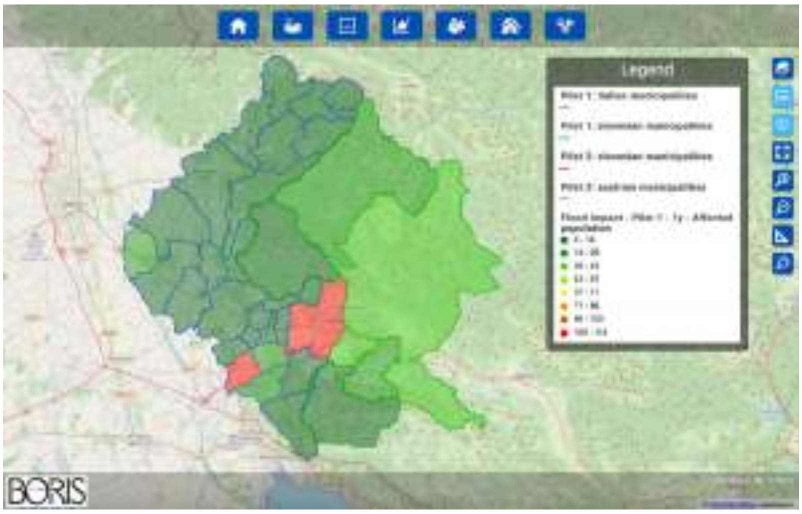


Figure 2.28: Map of affected population for flood risk in Pilot 1.

2.4.3. Limitations and Future needs

Analysis of the local provided by each country and uncertainty: Some critical issues emerged from the analysis of the materials available among the individual countries, related to the non-homogeneity of data. For example, Austria and Italy have building footprints as base layer, while Slovenia has land use, that is an area layer.

2.5. Cross-border multi-risk comparison and ranking

The ranking of flood and seismic risk was based on comparing the expected economic losses due to both hazards. This section first provides some results of the multi-risk comparison and ranking from the BORIS platform. Then, a brief discussion of the results is given.

2.5.1. Results and presentation on web platform

The multi-risk results on the BORIS platform are presented in several tables, maps and graphs displaying the following:

- The comparison of risk curves estimated for seismic and flood risk. Each risk curve represents the relationship between the annual probability of exceedance of an event (a flood or an earthquake) and the corresponding expected economic losses.
- The ratio between the EAL (expected annual loss) due to floods and EAL due to earthquakes.
- The total EAL, determined as the sum of the EAL due to floods and EAL due to earthquakes.

Figure 2.29 shows a screenshot of a table with the total EAL and the ratio between the EALs due to floods and earthquakes. The table includes the results of all municipalities in the Pilot 1 area. Moreover, examples of maps are presented in **Figure 2.30 Figure 3.30**and **Figure 2.32**. The map in **Figure 2.30** displays the total EAL in each municipality due to both hazards, while the map in **Figure 2.32** shows the ratio between the EALs due to floods and earthquakes. Further, **Figure 2.31Figure 3.32** and **Figure 2.33** each contain a pair of risk curves (related to flood and seismic risk) for one municipality. The risk curves in **Figure 2.31** are supplemented by the total EAL in the municipality (highlighted in yellow), while the ratio between the two EALs in the municipality supplements the risk curves in **Figure 2.33 Figure 3.30Figure 3.32**(highlighted in yellow).

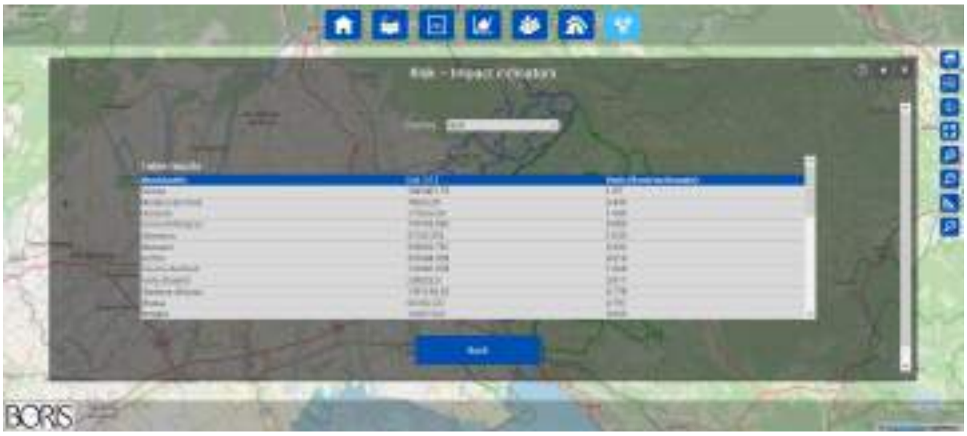


Figure 2.29: Multi-Risk in Pilot 1: table results.

Figure 2.30: Map of the total EAL for flood and earthquake in Pilot 1.

Figure 2.31: Risk curves and total EAL for the municipality of Gorizia in Pilot 1.

Figure 2.32: Map of the ratio between flood and earthquake EAL in Pilot 1.

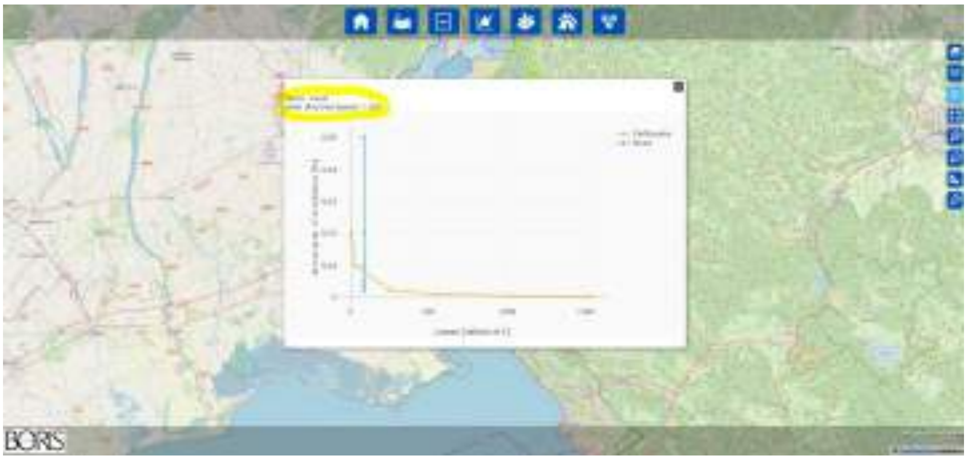


Figure 2.33: Risk curves and ratio (flood/earthquake) for the municipality of Kanal in Pilot 1.

The difference between the seismic and flood risk is reflected by the differences in the risk curves generated for the two hazards. The comparison of the risk curves generally indicates higher flood risk at high probabilities of exceedance (low return periods) and higher seismic risk at low probabilities of exceedance (high return periods). In order to obtain an unbiased ranking of risks, all return periods are considered, and the risk levels are compared based on the EALs rather than the consequences at a single return period.

The ratio between the EALs indicates that some municipalities in the Pilot 1 area are more threatened by floods, while the others are more threatened by earthquakes. In Italy 10 cities have a ratio greater than 1, while 17 have a ratio less than 1. Among the 10 cities most susceptible to flood risk, there are four of them where the EAL due to flood is about five times more critical than the seismic risk. They are Farra d'Isonzo, Gradisca d'Isonzo, Sagrado and Savogna d'Isonzo. The ratio between the EALs is above 2 for another three Italian municipalities, still indicating the criticality of the flood risk but to a lesser extent. Two municipalities, Grimacco and Dolegna del Collio, have a ratio basically equal to 1, indicating equal levels of flood and seismic risk. The city of Doberdò sul Lago has a ratio equal to 0 and a EAL which is worth about 30'000 €, due only to the seismic hazard. For 17 Italian municipalities, the seismic risk is the predominant one. These are the municipalities of Doberdò del Lago, San Floriano del Collio, San Lorenzo Isontino, Cormons, Premariacco, Manzano, Mariano del Friuli, Cividale del Friuli, Prepotto, Moraro, San Giovanni al Natisone, Stregna, Corno di Rosazzo, Mossa, Savogna, Buttrio, Dolegna del Collio.

The flood risk is predominant in four of six Slovenian municipalities. The ratio between the EALs due to floods and earthquakes in three of these is between 1.2 and 1.6. The highest ratio (about 4) was estimated for the municipality of Šempeter-Vrtojba. In the other two municipalities, the seismic risk is more critical. This includes the municipalities of Nova Gorica and Brda, where the seismic risk is about three times higher than the flood risk.

The sum of the multi-risk EAL for the Italian municipalities in the Pilot 1 is two times the Slovenian one, but the first four EAL values correspond to two Italian (Gorizia and Gradisca d'Isonzo) and two Slovenian cities (Nova Gorica and Šempeter-Vrtojba).

2.5.2. Limitations and Future needs

One of the limitations of the multi-risk assessment within the BORIS project is related to the type of assessment. In the project, a multi-layer single-risk assessment was performed, in which interdependencies between different hazards are not considered. Considering interdependencies between different hazards may be relevant if the consequences of one hazard impact the hazard, vulnerability or exposure related to another hazard. For example, we may be interested in scenarios where a failure of structures or infrastructures caused by an earthquake triggers floods. Such a multi-risk assessment requires advanced modelling, which exceeds the goal of the project.

Moreover, although economic losses are an important risk indicator, other risk indicators could be included in the multi-risk assessment, thus adding further dimensions to the ranking of risks. For example, the number of fatalities was not included in the multi-risk assessment but is an important risk indicator. The criticality of the seismic risk would probably increase if including this risk indicator because the evacuation time for an earthquake is shorter than for floods. The ranking of risks could also be affected by including additional assets in the risk assessment. This includes infrastructures and buildings other than residential buildings.

Furthermore, when implementing the methods developed in WP 4 in pilot region 1, it became apparent that different datasets and different interpretations of the data on the seismic and flood risk assessment present the main obstacle for cross-border risk assessment. It is worth noting that all data are not freely available and that some data access restriction policies must be considered especially related to the GDPR directive requirements. Therefore, it will be important to pay special attention to the harmonisation of cross-border data sets in the future. For the assessment of the transboundary flood risk, the scenarios for mapping the flood hazard first had to be harmonized, especially in view of (1) harmonizing the river discharge datasets) and (2) taking into account the same flood event return periods. Another thing worth mentioning is that not all areas potentially exposed to flood hazard have already been adequately analysed and mapped.

Further, when looking towards the possibilities of performing the multi-risk assessment, there are different national methodologies and approaches in the flood and seismic hazard assessment, as well as several differences in the vulnerability assessment methodologies (for both seismic and flood risk assessment). These methodologies and approaches should be harmonized as much as possible to obtain comparable results.

3. Pilot application of methodology and tool for multi-risk assessment at the Austrian-Slovenian border

This section deals with the assessment of seismic risk and flood risk in the region of the Mur(a) basin where the cross-border pilot site between Austria and Slovenia is located.

3.1. Definition of cross-border area Pilot 2

The Pilot 2 area was defined along the border between Austria and Slovenia (**Figure 3.1**). Several municipalities in the area on both sides of the border, which is also characterised by the river Mur, were selected. The region and its settlements are historically been at risk of flooding as it is characterized by the Mur (a) river and its tributaries, whereas also a long tradition of (cross-border) flood management and regulation measures exists. The origin of the river lies in the Austrian Hohe Tauern National Park. The total length is 454 km, of which 70 km along the border form Austria with Slovenia. The river flows into the Drava in Legrad, Croatia.The pilot area, described in more detail in the following sections, has a rather rural character with municipalities with with detached buildings, whereas also more urban areas with towns such as Bad Radkersburg and Leibnitz (AUT) and Gornja Radgona (SLO).

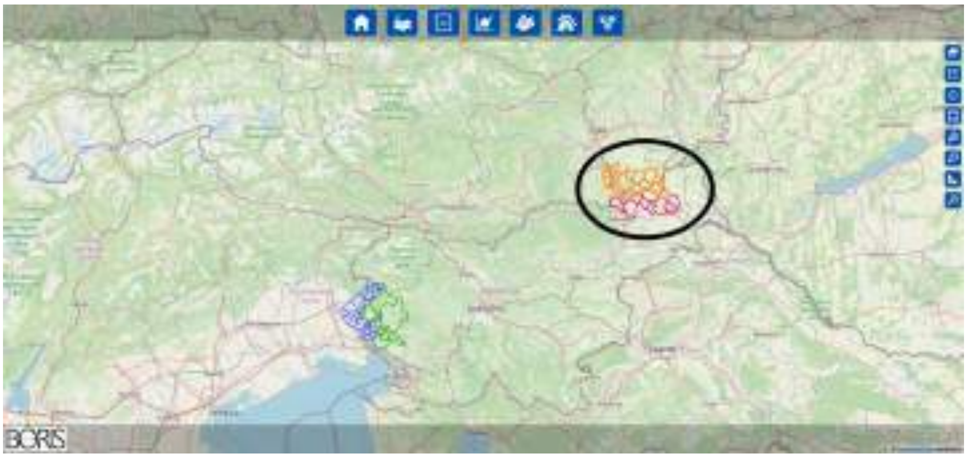


Figure 3.1: Pilot 2 area is located in Austria and Slovenia along the Mur(a) river

3.1.1. Austrian Region

The Austria pilot region is located in the federal state of Styria and includes municipalities directly bordering Slovenia as well as other municipalities in the hinterland, which can be seen on the map in **Figure 3.2**. The following 21 municipalities were selected: Straden, Sankt Peter am Ottersbach, Sankt Anna am Aigen, Deutsch Goritz, Tieschen, Halbenrain, Mureck, Mettersdorf am Saßbach, Sankt Veit in der Südsteiermark, Klöch, Straß in der Steiermark, Bad Radkersburg, Ehrenhausen an der Weinstraße, Wagna, Gabersdorf, Ragnitz, Gralla, Leibnitz, Tillmitsch, Lebring-Sankt Margarethen, and Lang. These municipalities were selected because they are located in the Austrian-Slovenian border region and in the catchment basin of the river Mur and its tributaries, which is an important part of the exposure to natural hazards in this area. In terms of seismic hazard, the Austrian side is less at risk than the Slovenian side. For example, for an event with a return period of 476 years, the European Seismic Hazard Map adopted in the project shows PGA between 0.056 g - 0.077 g on the Austrian side and between 0.073 and 0.084 g the municipalities of the Slovenian pilot area.

Figure 3.2: Austrian municipalities (orange) within the Pilot 2 area

3.1.2. Slovenian Region

At the Slovenian side of the Pilot 1 region, the following nine municipalities were selected: Kungota, Pesnica, Šentilj, Sveta Ana, Benedikt, Gornja Radgona, Radenci, and Tišina (**Figure 3.3**).

Figure 3.3: Slovenian municipalities in Pilot 2 area.

The main rivers in the Slovenian pilot region are Mura, Ščavnica, Pesnica with tributaries. Pesnica and Ščavnica Rivers have a mild snow-rainfall regime and are heavily regulated. Both rivers had a lot of meanders in the original watercourse and have often flooded the lowland plains. However, since both rivers are nowadays regulated, flooding is now a rare event. Mura River has a snow-rainfall regime, and peak discharge in May, caused by the snowmelt in the Alps. Mura has also been extensively regulated in the past. Recorded flood events by Slovenian Environment Agency in the area after 2000 are: 3.-4. 8. 2009; 5.-6. 11. 2012; and 23. 5. 2015. However, the area is less prone to earthquakes. The maximum PGA on rock or rock-equivalent sites for the return period of 475 years ranges from 0.07 g to 0.08 g, which refers to the low seismicity level.

3.2. Collection on input data on the regional level

3.2.1. Assets at risk - building stock

For the **Austrian** Pilot Region, the building data to define the exposure to seismic risk has been collected with two steps and of both qualitative and quantitative methods. Firstly, available data on residential buildings (request date 1 January 2022/raw data) collected in the AGWR (Building and Housing Register of Statistics Austria) were obtained from the province of Styria. During this data collection phase, it was discovered that there is a great lack of data about the main construction material used for the buildings, spanning from 40-80% in total for the Pilot Region - dependent on the different construction periods. This lack of data can be seen in below, where the blue part of the bars corresponds to the number of buildings with unknown construction material. The AGWR data provided by Statistics Austria should theoretically provide the data needed to identify the building typology in terms of construction material (masonry, RC and other types), construction period and number of storeys. The reason for the data gap regarding the building material is that it has only been mandatory for the municipalities to provide this information in the form for the construction of the database since 2011. In general, the database collects buildings' information on construction material with the subcategories masonry, reinforced concrete, wooden frame, steel frame, the number of storeys (1, 2, 3, 4 or more) and construction period (>1919, 1919–1944, 1945–1960, 1961–1970, 1971–1980, 1981–1990, 1991-2000, since 2001 for every year).

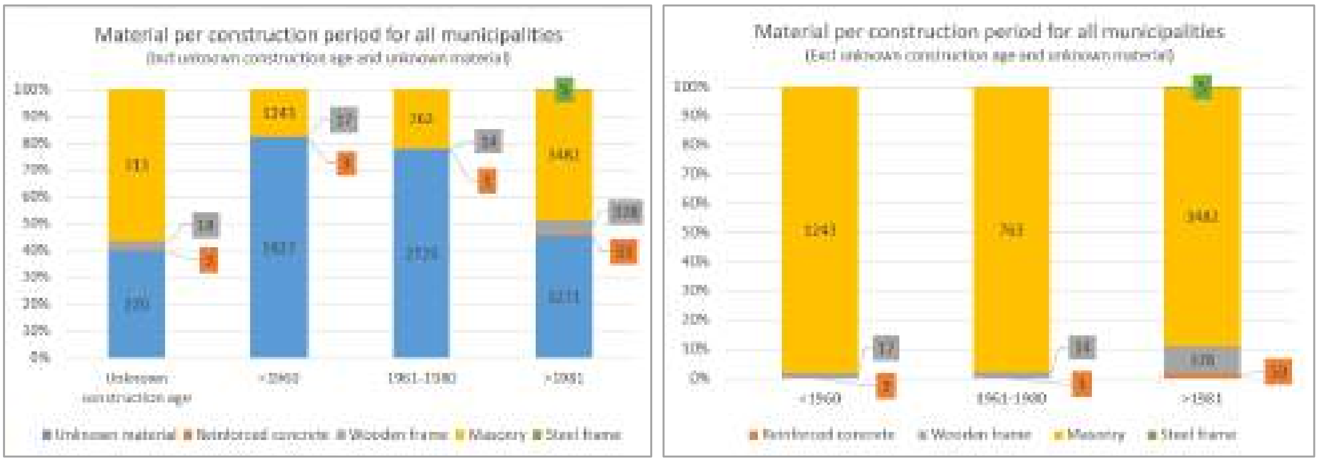


Figure 3.4: Distribution of different material of all residential buildings in the Austrian Pilot Region, including the category "Unknown material" (left). Distribution of materialtyps of residential buildings in the Austrian Pilot Region, excluding the category "Unknown material" (right).

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Project co-funded by the European Union Civil Protection

Figure 3.5 shows the criteria for building typologies identification adopted for Italy, Slovenia and Austria. Whereas for the harmonized building classes identified for vulnerability analysis the buildings categorized as "other" material are not included (see also D4.1).

	ITALY	AUSTRIA	SLOVENIA
Material	masonry	masonry	masonry
	reinforced concrete	reinforced concrete	reinforced concrete
	other	steel frame, wooden frame	other
Stories	1, 2, 3, >=4	1, 2, 3, 4, 5, 6	1, 2, 3, >=4
Period	< 1919	< 1919	< 1919
	1919 - 1945	1919 – 1944	1919 - 1945
	1946 - 1960	1945 – 1960	1946 - 1960
	1961 - 1970	1961 – 1970	1961 - 1964
			1965 - 1970
	1971 - 1980	1971 – 1980	1971 - 1981
	1981 - 1990	1981 – 1990	1982 - 1990
	1991 - 2000	1991 – 2000	1991 - 2000
	2001 - 2005	2001, 2002 … 2021	2001 - 2007
	> 2005		> 2007

Figure 3.5: : Criteria for harmonization of building typologies via grouping of age ranges (highlighted with different colours).

In addition to the existing data from the AGWR, expert interviews were conducted based on the Cartis method (Zuccaro et al. 2015). Building experts from the region were interviewed to collect data about the building stock and the common materials (see **Figure 3.6** below). They expressed their estimates in percentages. The results of the expert interviews were used to calculate mean values, which were then compared with the ESRM20 exposure model (GEM data set), which is not available at the municipal level but contains data for the whole of Styria. Based on these different data sets, the distribution of the materials of the building stock within the pilot region was evaluated and provided the basis to establish distribution rules. All buildings without a material classification were then assigned to a material type (masonry, reinforced concrete or other). The distribution rules used enable the division according to building period and height. To determine the vulnerability, the data set was again processed to allow all buildings to be assigned to either the masonry or reinforced concrete. This "new" estimated data set, was then used during the pilot application of the BORIS study for the further calculations and the platform.

Construction Period	Material	Stories	Aggregation type	Quality / Sub-categories	Comments on regional differences [Bad Rad & leibnitz]
<1960	Masonry percentage **80%**	1-3 stories **95%**	Isolated **50%**	Irregular, regular Regular, Seismic design	
			Aggregated **50 %**		
		4+ stories **5%**	Isolated		
			Aggregated **100%**		
	Reinforced concrete percentage **15 %**	1-3 stories	Isolated		
			Aggregated		
		4+ stories **100%**	Isolated		
			Aggregated		
	"Other" percentage **5 %**	1-3 stories	Isolated		
			Aggregated		
		4+ stories	Isolated		
			Aggregated		
1961-1980	Masonry percentage	1-3 stories	Isolated		
			Aggregated		
		4+ stories	Isolated		
			Aggregated		
	Reinforced concrete percentage	1-3 stories	Isolated		
			Aggregated		
		4+ stories	Isolated		
			Aggregated		
	"Other" percentage	1-3 stories	Isolated		
			Aggregated		
		4+ stories	Isolated		
			Aggregated		
>1981	Masonry percentage	1-3 stories	Isolated		
			Aggregated		
		4+ stories	Isolated		
			Aggregated		
	Reinforced concrete percentage	1-3 stories	Isolated		
			Aggregated		
		4+ stories	Isolated		
			Aggregated		
	"Other" percentage	1-3 stories	Isolated		
			Aggregated		
		4+ stories	Isolated		
			Aggregated		

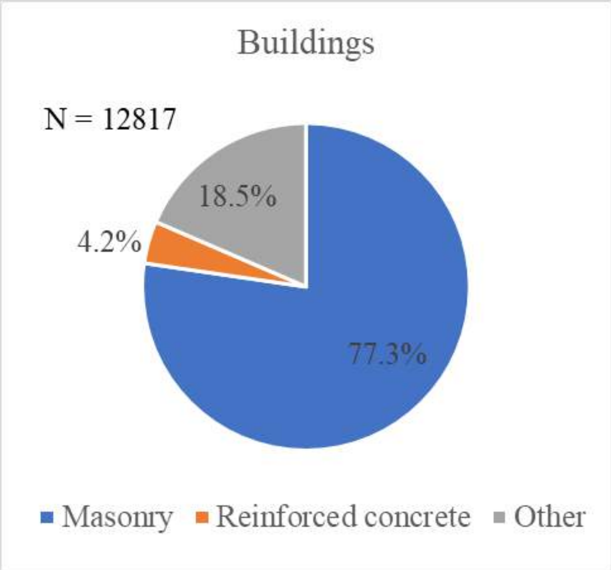
Figure 3.6: Table for the expert interviews in Austrian pilot region, with example answers in red

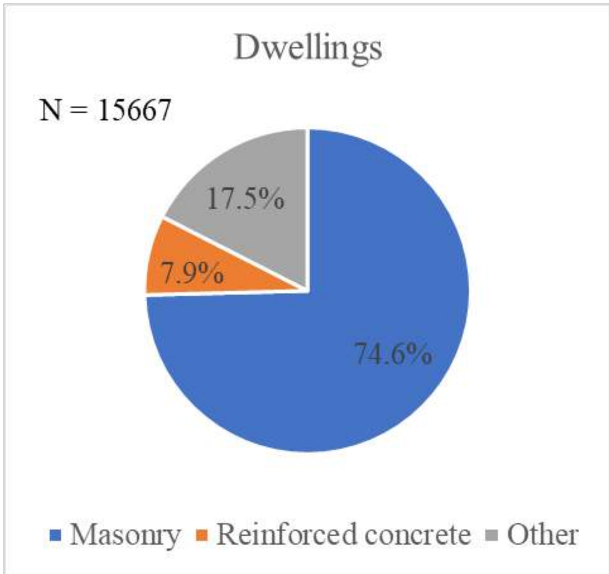
For the flood risk assessment, the building footprint of residential building, was needed, which is available for the Federal state of Styria including the building height, but not the exact number of stories. To characterize each building in term of number of storeys (a vulnerability characteristic for the association of the flood damage curve), the total height of the building was divided by three meters to obtain the number of floors. The value three meters is defined as the HAZUS (FEMA, 2009) curves - adopted in the vulnerability analysis - are obtained for buildings with an average height of three meters.

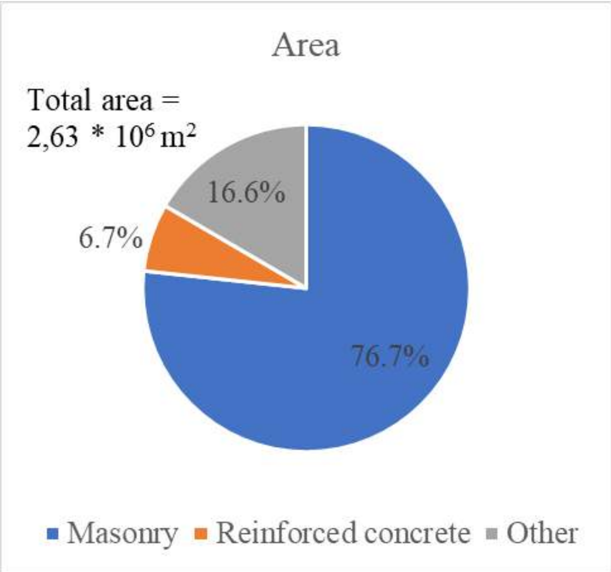
A total of 22897 residential buildings are located within the Austrian municipalities in the Pilot 2 area, according to the AGWRII dataset of January 2022. As **Figure 3.7** illustrates almost 75% of the buildings are classified as masonry, 11 % of the buildings are classified as reinforced concrete buildings and 14 % as buildings with an other main material. Most of the buildings have one to three stories. 43% of the buildings in the region were built after 1981, while 26% were built between 1961-1980, and 31% of the buildings are older than 1960.

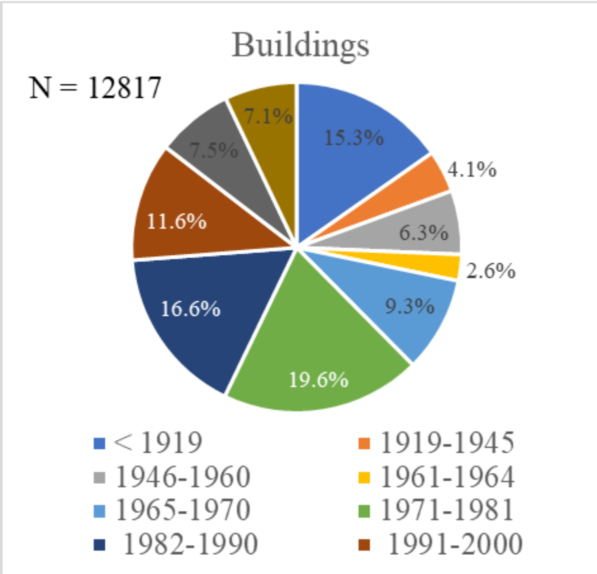
Figure 3.7: Distribution of main materials of Austrian building stock in Pilot 2 region (redistributed data)

On the **Slovenian** side of the Pilot 2 region, there are 12817 buildings located according to the census database from year 2020 (MOP, 2020). More than 77% of the buildings are classified as masonry, whereas only 4.2 % of the total buildings are classified with the main material reinforced concrete and 18.5% are defined as buildings with other main material. 93% of the buildings have one or two stories. The census database also includes information about number of stories, number of dwellings, population, and building material. In the region, 15.3% of the buildings were built before 1919, while between 1945 and 2000 66% of the buildings were built. The **Figure 3.8** below shows information about buildings in the region, more specifically, the number of buildings according to the construction material, number of dwellings in individual type of the building, area of the buildings in m^2, period of construction, number of storeys according to the construction material, and period of construction according to the construction material.


Buildings
N = 12817
18.5%
4.2%
77.3%
Masonry
Reinforced concrete
Other


Dwellings
N = 15667
17.5%
7.9%
74.6%
Masonry
Reinforced concrete
Other


Area
Total area =
2,63 * 10⁶ m²
16.6%
6.7%
76.7%
Masonry
Reinforced concrete
Other


Buildings
N = 12817
7.1%
7.5%
15.3%
4.1%
6.3%
2.6%
11.6%
9.3%
16.6%
19.6%
< 1919
1919-1945
1946-1960
1961-1964
1965-1970
1971-1981
1982-1990
1991-2000

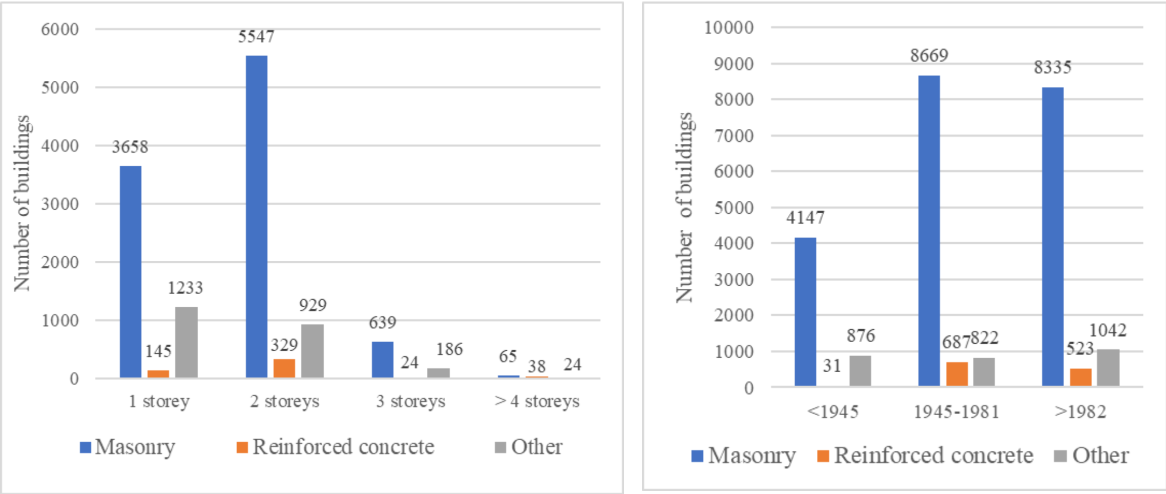


Figure 3.8: Building stock distribution in Slovenia in Pilot 2 region (border with Austria)

3.2.2. Assets at risk – population

The total population in the **Austrian** municipalities of Pilot 2 are 147271 people. The following diagrams in **Figure 3.10** underline that 75% of the population is living in masonry buildings, while 12% are living in reinforced concrete buildings and 13% in buildings with an other main material. The majority of the population lives in masonry 1-3 storey buildings, built after 1981.

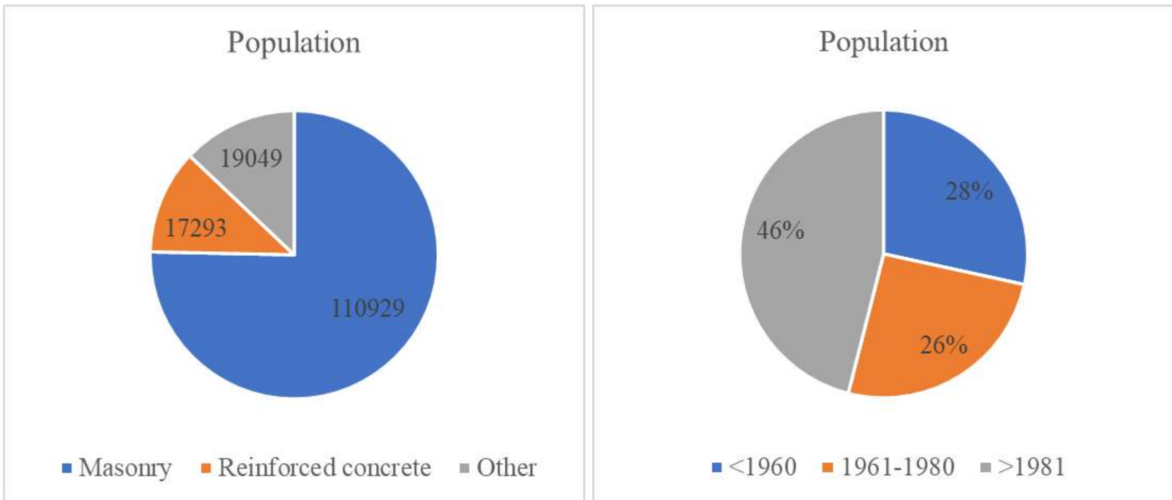


Figure 3.9: Distribution of population in the Austrian part of Pilot 2

In the **Slovenian** region of Pilot 2, according to the census data (MOP, 2020), people is living. Around 77% of the people live in masonry buildings, while in buildings classified as reinforced concrete and other, live 6.1% and 17.3% of the people, respectively. The majority of the population lives in buildings that were built after year 1945 (81.2%). Additionally, most of the population in the region (67%) lives in masonry buildings with one or two storeys. 10% of the people live in masonry buildings with three or more storeys. Some additional information about relation between number of population and construction type of the building in the region can be found on the **Figure 3.9**.

Figure 3.9: Distribution of Slovenian population in Pilot 2 region (border with Austria)

3.3. Cross-border seismic risk assessment

The seismic risk in the Pilot 2 region was assessed separately for each municipality constituting the region. In the risk assessment, the consequence model was the kept constant for the entire region. Its description is provided in a previous BORIS project deliverable (BORIS, 2022). The hazard and exposure models varied from one municipality to another and are described in Section 3.3.1 in this deliverable. The vulnerability model differed only between the two neighbouring countries; it was the same for all municipalities on the Slovenian side of the border, and the same for all municipalities on the Austrian side of the border. This model is also presented in Section 3.3.1 of the current deliverable.

The seismic risk was assessed in terms of the following indicators:

- The average number of residential buildings reaching the designated damage levels in a given time window.
- The average direct economic losses resulting from the residential buildings in a given time window.
- The average direct economic losses per 1 m^2 of floor area resulting from the residential buildings in a given time window.
- The average number of fatalities in a given time window.
- The average number of injured people in a given time window.
- The average number of short-term unusable residential buildings (excluding the collapsed buildings) in a given time window.
- The average number of long-term unusable residential buildings (excluding the collapsed buildings) in a given time window.
- The average number of displaced (homeless) people (short-term or long-term) in a given time window.

For each risk indicator, two-time windows were considered: a 1-year and a 50-year time window.

It was assumed that the risk indicators are equal to zero for PGAs below 0.03 g. This assumption is consistent with observations made after past earthquakes (Dolce et al. 2021).

3.3.1. Seismic hazard, vulnerability and exposure

The seismic hazard model constituted a set of hazard curves defined by the relationship between the PGA and the yearly probability of exceedance. Each hazard curve was developed for the centroid of one municipality. In the development of each hazard curve, the following steps were taken:

1. The hazard curve for rock-equivalent outcrop motion as given by the ESHM2020 model (Weatherill et al., 2020; Danciu et al., 2021) was obtained from the ESHM2020 webpage (EFEHR, 2022). This hazard curve was defined by six points representing the return periods of 50, 101, 476, 976, 2500 and 5000 years.
2. The soil amplification factors for the six PGA values obtained in Step 1 were calculated for all soil classes present in the municipality. Soil classification according to the Eurocode was considered. The calculation of the soil amplification factors was performed according to the draft of the new Eurocode 8 (CEN, 2022).
3. The hazard curves for different soil classes were defined by multiplying the PGAs from the hazard curve for rock-equivalent outcrop motion (Step 1) by the soil amplification factors (Step 2).
4. The hazard curves from Step 3 were interpolated to be locally linear in the logarithmic domain.
5. The weighted average of the probabilities from the hazard curves for different soil classes (Step 4) was calculated. A weighted average was calculated for each PGA of the curve. The weights were equal to the proportions of the soil classes in the municipality.
6. The "final" hazard curve was assembled from two parts. The first part was equal to the weighted average curve from Step 5 and was considered from the PGA of 0.03 g to the PGA corresponding to the highest return period in the ESHM2020 model (5000 years). The second part was considered for

higher values of the PGA and was determined by extrapolating the weighted average curve from Step 5. The extrapolation of the curve was done according to the following expression:

$$\log_{10} p = -bPGA^k,$$

where p is the yearly probability of exceedance, and parameters b and k are determined based on two points on the weighted average hazard curve (Step 5) corresponding to the lowest and highest return periods from the ESHM2020 model.

Note that the extrapolation was not needed to return periods lower than 50 years (the lowest return period in the ESHM2020 model), as the PGA corresponding to the return period of 50 years was lower than 0.03 g (i.e. the lower bound of the relevant PGAs).

Figure 3.10: Seismic hazard map for the Pilot 2 area considering an event with a return period of 2500 years. Similarly, hazard maps for other return periods can be viewed on the platform.

The proportions of the soil classes in the Slovenian municipalities were determined based on the known geological characteristics and past studies (Ferlan and Herlec, 2000; Ferlan and Herlec, 2002; Dolšek et al., 2020). For the Austrian municipalities, the proportions were determined based on the global Vs30 map produced by USGS (Worden and Heath 2019).

In **Figure 3.11 t**he soil classes map for the Pilot 2 area is reported. It shows, for each municipality, the value of Vs30 (average shear wave velocity at 30 m depth) calculated at the barycentre of the municipality. It is also possible to display in the pop-up windows the distribution of soil classes within each municipality, i.e. as % of soil A, B, etc.

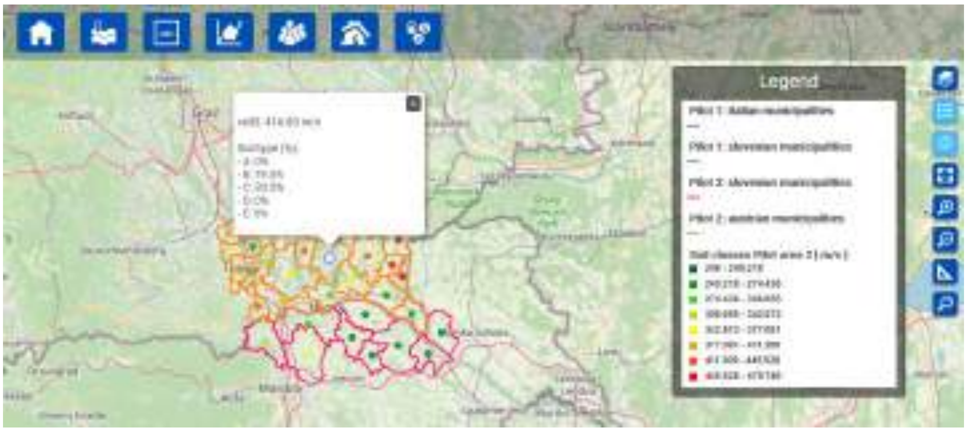


Figure 3.11: Soil classes map for the Pilot 2 area presented on the BORIS platform.

In **Figure 3.**12 and **Figure 3.**13**Figure 3.**12**Figure 3.**13, the hazard curves for different soil classes, their weighted average and the extrapolation of the weighted average are presented for the municipalities of Šentilj in Slovenia and Gralla in Austria. In both cases, soil class C is the prevailing one. Consequently, the weighted average of the hazard curves for individual soil classes is most similar to the hazard curve for soil class C.

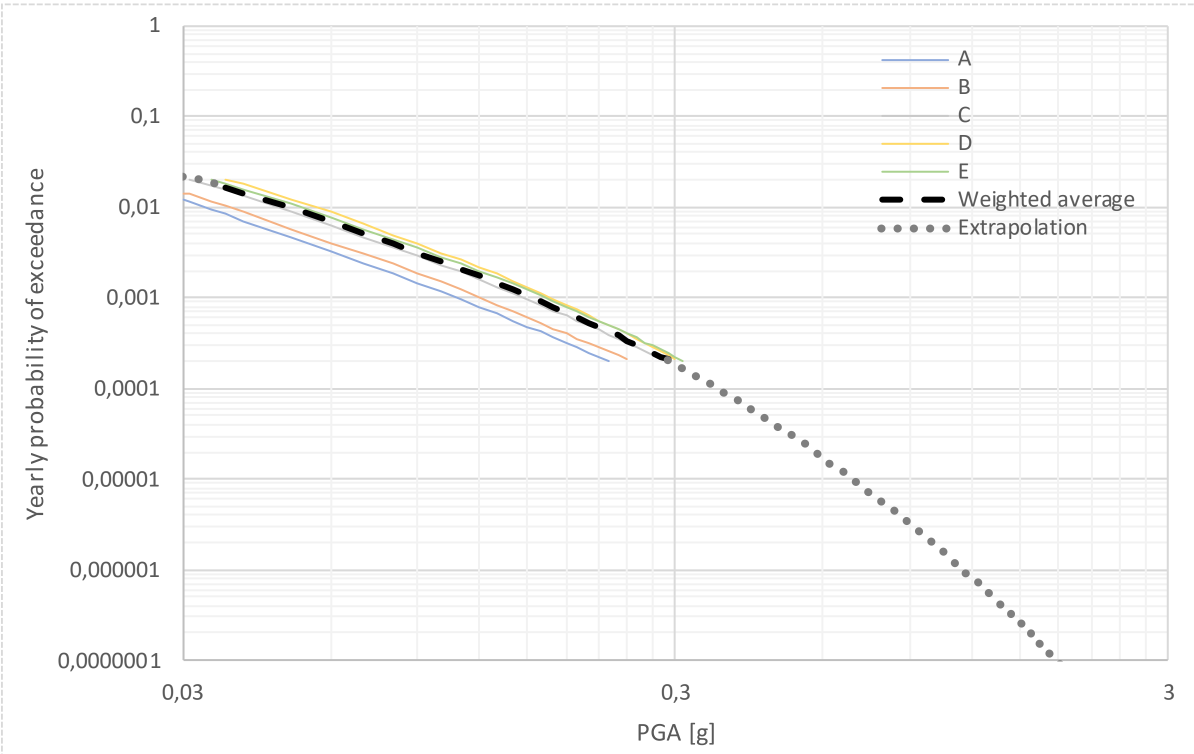


Figure 3.12: The hazard curves for individual soil classes, their weighted average and the extrapolated weighted average curve for the municipality of Šentilj in Slovenia.

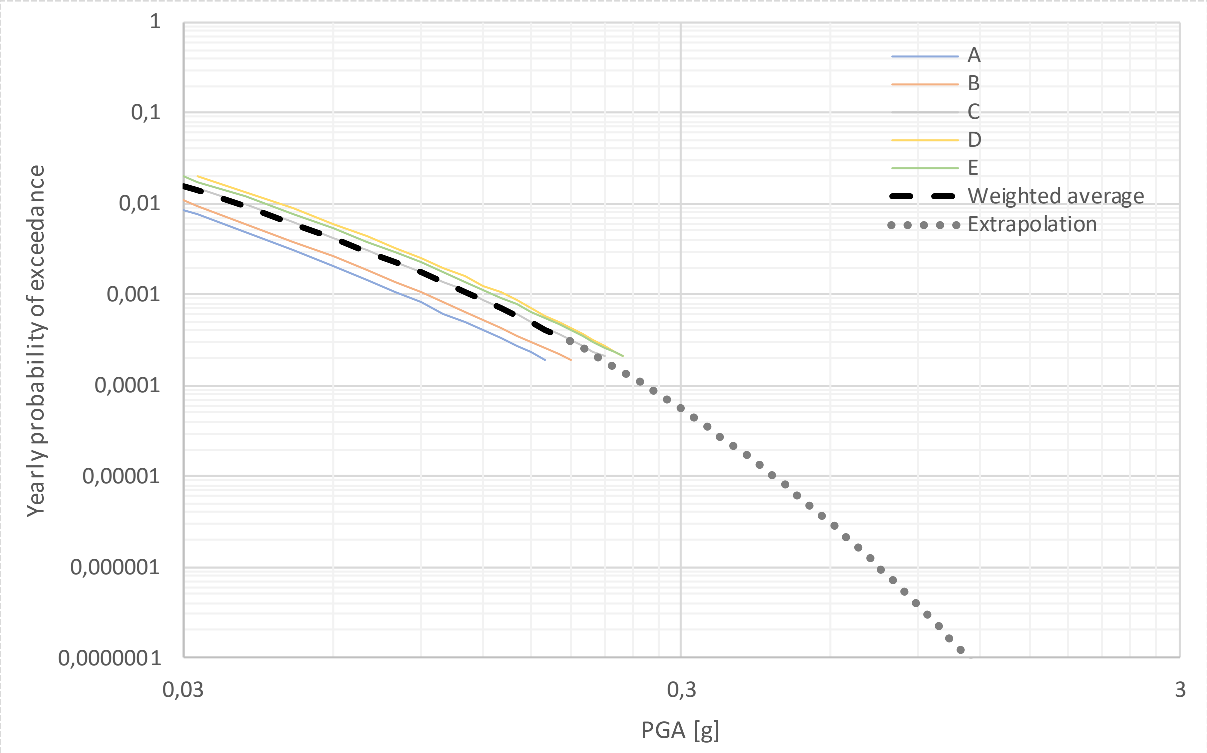


Figure 3.13: The hazard curves for individual soil classes, their weighted average and the extrapolated weighted average curve for the municipality of Gralla in Austria.

The exposure model constituted a set of data on the assets at risk. The data referred to the typological building classes characteristic of the given municipality. Each building class was defined by the construction period, range of the number of storeys and construction period. For each building class in each municipality, the number of residential buildings, the total floor area, and the number of residents were defined.

The basis for the exposure model was the data presented in Sections 3.1 and 3.2. However, some of the data needed to be processed in order to facilitate the fragility model. The processing of the data included the distribution of the buildings with "other" material of the load-bearing structure into the classes of masonry and reinforced concrete buildings. This was done by utilizing the procedure proposed by Dolce et al. (2021):

- Buildings with less than four storeys built after 1945 were distributed into classes of masonry and RC buildings proportionally to the number of masonry and RC buildings in the municipality (considering the same construction period and the same range of the number of storeys). If there were no masonry and RC buildings with the given characteristics (range of the number of storeys, construction period) in the given municipality, the buildings were evenly distributed between masonry and RC buildings.
- Buildings with less than four storeys built before 1945 were classified as masonry buildings.
- Buildings with four storeys or more built before 1919 were classified as masonry buildings.
- Buildings with four storeys or more built after 1919 were classified as RC buildings.

Figure 3.14 shows an example of how the exposure data is displayed on the BORIS platform for a selected Slovenian municipality.

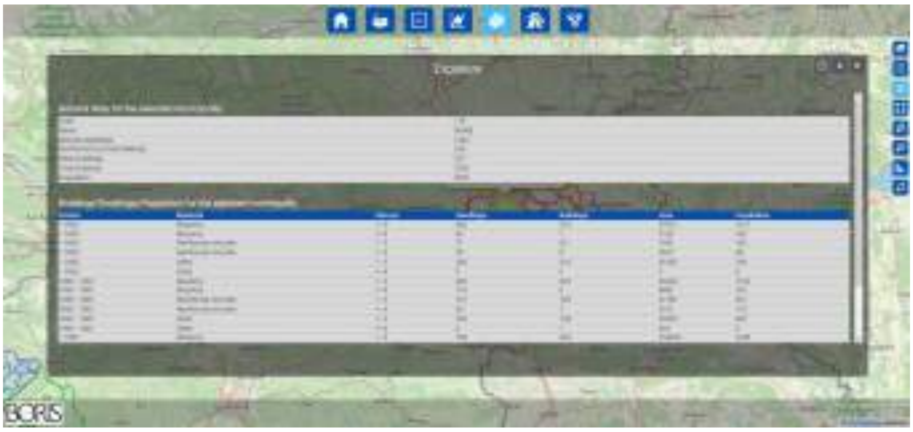


Figure 3.14: An example of exposure data for a Slovenian municipality (Šentilj) presented on the BORIS platform.

In the case of Austrian municipalities, data were further processed to obtain the number of residents and total floor area at the level of a building class, as such data were not available in the raw database. This was done based on the Slovenian and Italian data, which contain the number of residents and the total floor area for each building class separately. The following procedure was employed:

- The average number of residents and the average floor area per building in each class ($P_{avg,class}$ and $A_{avg,class}$, respectively) were determined.
- The ratios between $P_{avg,class}$ of different classes and the ratios between $A_{avg,class}$ of different classes were determined.
- The number of residents and the total floor area in a municipality were distributed into building classes using the same ratios as determined in the previous step.

Figure 3.15 shows an example of how the exposure data is displayed on the BORIS platform for a selected Austrian municipality.

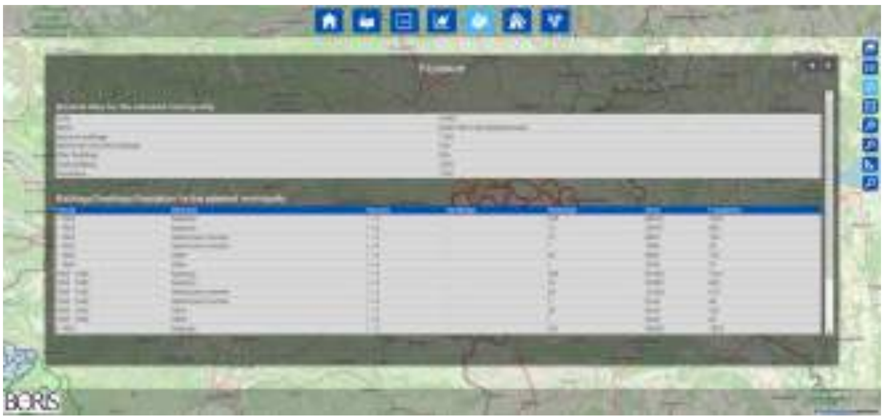


Figure 3.15: An example of the exposure data for an Austrian municipality (Sankt Veit in der Südsteiermark) presented on the BORIS platform.

It should also be pointed out that the replacement cost, which is an important exposure parameter, was assumed constant for all municipalities on a given side of the border. For the Slovenian municipalities, this parameter was set to 1250 €/m^2 (Dolšek et al., 2020). However, for the Austrian municipalities, the replacement cost was set to 1350 €/m^2, which is the value determined for Italy (Dolce et al., 2021), thus assuming that the construction costs are similar in the two countries. Given the rise in construction costs in Europe in recent years, the replacement costs may be underestimated, which should be considered in interpreting results.

The vulnerability model constituted a set of fragility curves. Five fragility curves associated with five damage states were defined for each building class, consistently with the general methodology described in D4.1 (BORIS, 2022). The fragility curves that were initially developed for the Slovenian territory (Dolšek et al., 2020) were applied to both Slovenian and Austrian municipalities, as no fragility model has been developed specifically for the Austrian building stock.

The fragility curves developed for the Slovenian building stock depend on the material of the load-bearing structure, construction period and range of the number of storeys. These parameters are also used in the classification criteria in the Slovenian exposure model. As the classification is the same in both the exposure and the vulnerability model, the selection of the fragility curves for the Slovenian municipalities was straightforward. However, applying the Slovenian vulnerability model to the Austrian municipalities required first identifying the similarities and differences between the buildings in the two countries. It was assumed that the number of storeys and the material of the load-bearing structure impact the seismic vulnerability similarly in both countries, as the buildings on both sides of the border have similar architecture. However, the impact of the construction period on the seismic vulnerability was assumed to be less similar due to the different evolution of codes for the seismic design. In Slovenia, the first seismic design code was implemented in 1964. The code prescribed lateral design load in the order of a few percent of the building weight (the exact load depended on the building vibration period and location). In 1981, the design level was further improved by the implementation of a new code, which already guaranteed a design level comparable to the Eurocodes. This evolution of codes is reflected in the classification of buildings in Slovenia.

The building classification in Austria is similar. However, the evolution of seismic codes is different. For example, the lateral design load was less than one percent of the building weight until a design code was implemented in 1979 in response to the devastating Friuli earthquake. The design level prescribed by the 1979 code was still lower than that prescribed by the 1981 code in Slovenia. However, the design level in both countries became similar when the use of the Eurocodes became mandatory (2008 and 2009 in Slovenia and Austria, respectively). Based on the comparison of code evolution in the two countries, the fragility curves developed for Slovenian buildings built before 1964 (pre-code buildings) were assigned to the Austrian buildings built before 1982. For the Austrian buildings built after 1982, the fragility curves developed for Slovenian buildings built after 1982 were applied, thus considering that the design level in both countries was similar after 1982. This simplification may lead to a slight underestimation of the risk for the Austrian municipalities. However, there is also a slight mismatch in the period used as a criterion in the exposure classification (before and after 1982) and the period important in the evolution of codes (before and after 1979). This mismatch may cause the results to be slightly conservative.

Figure 3.16 shows an example of the seismic fragility curves for the Pilot 2 area on the BORIS platform. The example is reported for masonry buildings, built from 1965 to 1982 with a number of storeys between 1 and 3 (both the curves for Austrian and Slovenian buildings are shown).

Figure 3.16: Visualization of an example of the seismic fragility curves for the Pilot 2 area on the BORIS platform.

3.3.2. Risk Results

The results of the risk analysis for each selected risk indicator (listed at the beginning of Section 3.3) are visualized in the BORIS platform in several tables and maps. In tables, the results are presented for each municipality separately and for the whole area. On maps, the results are displayed by colouring each municipality depending on the value of the risk indicator the user decides to visualize. For example, each municipality can be coloured according to the average number of buildings reaching damage level D2 in the 50-year time window. In the following of this section, some results presented on the BORIS platform are shown. Then, a brief discussion of the results is given.

The table in **Figure 3.17** shows an example of how the results of the seismic risk analysis are visualized on the BORIS platform: for each municipality in the Pilot 2 area, the average number and the percentage of buildings in the five damage levels (from D1 to D5) in a 50-year time window are reported. **Figure 3.18**, **Figure 3.19** and **Figure 3.20** show the maps of the average percentages of residential buildings in damage levels D1, D3 and D5 for time windows of 1 year and 50 years.

Figure 3.17: An example of a table in the BORIS platform displaying the results of the seismic risk analysis for the Pilot 2 area. The table presents the average number and percentage of residential buildings reaching damage levels D1–D5 in a time window of 50 years.

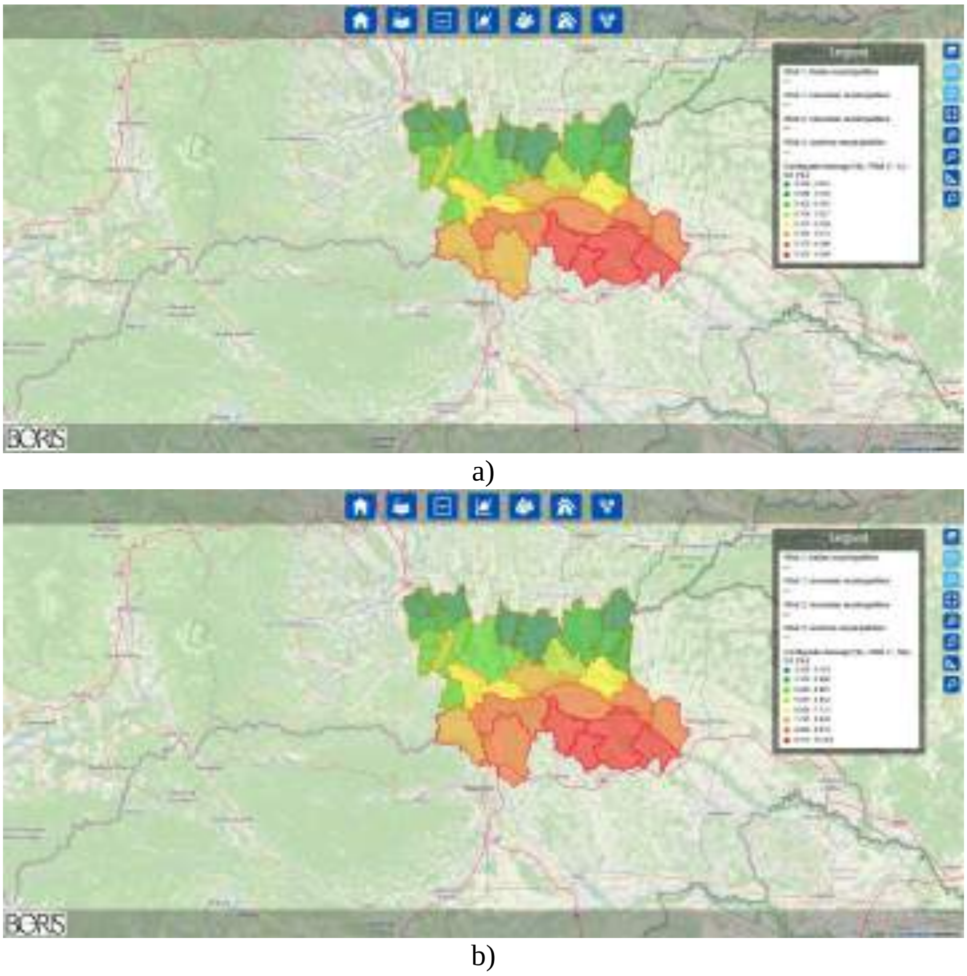
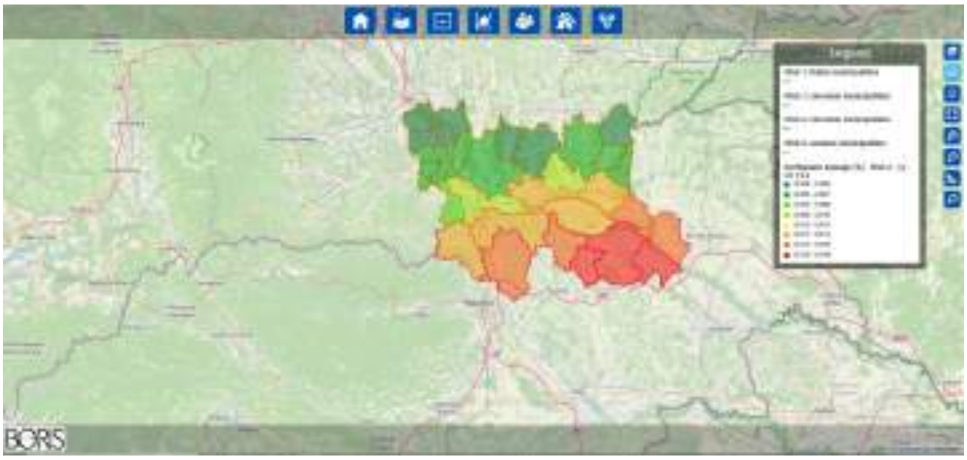
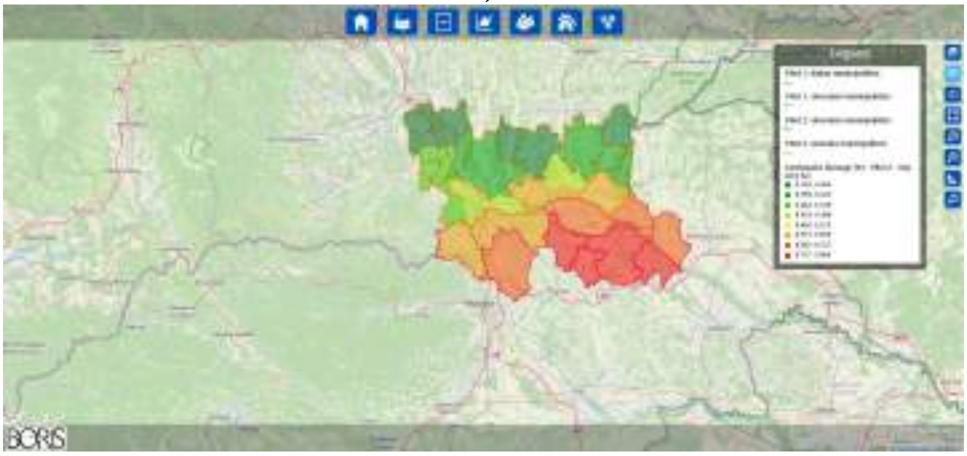


Figure 3.18: An average percentage of residential buildings in the D1 damage state due to earthquakes in the Pilot 2 area: a) in 1 year; b) in 50 years.



a)



b)

Figure 3.19: An average percentage of residential buildings in the D3 damage state due to earthquakes in the Pilot 2 area: a) in 1 year; b) in 50 years.

a)

b)

Figure 3.20: An average percentage of residential buildings in the D5 damage state due to earthquakes in the Pilot 2 area: a) in 1 year; b) in 50 years.

Figure 3.21 shows the table with the average economic losses due to earthquakes in a time window of 50 years for the Slovenian and Austrian municipalities in the Pilot 2 area. These losses can also be shown on a map: **Figure 3.22** shows, for example, the map of the average number of homeless people due to earthquakes in a 50-year window for the municipalities in the Pilot 2 area.

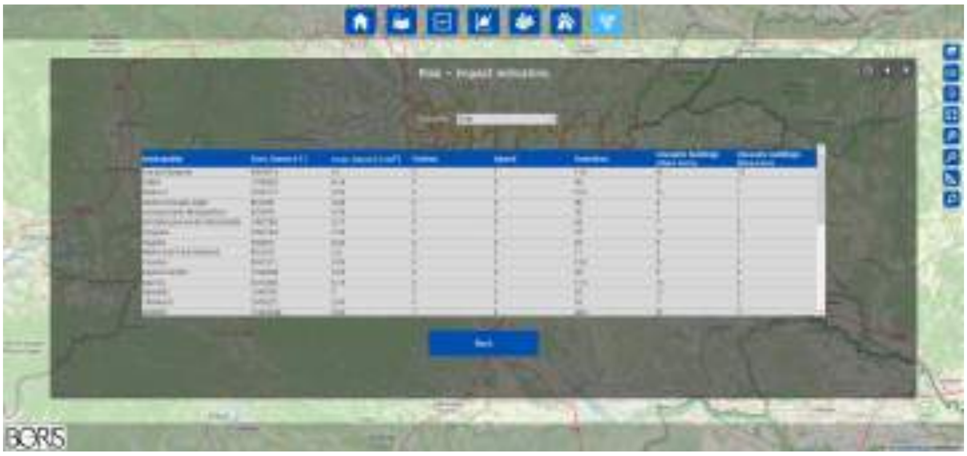


Figure 3.21: Average economic losses in a time window of 50 years due to earthquakes for the municipalities in the Pilot 2 area.

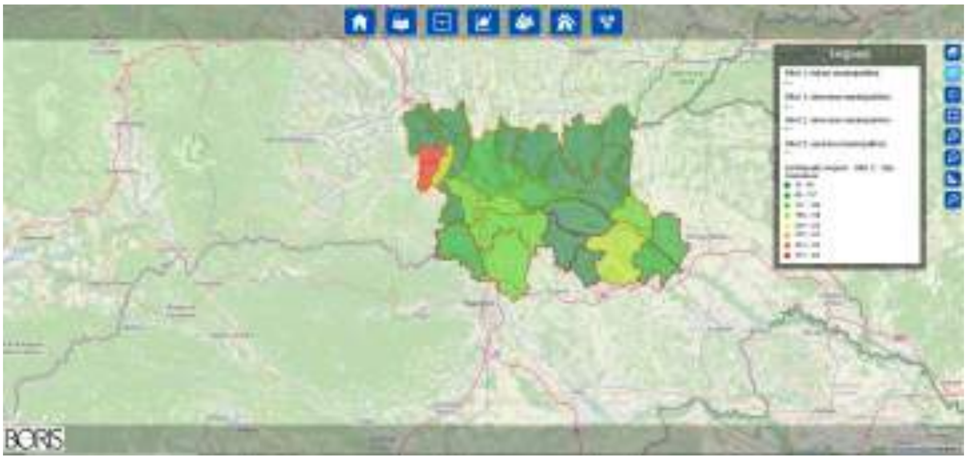


Figure 3.22: A map of the average number of homeless people due to earthquakes in a time window of 50 years for the municipalities in the Pilot 2 area.

The seismic risk in the Pilot 2 area is relatively low. The economic losses due to earthquakes in the next 50 years are expected to be between 3.2 € and 9.8 € per 1 m^2 of a municipality's residential floor area. Such losses are five times lower than those estimated for 50 % of Slovenia's buildings (Dolšek et al., 2020). The lowest and the highest floor-area-normalized losses in the Pilot 2 area correspond to the municipalities of Sankt Anna am Aigen and Bad Radkersburg, respectively (both in Austria). Among the Slovenian municipalities in the Pilot 2 area, the lowest floor-area-normalized losses in a 50-year window are expected in the municipality of Kungota (7.4 €), while the highest losses were calculated for the municipality of Gornja Radgona (9.7 €). The latter is also a neighbouring municipality of Bad Radkersburg, indicating that the seismic risk does not significantly change when passing the state border.

Other risk indicators also indicate relatively low seismic risk. The proportion of buildings in a municipality reaching the D1 damage states in 50 years is expected to range between 3.4 % and 8.8 %. For the D2 damage state, this proportion is expected to be between 1.2 % and 3.4 %, for the D3 damage state between 0.23 % and 0.77 %, for the D4 damage state between 0.045 % and 0.17 % and for the D5 damage state between 0.015 % and 0.061 %. The proportion of buildings in a municipality that are expected to be short-term unusable due to earthquakes in the next 50 years ranges from 0.46 % to 1.3 %. For the long-term unusable buildings, this proportion is further reduced by about a factor of three. Furthermore, it is expected that earthquakes in a 50-year window will be fatal for 0.0019 % to 0.0079 % of the municipality's population, while the expected number of injured people is about 3.3-times higher. It is also expected that 0.64 % to 2.0 % of the population in a municipality will lose their home (at least for a short term) due to earthquakes in the next 50 years.

The variation of the seismic risk across the Pilot 2 area is mostly affected by the seismic hazard. The floor-area-normalized losses are the lowest in the northern part of the area, where the hazard is the lowest, and increase towards the south, where the hazard is the highest. However, the hazard is not the only factor affecting the seismic risk. The importance of vulnerability and exposure is evident from the risk assessment results for Bad Radkersburg, where the expected floor-area-normalized losses are the highest, although the seismic hazard is not as high as in some Slovenian municipalities. This is because the buildings on the Slovenian side of the border are less vulnerable. Still, the difference in the vulnerability between Slovenian and Austrian buildings is not substantial and does not cause a significant difference in the risk when passing the state border, as noted above.

3.3.3. Limitations and Future needs

The seismic risk assessment for the Pilot 2 area contains several limitations. One of the limitations is the use of the ESHM2020 model for the characterization of seismic hazard. The ESHM2020 model is not as precise as the national seismic hazard models. However, it was used in the BORIS project nonetheless because it provides smooth hazard over country borders. The ESHM2020 model also provides PGA values only for return periods up to 5000 years. For higher return periods that also affect the risk calculation, the PGA values were obtained by extrapolating the hazard curves. This may result in a slight bias in the risk estimates. It is therefore suggested to focus, as a part of future studies, on the development of a hazard model specifically for the cross-border area under consideration. In such a model, the region-specific systematic effects that impact the seismic hazard could also be considered. This includes not only the local soil effect but also other site effects, source effects and path effects, which can be taken into account by utilizing non-ergodic ground-motion models (e.g., Lavrentiadis et al., 2022).

Limitations were also identified in the exposure model used in the seismic risk assessment. The exposure model included only residential buildings and population, while other buildings and infrastructures were disregarded. These assets could be included in future risk assessment studies. However, even the exposure model for the residential building stock could be improved, especially for the Austrian municipalities, where some data were determined based on expert judgement. It is therefore suggested to improve the accuracy level of the building data relevant to the risk assessment (material of the load-bearing structure, year of construction, number of storeys, floor-area surface) by field inspection. Moreover, it should be noted that the exposure data varies over time, which imposes bias in the risk estimation. Some exposure parameters evolve slowly, while others can change rapidly. One such parameter is the building replacement cost, which is impacted by construction costs. This limitation can be addressed by periodically repeating the risk assessment.

It is also necessary to point out the limitations of the vulnerability model. For the Austrian municipalities, the vulnerability model developed for the Slovenian territory was used, as no vulnerability model has been developed specifically for the Austrian building stock. It is therefore recommended to develop such a vulnerability model as a part of future studies. Preferably, the vulnerability model would consider the local characteristics of the buildings in the region of interest. However, a sound vulnerability model for Austrian building stock as a whole could already provide an improvement in risk estimation. Improvements can also be made to the vulnerability model used for the Slovenian municipalities. In the current application, the vulnerability model developed for the entire Slovenian territory was used. This vulnerability model may be biased as the building stock in the investigated region varies from that in Slovenia as a whole. The development of a region-specific vulnerability model could address this limitation. However, it should be emphasized that developing a building vulnerability model is not straightforward, as no standardised approach to seismic vulnerability assessment has been developed thus far. In the future, extensive effort is required to develop a standardised European methodology analogously to the one addressing the seismic hazard, as discussed in Deliverable 4.1.

3.4. Cross-border flood risk assessment

For the flood risk assessment of the Pilot 2, the area of interest is the hydrological basin of Mur(a) river. The Mur(a) river is a border river that starts in Austria and runs through Slovenia, along the Slovenian-Croatian border and along the Croatian-Hungarian border until it flows into the Drava. More than half of the Mur's catchment area is in Austria, the lowland section of the river's course belongs to Slovenia, Croatia and Hungary.

Its total length is 469 km and the entire catchment area covers 14,4 km^2 of which 10,3 km^2 are in Austria, 1,4 km^2 in Slovenia.

According to the methodology proposed in D4.1, the harmonized approach for the cross-border flood risk analyses is based on the following steps (already reported in section 2):

- ***For the hazard component***: for each flood map with assigned return period the corresponding flood depth (if not already available) was calculated and then interpolated to receive more flood hazard maps for different return periods. As a starting point needed data are at least one flood extension map (from EU floods Directive) and high-resolution DTM (at least 5mx5m);
- ***For the exposure component***: the procedure for the definition of the harmonized spatial scale and exposure model consisted of the integration of information on built-up area and population at global level, additional data available at local scale and downscaling methodology to implement the global information on the building footprints;
- ***For the vulnerability component:*** The selected library for describing the relationship between the the condition parameters describing the forces affecting a given property in the event of a flood event and the damage caused is the HAZUS model (FEMA, 2009), which is based on a function of occupancy and the number of floors (and, if available as information, the presence of a basement), and is provided separately for the building structure and for its contents;
- ***For the consequence component:*** in the shared methodology the indicative number of inhabitants potentially affected and the economic consequences in terms of AAL and PML are considered.

These steps are proposed to carry out ***a baseline assessment***, based on the same information on each element of risk analysis (above all the exposure one) among the different countries. It should be a more easily replicable and simpler procedure. In this way the uncertainty due to different input data could be reduced.

3.4.1. Flood hazard, vulnerability and exposure

The methodology described before has been implemented in detail for pilot project 1 as follows. The result of the ***hazard element*** in a risk analysis is the flood hazard map. Flood hazard maps are maps of flood extension and water depth for a specific probability of occurrence (return period). For the cross-border flood risk assessment, the first activity was to obtain homogeneous hazard maps (for the same return period) that can be used for risk mapping having as input not homogenous maps of flood prone areas (different return period and without depth). For Austria flood extension and flood depth maps for the following return periods 30/100/300 were available as basis for further calculations and for Slovenia the flood extension maps of the following return periods 10/100/500 were available. The procedure followed for estimating the flood hazard maps both in terms of flood extension and depth is the same applied for Pilot 1 described in more detail in section 2.4.1.

Figure 3.23 shows an example of flood hazard maps available for consultation from the BORIS platform for Pilot 2, considering an event with a return period of 300 years: the five colors correspond to different water depth values [m].

Figure 3.23: Flood hazard map for Pilot 2 considering an event with a return period of 300 years

The availability of reliable and accurate information is a fundamental pre-requisite for deriving an acceptable ***exposure model***, and consequently a useful and reliable risk profile. For this reason, the phase of collection and comparative analysis of available data is a crucial part of the analysis, but requires significant time to conduct. As mentioned for the Pilot 1, the exposure model has been defined starting from the following available data:

- Statistical data;
- Available exposure models, consulted but not adopted in the Boris project;
- Global datasets on population distribution, settlement identification and land use / land cover;
- Building footprints.

For Austria, the statistical information derives from Statistik Austria that provide statistics on population at federal province level, and most are also available for smaller administrative units (NUTS 3, political districts, municipalities). These units measure 250x250 m (**Figure 3.24)**. With this data, the procedure for downscaling the population consist of the sum of all areas multiplied with the number of storeys of each building inside the NUTS, then the population density at NUTS level is obtained as the ratio between population and this area. From the area and the density, the ***residential population*** for each building are obtained. Also, the occupancy data are available for the smaller administrative units (NUTS 3, political districts, municipalities).

While for Slovenia, the average number of people per housing unit in each municipality is provided by Central Population Register (§3.2.2) and the ***residential population*** for each building have been determined as in the pilot 1. Within each administrative unit, the corresponding population is assigned to the buildings weighting with the overall available surface, thus also considering the number of floors. These data are used to evaluate affected people.

Figure 3.24: The smaller administrative units NUTS 3 (yellow cells) for the Austrian municipalities (blue ones).

For Slovenia, OSM layer of building footprints updated to the 2020 has been adopted (**Figure 3.25**). In the case of the Austria country (**Figure 3.25**), OSM layer of building footprints is not adopted, since a shape polygon layer is available as described in the §3.2.1

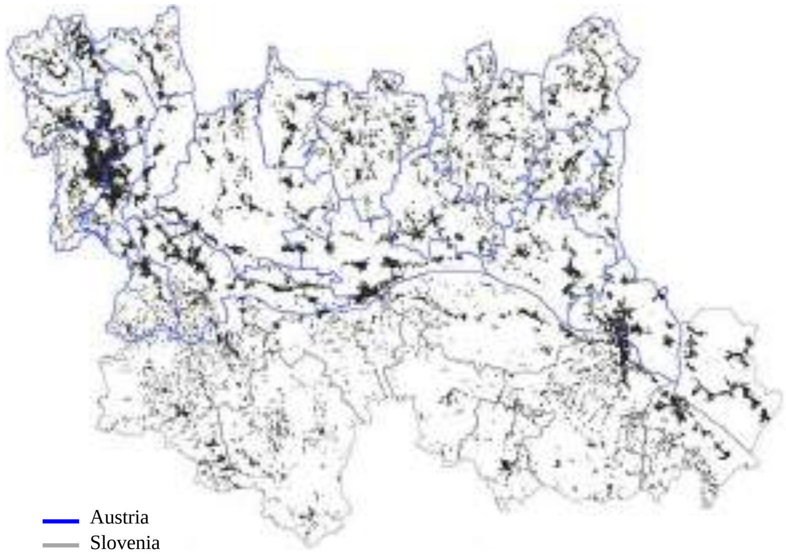


Figure 3.25: Open Street Map building layer for Slovenia and the building footprints developed with data from the ALS survey 2008-2012 and local updates in the following years for Austria – PILOT 2

For the exposure characterization in terms of the ***vulnerability characteristics***, that are building use and number of storeys, as introduced in the §2.4.1 a logic tree approach has been implemented. Logic-trees were made to assign the vulnerability characteristics to each building. Weights of discrete branches that represent alternative hypotheses and interpretations were determined by: 1) the abovementioned GHS-BUILT-S R2022A (Pesaresi and Politis, 2022) for the building use (in $_{RES}$ and GHS-$W_{NOT-RES}$); 2) local data aggregated at municipality level for the number of storeys (adopted also in the seismic analysis, MUN-W_{NoS}) for Slovenia, while for Austria the number of storey for each building is available. After this process each building has to be associated to four vulnerability curves for Slovenia (function of building usage and number of floors) and two for Austria as a function of the variability of use.

3.4.2. Risk Results

Each hazard map was used as input for the evaluation of impacts in terms of **potentially affected people, expected damage ratio** and **economic losses**; to this end, the following actions were performed and applied to each hazard map, also by adopting the RASOR Platform (Arrighi et al. 2018):

- A value of water depth – obtained through the overlaying with the hazard map – was assigned to each feature in the exposure model;
- By using specific physical vulnerability functions – depending on the physical characteristics of the assets – the expected damage ratio was evaluated;
- A set of performance criteria (damage states) for buildings subjected to flood hazards developed by Nofal et al. (2020) has been adopted. These performance criteria describe flood damage to buildings in terms of five damage states (DSs) ranging from insignificant damage (DS0) up to complete damage (DS4);
- Such impacts are then used to obtain the Average Annual Losses (AAL) and the Probable Maximum Losses (PML) values for each return period, for each country, considering the product among the damage ratio [%], the replacement cost [€/m2] (adopted the same for the seismic analysis), the area of the footprint [m2] and the number of storeys;
- The number of people potentially affected, considering a water depth greater than 20 cm.

Figure 3.26 shows in tabular form the results in terms of damage for the municipalities in Pilot 2. On the other hand, **Figure 3.27** shows the economic losses and the affected population. All these results can also be displayed on the BORIS platform as a map, as is shown in **Figure 3.28**.

Considering the time frame of 1 year, the value of direct economic losses in terms of EAL amounts to € 0.47 million for Slovenia, or roughly 0.001% of the total exposure value, while for Austria amounts to € 7.7 million, 0.02% of the total exposure value.

In Austria, at municipality level, the most affected city is Bad Radkersburg, in terms of ratio between AAL and the total exposure value, equal to 0.25%. It is followed by Gabersdorf, for which the previous ratio is equal to 0.20%. In absolute terms the most affected city is Bad Radkersburg, where AAL is about € 1.60 million, followe by Leibnitz with a value of AAL equal to € 1.10 million. The cities with the most affected population result Bad Radkersburg and Straß with 30 people, respectively.

In Slovenia, at municipality level, the most affected cities are Sveta Ana, Gornja Radgona and Šentilj, in terms of ratio between AAL and the total exposure value, equal to 0.02%. In absolute terms the most affected cities are Gornja Radgona and Šentilj where AAL is about € 0.13 million. The same cities have the most affected population, with about 10 people, respectively.

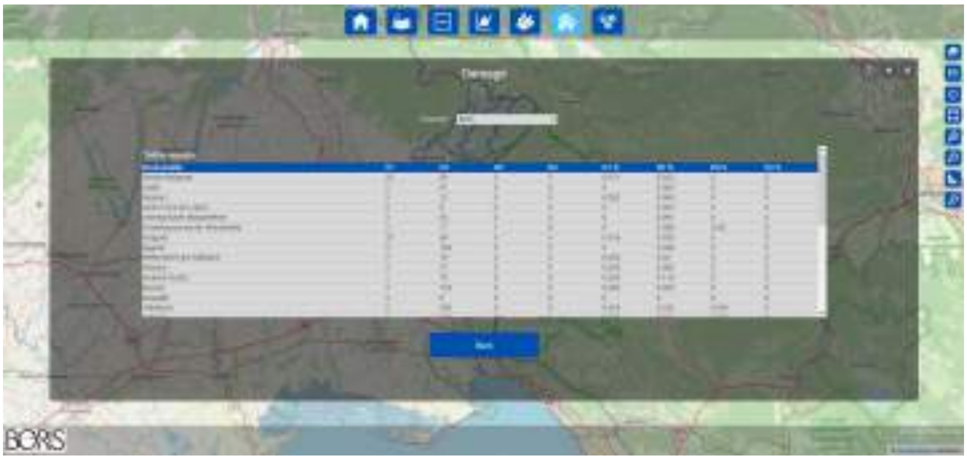


Figure 3.26: Damage results for flood in Pilot 2 in tabular form.

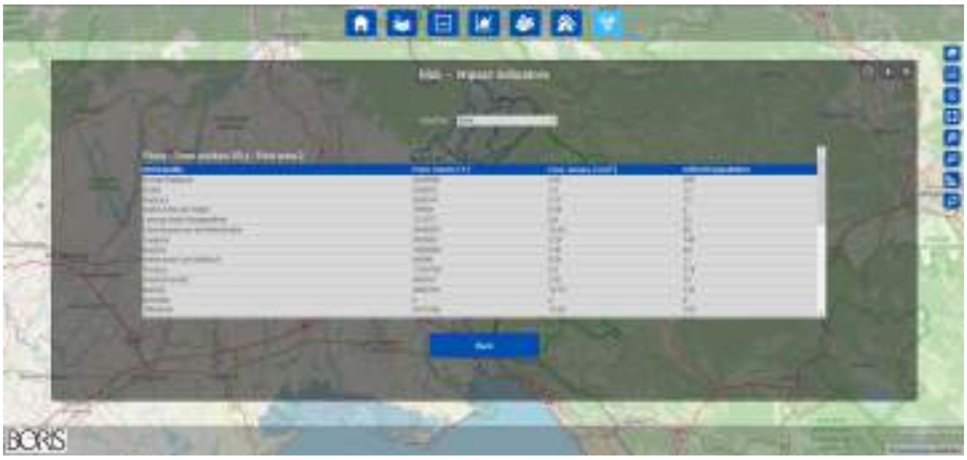


Figure 3.27: Economic losses and affected population for flood analysis in Pilot 2 in tabular form.

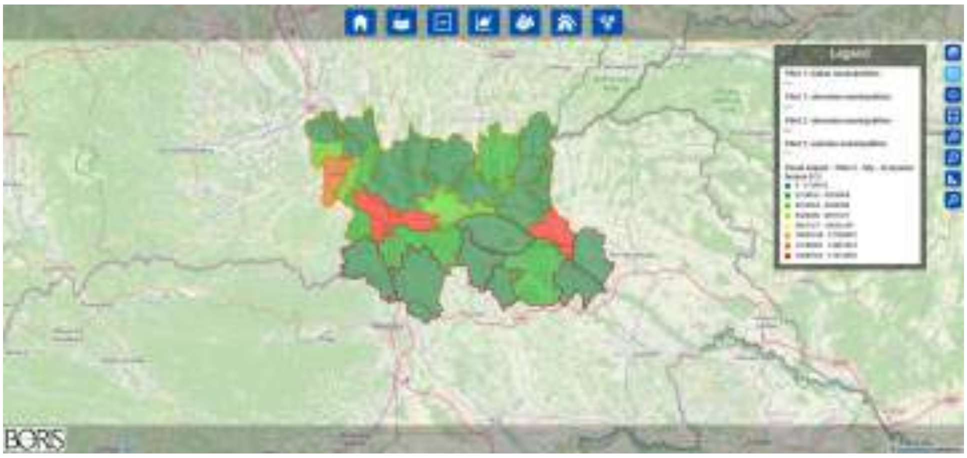


Figure 3.28: Map of economic losses for flood risk in Pilot 2 in a time window of 50 years.

3.4.3. Limitations and Future needs

During the application of the methods developed in WP 4 in pilot region 2, it became apparent that one limiting factor are the different data sets and also data gaps. Furthermore, not all data are openly available and the request for data from the responsible authorities requires a considerable amount of time. Some data are still only available for regional or national analyses and cannot be used in scientific international projects (example building footprint Slovenia). Therefore, it is important to pay attention to the harmonisation of cross-border data sets in the future. For the assessment of the transboundary flood risk, the scenarios for mapping the flood hazard first had to be harmonised in order to obtain the same annualities. When overlaying the calculated water depths with the building stock to estimate the consequences, the challenge emerged that the data are available in different spatial resolutions. The water depths were mapped as raster data, which in some cases resulted in an incorrect water depth, which was the one from the channel, being intersected with the buildings. Here, very precise corrections had to be made using the bank lines. This example shows how important local post-processing of the results is. Overall, there are different national traditions and approaches in hazard assessment, as well as in the availability of vulnerability models. There is a need for harmonised data, acquisition of further data on exposure and vulnerability of buildings and people, publicly available data (building material data, building floor plans, harmonised technical and statistical data) as well as the need to address regional differences such as building typologies.

3.5. Cross-border multi-risk comparison and ranking

The ranking of flood and seismic risk was based on comparing the expected economic losses due to both hazards. This section first provides some results of the multi-risk comparison and ranking from the BORIS platform. Then, a brief discussion of the results is given.

3.5.1. Results and presentation on web platform

The results on the BORIS platform are presented in several tables, maps and graphs displaying the following:

- The comparison of risk curves estimated for seismic and flood risk. Each risk curve represents the relationship between the annual probability of exceedance of an event (a flood or an earthquake) and the corresponding expected economic losses.
- The ratio between the EAL (expected annual loss) due to floods and EAL due to earthquakes.
- The total EAL, determined as the sum of the EAL due to floods and EAL due to earthquakes.

Figure 3.29 shows a screenshot of a table with the total EAL and the ratio between the EALs due to floods and earthquakes. The table includes the results of all municipalities in the Pilot 2 area. Moreover, examples of maps are presented in Figures **Figure 3.30** and **Figure 3.31** The map in Figure **Figure 3.30** displays the total EAL in each municipality due to both hazards, while the map in **Figure 3.31** shows the ratio between the EALs due to floods and earthquakes. Further, **Figure 3.32** and **Figure 3.33** each contain a pair of risk curves (related to flood and seismic risk) for one municipality. The risk curves in **Figure 3.32** are supplemented by the total EAL in the municipality (highlighted in yellow), while the ratio between the two EALs in the municipality supplements the risk curves in **Figure 3.33** (highlighted in yellow).

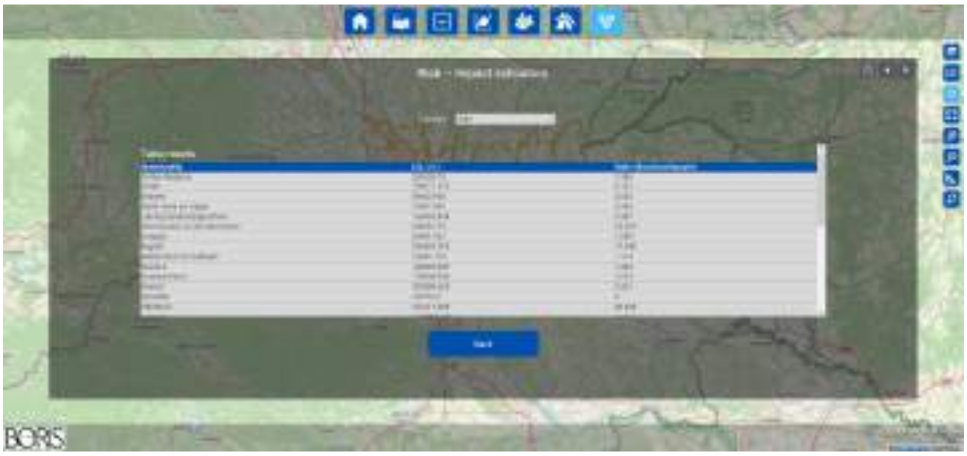


Figure 3.29: Multi-Risk assessment in the Pilot 2 area: tabular results.

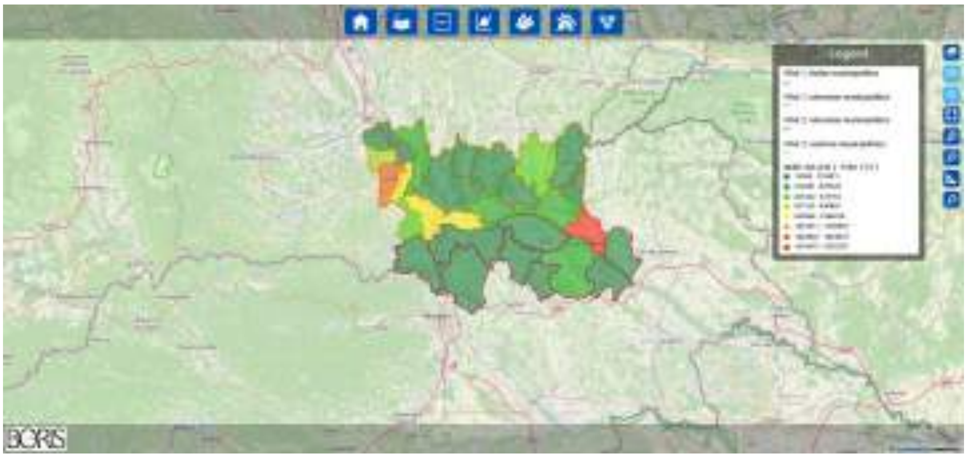


Figure 3.30: A map of the total EAL for floods and earthquakes in the Pilot 2 area.

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Project co-funded by the European Union Civil Protection

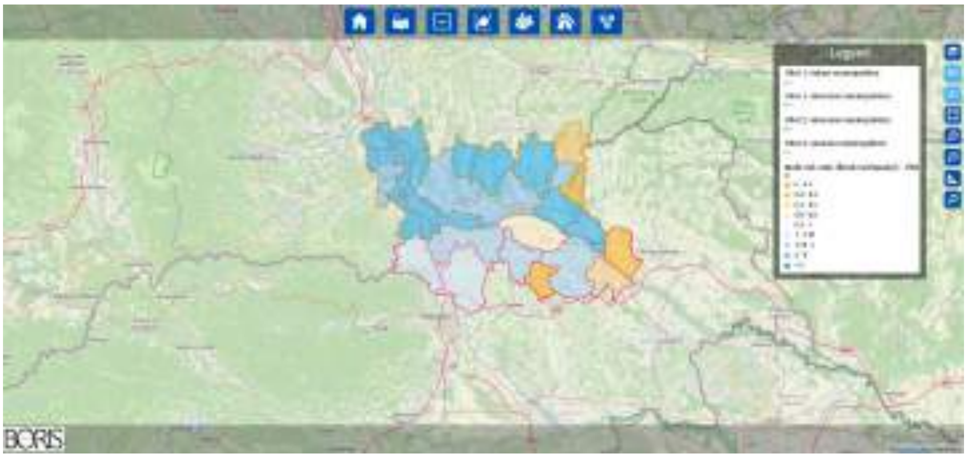

Figure 3.31: A map of the ratio between the EAL due to floods and EAL due to earthquakes in the Pilot 2 area.

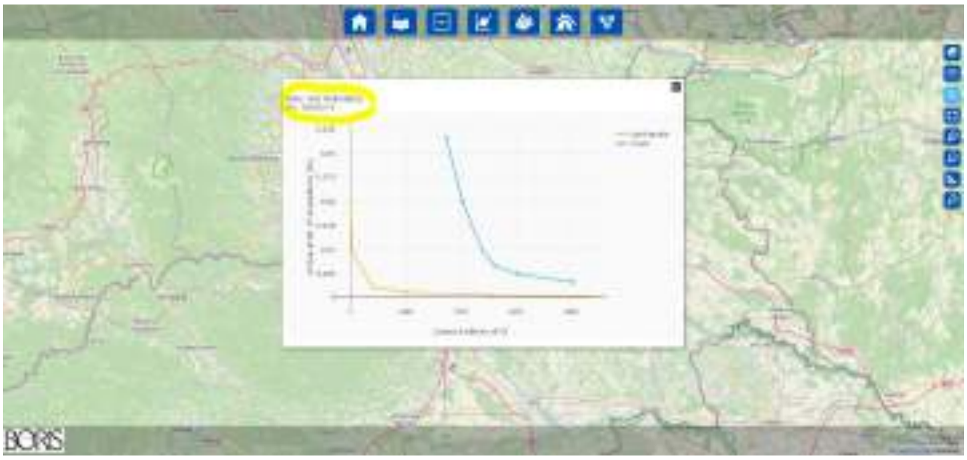

Figure 3.32: Risk curves and the total EAL for the municipality of Bad Radkersburg in the Pilot 2 area.

Figure 3.33: Risk curves and the ratio between the EALs due to floods and earthquakes for the municipality of Gabersdorf in the Pilot 2 area.

The difference between the seismic and flood risk is reflected by the differences in the risk curves generated for the two hazards. The comparison of the risk curves generally indicates higher flood risk at high probabilities of exceedance (low return periods) and higher seismic risk at low probabilities of exceedance (high return periods). In order to obtain an unbiased ranking of risks, all return periods are considered, and the risk levels are compared based on the EALs rather than the consequences at a single return period.

The ratio between the EALs indicates that some municipalities in the Pilot 2 area are more threatened by floods, while others are more threatened by earthquakes. The flood risk is predominant in the Austrian part of the area. For six of 21 Austrian municipalities, the ratio between the EALs is above 10, meaning that the flood risk is at least ten times more critical than the seismic risk. This includes the municipality of Bad Radkersburg, where both the flood and the seismic risk are the highest among all municipalities in the Pilot 2 area. The ratio between the EALs is above 2.0 for another 13 Austrian municipalities, still indicating the criticality of the flood risk but to a lesser extent. For only two Austrian municipalities, the seismic risk is the predominant one. These are the municipalities of Klöch and Sankt Anna am Aigen. Overall, the flood risk in the Austrian part of the area is about eight times higher than the flood risk.

The difference between the flood and seismic risk levels is less significant on the Slovenian side of the border. The flood risk is predominant in four of nine Slovenian municipalities. The ratio between the EALs due to floods and earthquakes in these four municipalities is between 1.2 and 1.8, much less than in most Austrian municipalities. The highest ratio was estimated for the municipality of Šentilj. In another four municipalities, the seismic risk is critical. This includes the municipalities of Tišina and Benedikt, where the seismic risk is at least ten times higher than the flood risk. Lastly, in one Slovenian municipality (Kungota), both EALs are approximately equal, indicating equal levels of flood and seismic risk. Overall, the flood risk in the Slovenian part of the Pilot 2 area was estimated to be about 6 % higher than the flood risk, which can be considered a negligible difference.

The total EAL implies that the Austrian municipalities in the Pilot 2 area are exposed to higher combined risk due to floods and earthquakes. For 17 Austrian municipalities, the total EAL is higher than that estimated for the most threatened Slovenian municipality. The highest total EAL on the Austrian side of the border was identified for the municipality of Bad Radkersburg (3.5 € per 1 m^2 of the residential floor area), while in Slovenia, the highest total EAL was calculated for Gornja Radgona (0.46 € per 1 m^2 of the residential floor area), a neighbouring municipality to Bad Radkersburg. The difference in the total EAL results from the flood risk, while the seismic risk in the two municipalities is practically equal. Interestingly, the two municipalities with the lowest total EAL are also located in Austria. These are the municipalities of Sankt Anna am Aigen and Klöch (0.08 € and 0.10 € per 1 m^2 of the residential floor area, respectively), where the seismic risk is low, and the flood risk is negligible.

3.5.2. Limitations and Future needs

The limitations in the multi-risk assessment in the BORIS project are mostly methodological. Therefore, the limitations discussed in Section 2.5.2, dedicated to Pilot application 1, also persist in Pilot application 2.

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