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Evidence for Disaster Risk Management from the Risk Data Hub

Analytical reports on natural hazards, vulnerabilities and disaster risks in Europe based on the DRMKC - Risk Data Hub

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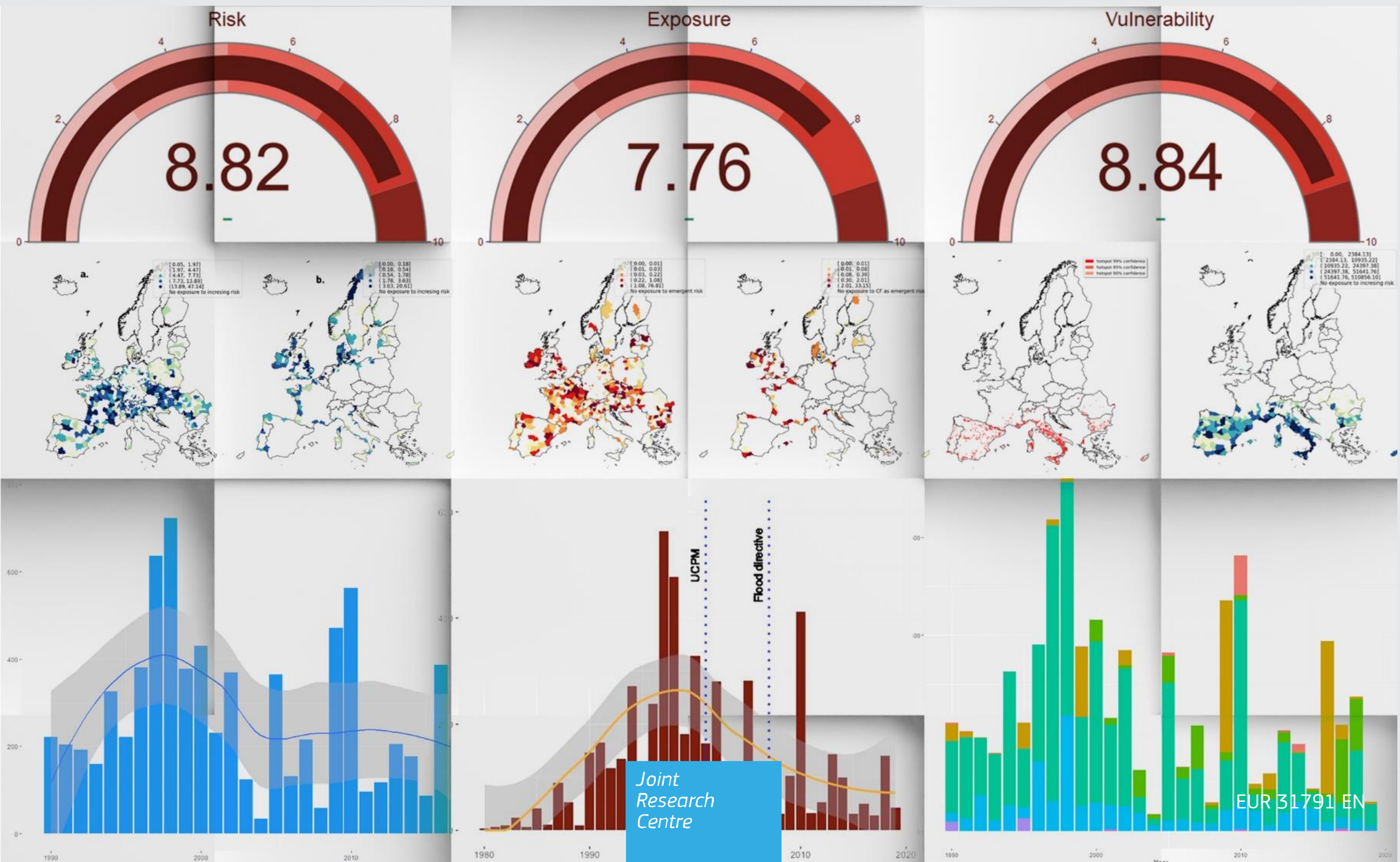

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Contents

Abstract

The EU Disaster Risk Management Knowledge Centre (DRMKC) is developing and maintaining the Risk Data Hub (RDH): a web platform, for collecting, managing and sharing disaster risk as well as damage and loss data. The RDH aims at supporting the implementation of the EU Strategy on Climate Change Adaptation and the understanding of the EU risk landscape as part of the Sendai Framework for Disaster Risk Reduction and at facilitating reporting by Member States, to help meet the objectives of Decision No 1313/2013/EU of the Union Civil Protection Mechanism.

The development of the platform is based on the results of ''Needs and Gap analysis" performed as part of the preparation of the European Commission Staff Working Document – ''Overview of Natural and Man-made Disaster Risks the European Union may face'' (latest two versions 2017[1], 2020[2]). The RDH adopts the comprehensive framework of policies and guidelines, data sharing initiatives and spatial data infrastructures with the purpose of setting the bases for knowledge for DRM at local, regional, national and Europe-wide level.

The platform hosts, curates and disseminates data, tools and methodologies for Disaster Risk Management (DRM). Among its key functionalities, it offers an open-source methodology for risk assessment as well as an authoritative loss and damage database that can provide an analysis of the losses due to disasters at European level. The Risk Analysis and Disaster Loss data portals are hosting open data and analysis with European wide coverage. They offer an overview on available and commonly used data in terms of risk components (hazards, exposure and vulnerability that in turn are used to estimate an overall risk indicator) for the risk analysis module and disaster loss and damage data (fatalities, economic losses, non-economic losses) for the disaster loss data module. These data and European-wide analysis and indicators are managed by the DRMKC RDH administrators and are freely available for download. The RDH provides decision makers with access to robust statistics and analytics for evidence-based policy formulation. Post-event records and pre-event assessments support the development of decision-making tools such as Cost Benefit Analysis. Furthermore, identifying the geographically located drivers of disasters (exposure and vulnerability), the RDH allows to intertwine the global/international policies and the local scale of practice and implementation. This report puts together five analytical reports based on the analysis of the data available within the RDH. It aims at providing a glimpse of the multiple analysis that can be derived from the intersection of different datasets on hazard, exposure, vulnerability and disaster damage and loss data hosted on the platform.

1 https://www.preventionweb.net/publication/overview-natural-and-man-made-disaster-risks-european-union-may-face-0
2 https://www.preventionweb.net/publication/overview-natural-and-man-made-disaster-risks-european-union-may-face-2020-edition

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1 Introduction

The Joint Research Centre (JRC) is currently in the process of developing web platform, the Risk Data Hub (RDH), within the Disaster Risk Management Knowledge Centre (DRMKC). The primary objective of this online platform is to document, evaluate, and share disaster risk data, while also providing support for risk management activities throughout Europe. The RDH architecture aligns with the reporting guidelines of the Sendai Framework. However, the platform is still undergoing overall infrastructure development in order to effectively host and present data in a user-friendly format. Streamlining the user interface is crucial to enhance accessibility for both the general public and specialized users, ensuring easy navigation through a step-by-step approach to curating information. In order to facilitate seamless integration and analytical work on data, it is recommended to continue supporting the improvement efforts of the RDH in two specific areas:

- Data analysis within the existing RDH, which will allow users to request ad hoc analytical reports based on available data.
- Enhancements to data collection within the existing RDH, following the predefined Work-plan and Roadmap. This report compiles five analytical reports aimed at enhancing data analysis capabilities within the RDH, enabling the generation of ad hoc analytical reports based on existing data.

The aforementioned reports are listed the following:

Report: 1. **Analysis of European wide losses and risks from single hazards**

This analysis shows a set of relevant hazards at European level comparing historical damages and losses, and current risk levels.

Report: 2. Identifying European wide regions with multi-hazard potential and quantify their population at risk

This analysis assesses population at risk from multiple hazards at the level of Local Administrative Units (LAU) and the multi-hazard interactions based on a theoretical framework.

Report: 3. Identifying European regions with Emerging and Increase in risk

This analysis at European level identifies regions with emerging and increase in risk that are the result of low probability hazard occurrence.

Report: 4. Identifying drivers of vulnerability and disaster risk

This analysis is an assessment of the trends in terms of disaster vulnerability and its components.

Report: 5. Country Reports

This analysis is an overview of the risk and its components for a selected country.

2 Analysis of European wide losses and risks from single hazards

This report presents examples of single hazards analysis from the RDH. The latter offers an open-source methodology for risk assessment as well as an authoritative loss and damage database that can provide indication of what has been lost. The report starts by presenting and visualizing loss data at the European level from relevant hazards. Furthermore, it shows their trend and evolution over time. The historical data on disaster losses available in the RDH shows that river floods are among the most frequent and damaging natural hazards of the last decades when it comes to fatalities and economic cost. The estimated annual losses for these events at the European level amount to 4812 million €. As for fatalities, the estimated annual value amounts to 162 casualties. Taking river floods as an example we show how future risks cluster in space at different levels of spatial aggregation. The report aims to highlight how RDH data can provide fruitful insights to assess past disastrous events and their impacts, estimate trends and provide insights on future risks.

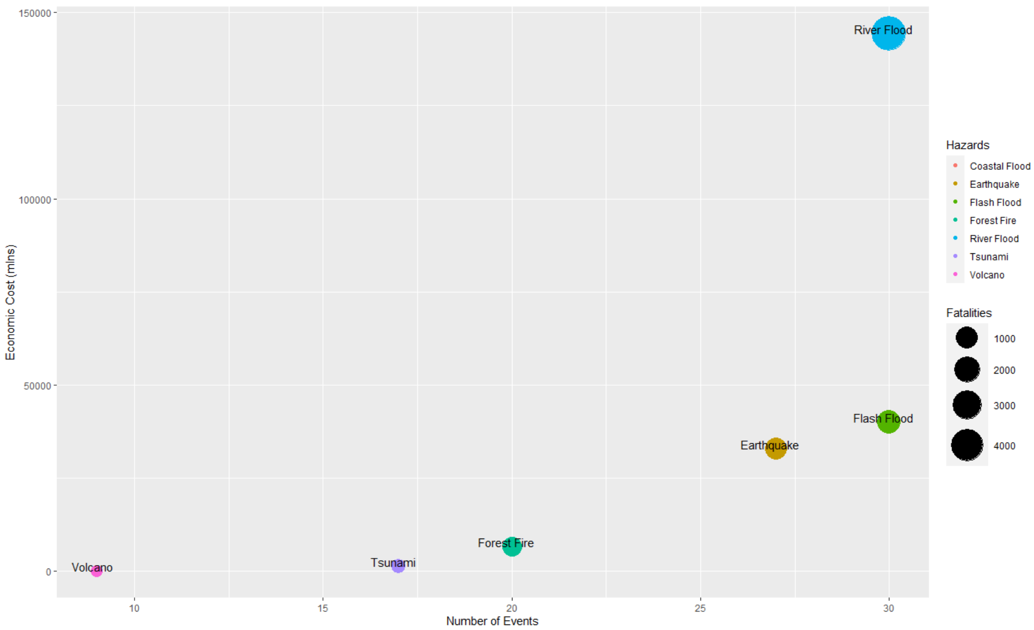
2.1 Loss Data

Since the 90s, disaster losses and damages have been showing a considerable temporal variation while being relatively persistent at the spatial level. Thanks to the variety of input data sources, the RDH is able to portray the geo-temporal dimensions of these patterns. The platform offers an optimal integration of many different data sources to record lost and damage data to serve the post-event phase of the Disaster Risk Management (DRM) cycle. Sources include Emergency Events Database (EM-DAT), Dartmouth Flood Observatory (DFO), Historical Analysis of Natural Hazards in Europe (HANZE), Emergency Management Service (EMSR), European Forest Fire Information System (EFFIS), National Centers for Environmental Information / World Data Service (NCEI/WDS), Global Landslide Catalog (GLC), European Drought Impact Report Inventory (EDII), European Media Monitor (EMM), Centre of Documentation, Research and Experimentation on Accidental Water Pollution (CEDRE), The Mariners' Alerting and Reporting Scheme (MARS), Windstorm Information Service (WISC) and Wikipedia.

On the platform, disaster loss data values are represented in absolute and relative terms as 1/100.000 people for human losses, while for economic losses, values are represented by absolute terms and relative share of countries gross domestic product (GDP). The RDH loss data are aggregated in temporal ranges of 5, 10, 15, and 25 years. For the sake of this paper, raw counts from events data are presented, e.g. absolute values of fatalities and a logarithmic transformation of economic cost. Currently the data available in the RDH covers the period 1900 to 2020 depending on the type of hazard. Over the last 30 years, 2449 disasters were recorded from different hazards.

Figure 1 presents an overview of a sample drawn from RDH data of 8 relevant hazards damages from 1990 to 2019.

Figure 1. Frequency and magnitude (fatalities and log of economic losses) of natural hazards in Europe (1990- 2019).

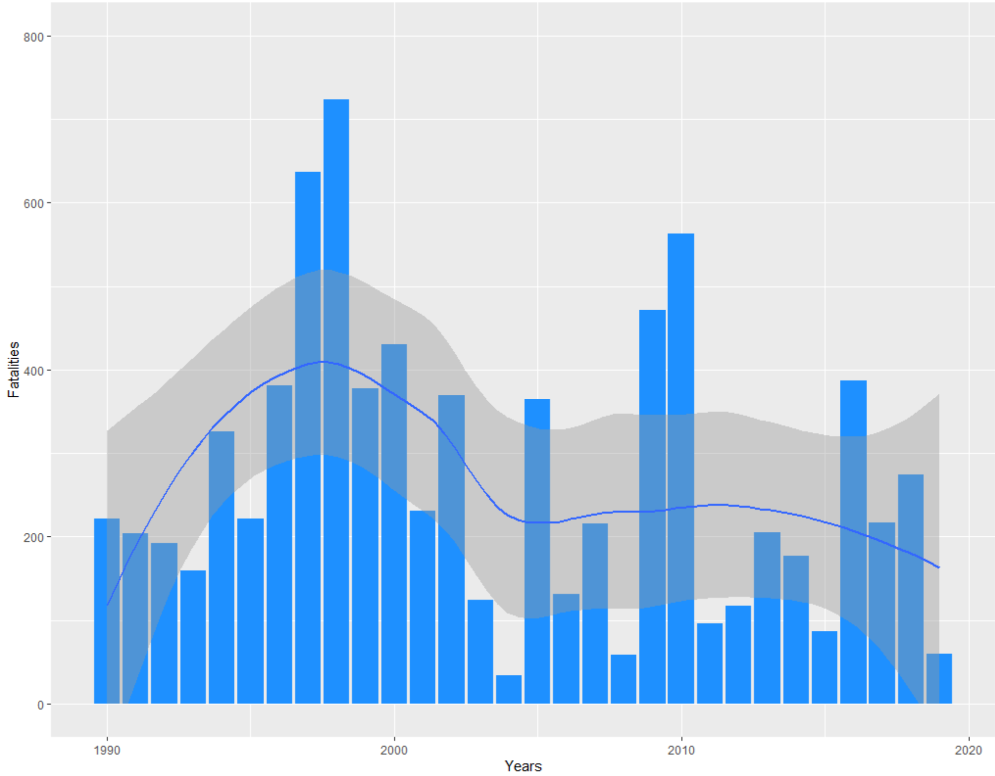


Source: JRC, 2022

Figure 1 displays the absolute frequency of each hazard on the horizontal axis over the course of 31 years, portraying their damages as the absolute number of fatalities they yielded. Similarly, the vertical axis shows the log of economic cost of said events as collected through open sources at the European level. Most of the economic losses in Europe, were mainly due to river floods, flash floods and earthquakes with over 42%, 12%, 10% shares of total losses respectively. Countries most affected by natural hazards have been Italy, Germany and Spain. The year 2013 recorded the worst economic losses from floods while 2012 has had the largest economic losses overall across all hazards available in RDH.

In terms of fatalities, when looking at the aggregated level, most fatalities occurred in 1997 with over 700 casualties from natural hazards (see **Figure 2**). We can also see a decreasing trend when locally weighted smoothing is applied in order to show the trend over time. Locally weighted smoothing, is used in this case for the regression analysis since it creates a smooth line through the time-plot to visualise the relationship over time through a trendline.

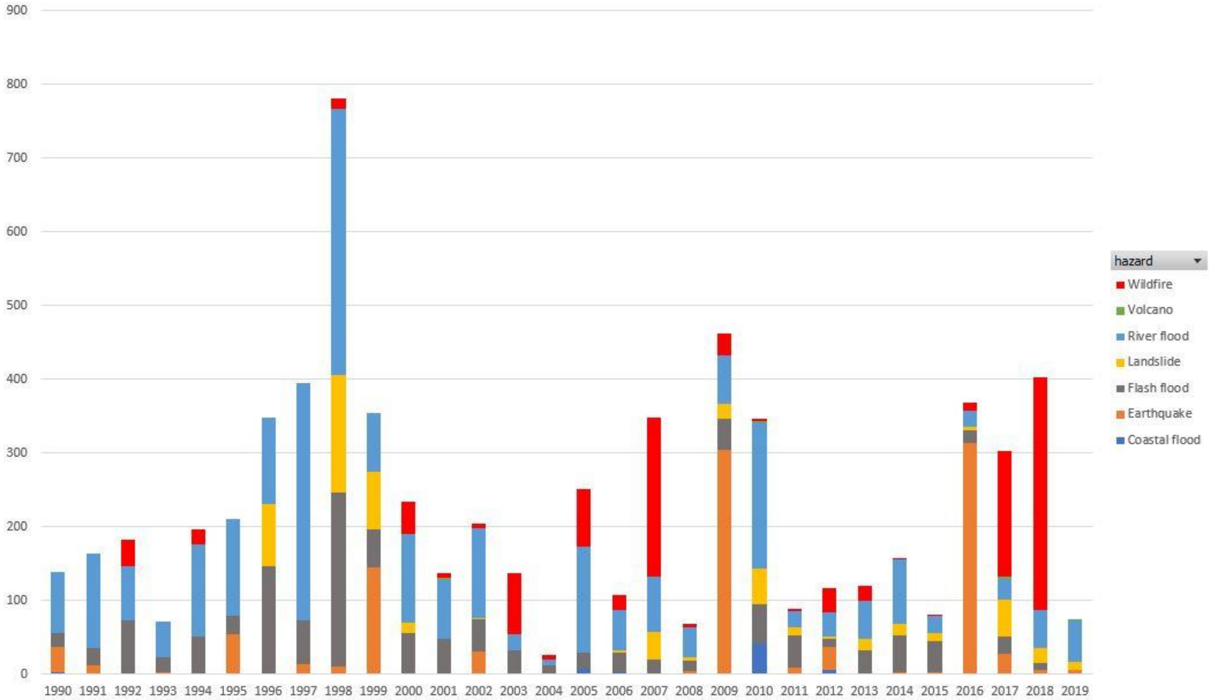
Figure 2: Bar plot of total fatalities in the European from natural hazards from 1990 to 2019. The trend is estimated with locally weighted smoothing.



Source: JRC, 2022

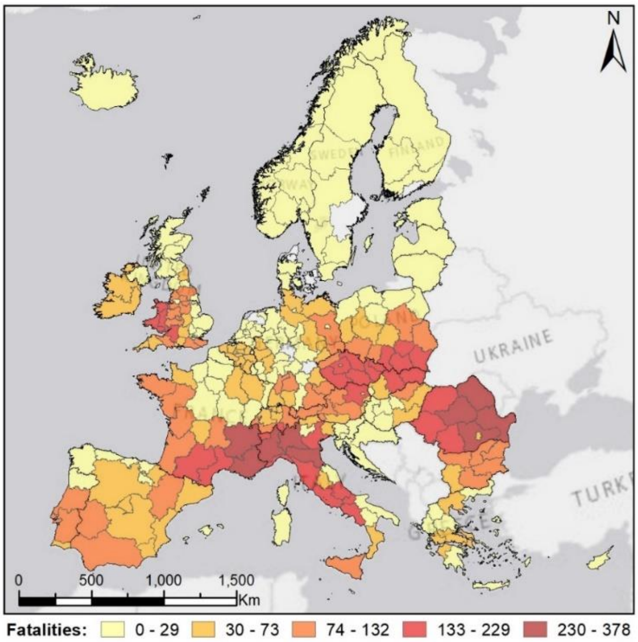
From **Figure 1** and **Figure 3**, river flood appears to be the most frequent disasters recorded and appear to cause the largest damages. This high frequency and high-magnitude features bring the need to improve the flood risk management cycle in order to prepare or respond to such events. In economic terms, river floods impacted Bulgaria, Italy and Slovakia in particular (with losses reaching roughly 3%, 1.4% and 1.1% of the total country's GDP respectively). River flood has had extremely high records of fatalities in the 30-years period under examination (see **Figure 3**) as they yielded consistently more fatalities (over 5000 fatalities corresponding to 59% of the total share of fatalities) than other disasters recorded in RDH data.

Figure 3: Stacked bar plot of fatalities from natural hazards from 1990 to 2019. Each portion of the bars portrays a different hazard as indicated in the legend.



Source: JRC, 2022

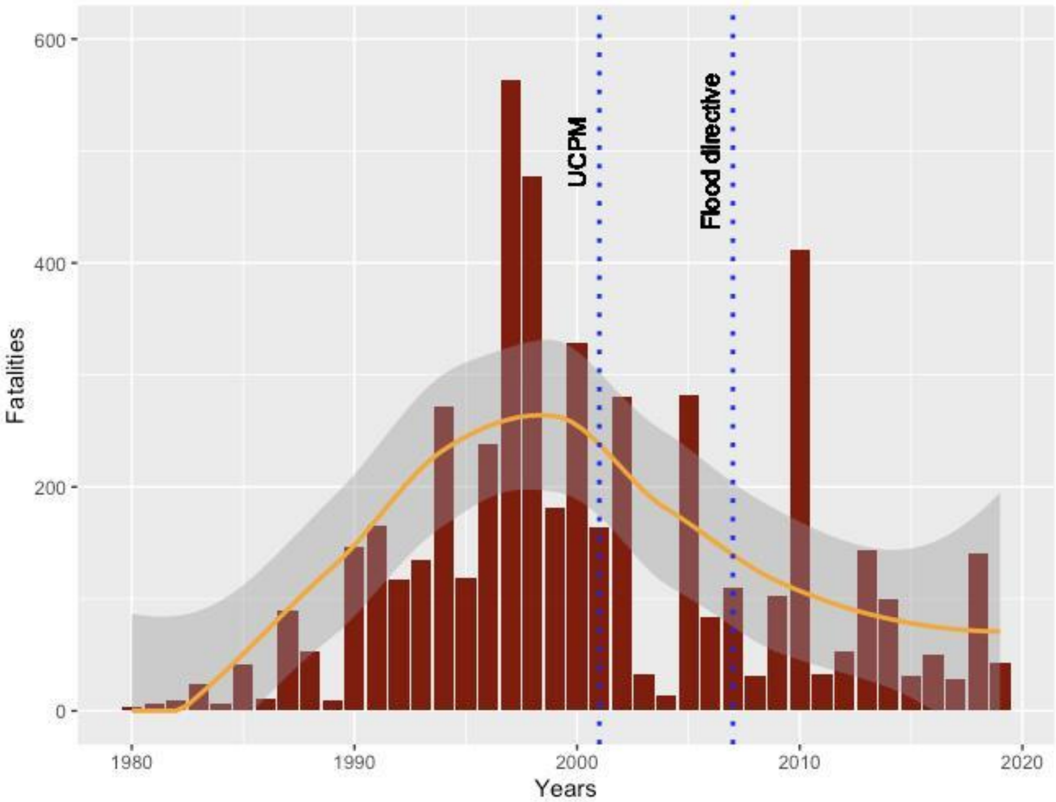
Figure 4: Spatial distribution of River Floods' fatalities in Europe over the period 1990-2019 at NUTS 2 level.



Source: JRC, 2022

As shown in **Figure 4**, countries most affected by river floods in terms of victims have been Italy, France and Romania with more than 390 fatalities each. In terms of temporal variation, 1997 and 1998 display the largest number of victims with 563 and 477 fatalities respectively. The count of casualties can be seen in **Figure 5**.

Figure 5: Bar-plot of River Floods fatalities in Europe (1990-2019) with locally weighted smoothing.



Source: JRC, 2022

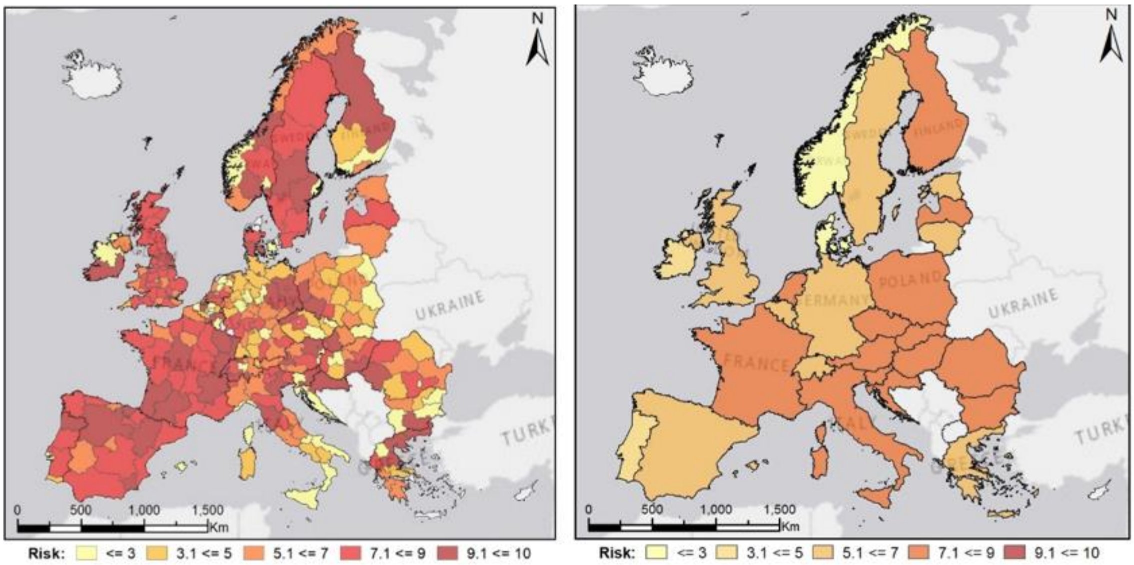
2.2 Risk overview

Despite the statistics that emerge from loss data, **Figure 5** seems to suggest a rather descending trend in impact of river floods in recent years. Observing the trend, the EU civil protection mechanism – implemented in 2001 - appear to have been an important contributing factor. Similarly, the Flood Directive (2007/60/EC)[3] seem to be an important contributing factor in the descending trend.

The DRMCK RHD contains also a Risk Assessment module able to support the pre-event phase of the DRM cycle. **Figure 6**, shows the estimated risk level for river floods and the population at risk based on 25-years exposure at the NUTS2 level of aggregation. Risk is estimated with an indicator varying from 1 to 10 and is calculated as a function of hazard, exposure and vulnerability. As displayed, several countries that already suffered from the impact of river flood are at high level of risk. As shown in the right facet of **Figure 6**, at the national level of aggregation, in the case of Italy for instance, the risk level amounts to 7.2, a value most likely driven by its high vulnerability score of 8.4 rather than by its exposure level of 6.2. Conversely, France – with a risk level of 7.1 – shows a relatively low vulnerability score of 4.9 but a large exposure score of 7.2. Even more interestingly, several countries – despite their comparatively lower levels of past losses – display high level of risk for the future. Among these, Hungary, the Netherlands, Slovakia, Latvia and Hungary respectively have a high risk of experiencing significant losses from river floods.

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32007L0060

Figure 6: RDH estimation of River Floods' Risk on population in a 25-years horizon at NUTS 2 level and Country level respectively.



Source: JRC, 2022

2.3 Data Analysis

While – as seen above – the number of fatalities from river floods has been consistently decreasing, the frequency of said event has been increasing. This could be due to several factors:

- Increased exposure of population to floods due to expansion of build-up area in river-floods prone areas such as flood plains which commonly attract economic and urban development. Concurrently urban development affects the occurrence of floods;
- Increased reporting of low-impact events in recent times due to better data technologies and more stringent regulations;
- Increased occurrence of extreme events due to climate change factors.

This brief analysis shows how harmonised and homogeneous loss data are crucial to establish a forward-looking post-event assessment of what has been lost and to design DRM plans building on lessons learnt from previous events.

2.4 Full Data Catalogue

This in a not exhaustive selection of data available on the RDH. Users are able to choose between a variety of Hazards and Assets as first selections as well as the geographical area and the spatial aggregation of interest (currently countries, NUTS2 and NUTS3). Furthermore, they can visualise different measures computed by the platform: risk, exposure, vulnerability, and single hazard layers. Additionally, they can pick projected exposure at different year intervals as well temporal aggregations of past losses (2, 5, 10, 15, 25 years). Finally, for loss data, they can choose the measure of losses and damages as: area at risk, economic impact, fatalities, people affected, and people injured.

Comprehensive table of all available hazards, assets and metrics for both losses and risk estimation is available in **Table 1** and **Table 2**. Accordingly, the platform is able to generate insights on all combinations of said hazards and assets.

Table 1. Loss Data Catalogue of the RDH

Category	Subcategories	Abbreviation	Data Source	1st event recorded	Last event recorded	No. of events	Spatial data
Geophysical	Landslide	LS	COOLR	1905-06-01	2021-07-18	1,128	Yes
			EM-DAT	1922-01-08	2020-12-30	33	No
			Media	2018-10-13	2021-12-10	20	No
			Wikipedia	1905-01-15	2020-12-30	36	No
	Earthquake	EQ	EM-DAT	1904-08-11	2021-09-27	132	No
			Media	1928-04-22	1933-09-26	2	No
			Wikipedia	1904-08-11	2022-04-04	106	No
			NOAA	1901-03-31	2021-10-12	353	Yes
	Volcano	VO	EM-DAT	1906-04-18	2021-09-19	12	No
			NOAA	1905-03-10	2019-08-28	39	Yes
	Tsunami	TS	EM-DAT	1979-10-16	1979-10-16	1	No
			NOAA	1901-03-31	2021-10-12	147	Yes
Hydrological	River Flood	FL	DFO	1985-07-06	2021-10-04	412	Yes
			EM-DAT	1906-04-01	2021-12-09	406	No
			HANZE	1900-09-27	2016-11-23	587	No
			Wikipedia	1910-01-21	2021-12-01	155	No
			Media	2018-10-13	2022-02-20	126	No
	Coastal flood	CF	EM-DAT	1953-01-31	1977-11-11	3	No
			HANZE	1906-03-12	2014-01-03	74	No
			Media	2018-10-29	2020-11-30	4	No
			Wikipedia	1953-01-31	2020-01-19	23	No
	Flash floods	FLSH	EM-DAT	1962-09-27	2021-08-29	73	No
			HANZE	1900-09-29	2016-12-03	824	No
			Media	2019-04-18	2022-05-02	40	No
			Wikipedia	1944-05-29	2021-07-25	22	No
Climatological	Forest Fire	FF	EFFIS	2020-01-01	2022-05-11	13,437	Yes
			EM-DAT	1949-08-01	2021-08-02	85	No
			Media	1982-08-24	2011-05-02	2	No
			Wikipedia	1949-08-19	2021-08-03	73	No
	Drought	DR	EM-DAT	1976-07-01	2018-06-01	30	No
			Wikipedia	2016-05-01	2016-05-01	1	No
Meteorological	Heat wave	HW	EM-DAT	1985-08-05	2020-08-05	77	No
	Windstorm	WS	EM-DAT	1928-05-01	2021-10-21	504	No
			Media	2019-06-10	2020-12-24	12	No
			Wikipedia	1976-01-01	2018-10-29	14	No
			C3S	1979-12-05	2017-10-16	20,461	No
	Cold wave	CW	EM-DAT	1963-01-01	2018-12-01	106	No
Technological	Chemical Spill	CH	EM-DAT	1967-03-17	2010-10-04	27	No
	Industrial	IN	EM-DAT	1901-04-27	2018-12-20	111	No
			Wikipedia	1988-07-06	1988-07-06	1	No
	Miscellaneous Other	MO	EM-DAT	1946-03-09	2021-05-23	21	No
			Wikipedia	2021-05-23	2021-05-23	1	No

Category	Subcategories	Abbreviation	Data Source	1st event recorded	Last event recorded	No. of events	Spatial data
	Structural collapse	SC	EM-DAT	1955-11-20	1994-10-15	5	No
	Miscellaneous Fire	TF	EM-DAT	1903-08-10	2020-11-14	68	No
	Miscellaneous Explosion	TX	EM-DAT	1904-10-08	2019-12-06	17	No
Transportation	Aviation	AI	EM-DAT	1913-10-17	2018-08-04	158	No
			Wikipedia	1986-12-12	1988-10-18	2	No
	Roads	RO	EM-DAT	1951-12-04	2021-11-22	103	No
			Media	1986-06-23	1995-05-23	5	No
			Wikipedia	1951-12-04	1999-03-24	17	No
	Railways	RW	EM-DAT	1906-07-01	2016-07-12	111	No
			Wikipedia	1955-11-20	1994-10-15	5	No
	Sea travel	ST	EM-DAT	1906-04-19	2021-12-24	134	No

Source: JRC, 2022

Table 2. Risk Data Catalogue available on RDH

Hazard	Asset	Asset Name	Metric	Unit metric
Coastal flood	Agriculture	agriculture	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Commercial built-up	commercial_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Population	population	Risk, as f(E, V)	absolute (people amount) and normalized (0-10)
	Residential built-up	residential_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Infrastructure	railways	Risk, as f(E, V)	Annual freight transported (k) and normalized (0-10)
Earthquake	Commercial built-up	commercial_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Population	population	Risk, as f(E, V)	absolute (people amount) and normalized (0-10)
	Residential built-up	residential_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Infrastructure	energy	Risk, as f(E, V)	Tonnes (k) of oil equivalent and normalized (0-10)
Forest fire	Commercial built-up	commercial_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Population	population	Risk, as f(E, V)	absolute (people amount) and normalized (0-10)
	Residential built-up	residential_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
River flood	Agriculture	agriculture	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Commercial built-up	commercial_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Environment	natural_cultural_heritage	Risk, as f(E, V)	absolute (km2) and normalized (0-10)
	Population	population	Risk, as f(E, V)	absolute (people amount) and normalized (0-10)
	Residential built-up	residential_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-10)

Hazard	Asset	Asset Name	Metric	Unit metric
	Infrastructure	education_facilities	Risk, as f(E, V)	Absolute (Mil. Eur) and normalized (0-1)
Landslide	Agriculture	agriculture	Risk, as f(E, V)	absolute (km2) and normalized (0-1)
	Commercial_built_up	commercial_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-1)
	Residential_builtup	residential_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-1)
	Environment	natural_cultural_heritage	Risk, as f(E, V)	absolute (km2) and normalized (0-1)
	Environment	natural_cultural_heritage	Risk, as f(E, V)	absolute (km2) and normalized (0-1)
	Population	population	Risk, as f(E, V)	absolute (people amount) and normalized (0-1)
	Infrastructure	education_facilities	Risk, as f(E, V)	Absolute (Mil. Eur) and normalized (0-1)
Subsidence	Commercial_built_up	commercial_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-1)
	Population	population	Risk, as f(E, V)	absolute (people amount) and normalized (0-1)
	Residential_built_up	residential_buildings	Risk, as f(E, V)	absolute (km2) and normalized (0-1)

Source: JRC, 2022

3 Identifying European wide regions with multi-hazard potential and quantify their population at risk

This analysis supports the integration of multi-hazard risk assessment and mapping into evidence-based decision-making, risk-reduction strategies and adaptation plans. It provides the spatial overview of regions expected to suffer significant impacts on population from multi-hazards occurrence across Europe at LAU level.

3.1 Methodology

The methodological approach is based on a hotspot analysis applied on population exposed to single hazards such as: river flood, coastal flood, earthquake, landslide, forest fire and soil subsidence. Based on LAU aggregations of the exposure it is possible to identify the statistically significant hotspots for the considered single hazard exposure. Using the Stouffer's method (Stouffer et al., 1949) for meta-analysis, the statistically significant exposure hotspots for single hazards are combined and subsequently spatial extension and location of multi-hazards exposure can be identified. Consequently, we provide the spatial overview of LAU expected to suffer significant multi-hazards exposure across Europe.

The analysis focuses on the following natural hazard interactions:

- Triggered and increased probability of secondary hazards
- Spatial overlap and temporal likelihood for triggered secondary hazard

3.2 Data sources

The Global Human Settlement Layer (GHSL) settlement model grid (model that classifies the human settlements on the base of the built-up and population density) was used to assess the "degree of urbanization" and it is available at: http://ghsl.jrc.ec.europa.eu/ (Sergio Freire et al, 2016).

Table 3: Dataset used for the present multi-hazard assessment

Hazards	Dataset	Link
River flood	Flood inundation maps	https://data.jrc.ec.europa.eu/collection/id-0054
Coastal flood	Coastal inundation maps	
Earthquake	The pan-European seismic hazard map (Giardini, D., et.al., 2013)	http://www.efehr.org/start/
Landslide	The landslide susceptibility hazard layer ELSUS_v2	https://climatedataguide.ucar.edu/climate-data/gpcc-global-precipitation-climatology-centre
Forest fire	Forest Fires Information system (Camia et al, 2014).	https://effis.jrc.ec.europa.eu/
Ground subsidence	Dominant surface texture mask	https://esdac.jrc.ec.europa.eu/content/european-soil-database-derived-data

Source: JRC, 2022

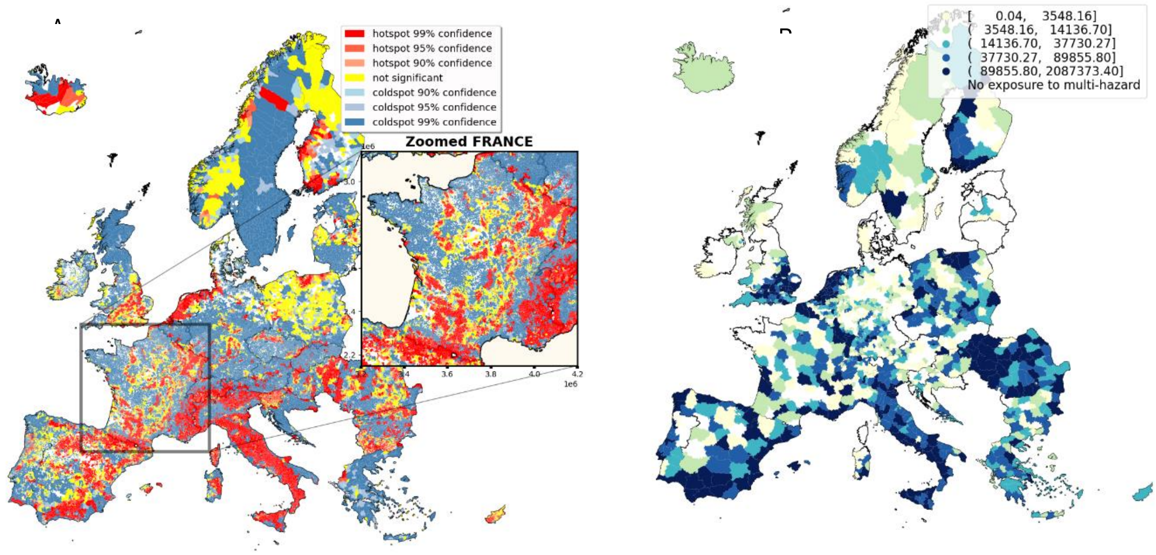
3.3 Results

The (multi-hazard) occurrence is based on the intersection hazard / assets (population). In this way, the spatial location and extension of the hazard is located where the specific elements are exposed. Meaning that the location and spatial extent of the hazard can be identified with (equal to) the location and spatial extent of the exposure. However, it is the exposure where the hazard occurs that is quantified in this report. Probabilistic exposure assessment is not used, but rather a deterministic approach selecting hazards with average temporal (frequency of occurrence) and spatial (susceptibility) probability, as for some hazards (subsidence, wildfire) probabilistic assessment of the hazard is not available. The average probability for hazards is chosen because in general the DRM is based on their protection levels (e.g., the DRM for river flood and coastal flood protection level is set to 100 years return period (RP) for most of Europe). For hazard definition please see (Antofie et al, 2019).

3.3.1 Population at risk to multi-hazards occurrence

There are close to 36 mil people that are at risk from significant multi-hazard occurrence (only hotspots regions with > 90 % confidence interval, **Figure 7** (A)), Europe wide (considering the 6 hazards of this analysis). The countries with most people at risk from multi-hazard occurrence are Italy (5.8 mil), France (4.6 mil), UK (3.5 mil), Spain (3.2 mil), Germany (2.1 mil) and Romania (2.1 mil).

Figure 7: On the left: regions (LAU) with population at risk to multi-hazard by significance level. On the right: sum of population at risk to multi-hazard assessed at NUTS3 (only hotspots regions with > 90 % confidence interval).



Source: JRC, 2022

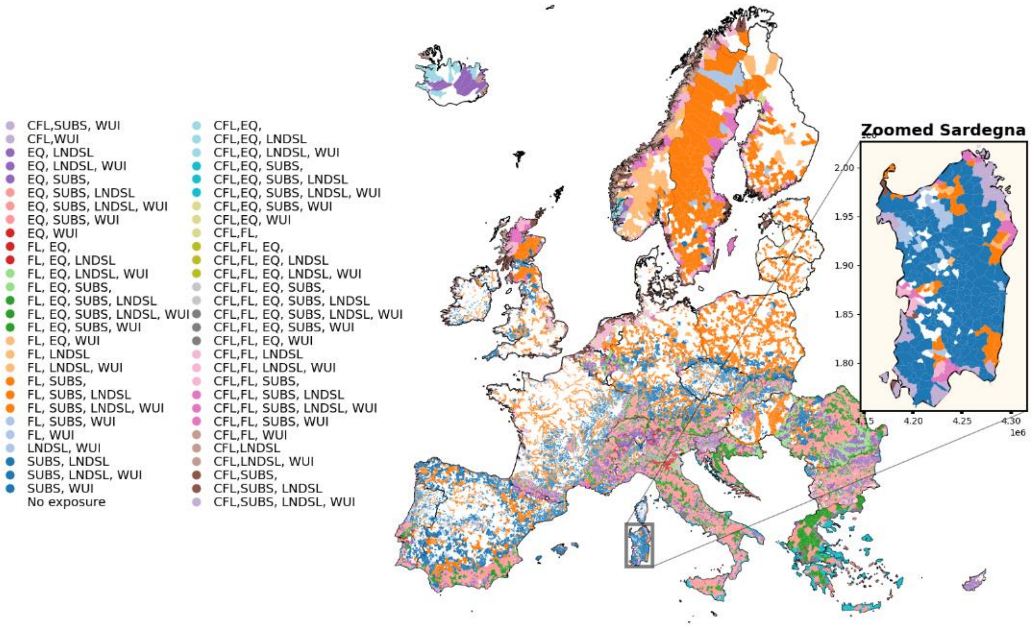
They are 33 527 LAU that are prone to multi-hazard occurrence in Europe (only hotspots regions with > 90 % confidence interval). Italy has 4773 LAU, France has 10577 LAU and Spain 2919 LAU, UK 1618 LAU and Germany has 1384 LAU.

3.3.2 Multi-hazard interaction

Multi-hazard interaction analysis is made on the typology of the hazards (**Figure 8**) and the theoretical framework developed by Gill and Malamud (2014). The typology and different types of hazard interaction is being looked at.

There are close to 123 000 LAU at European level, some of them are prone to exposure to one hazard type, some to all, some to diverse combination of hazard types. **Figure 8** shows the presence of all the possible combination.

Figure 8: Multi-hazard typology mapped at the level of LAU (CF= Coastal Flood, WUI = wildland urban interface used for wildfire, SUBS = subsidence, LNDSL = landslide, EQ = Earthquake, FL = River flood

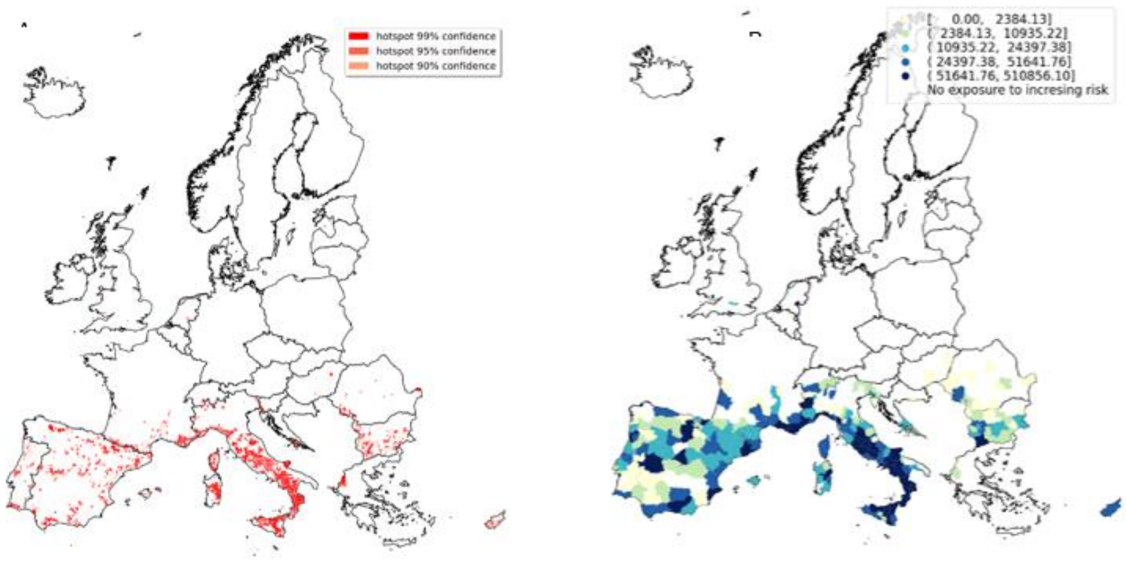


Source: JRC, 2022

3.3.2.1 Hazard interaction – triggered and increased probability of secondary hazards given information from the primary hazard.

From **Figure 9** (left) and **Figure 10**, it is possible to assess with high significance (only hotspots regions with > 90 % confidence level) the regions where wildfire as primary hazard increases the probability (of occurrence) of a secondary hazard (River Flood and Landslide) based on the theoretical framework of Gill and Malamud (2016). As seen from the key of the **Figure 10**, wildfire only increase the probability, it does not trigger the secondary hazards considered.

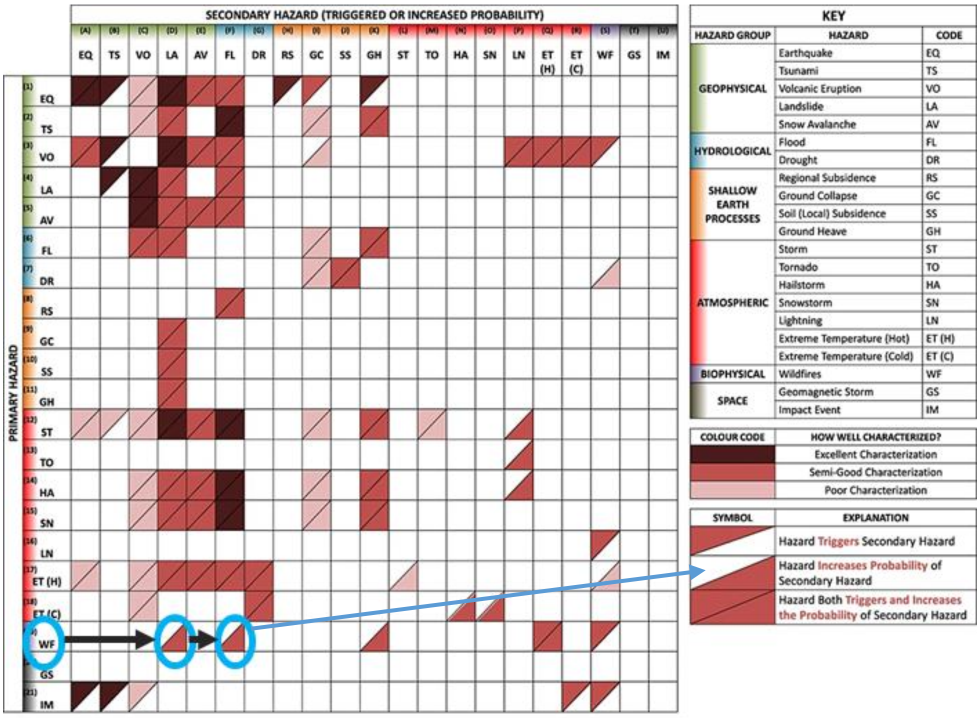
Figure 9. On the left: Regions (LAU) where Wildfire increase the probability of a secondary hazard (in this case Landslides and river flood) with a good characterization (according to Gill and Malamud (2016) theoretical framework). On the right: LAU with high significance level (only regions with > 90 % confidence interval) in multi-hazard occurrence wildfire/landslide/river flood; B. Population sum assessed at NUTS3 level (only for hotspots regions > 90 % confidence interval).



Source: JRC, 2022

The total population living in these regions is close to 8 mil. Most of the population at risk (**Figure 9** (B)) are found in Spain (cca. 1.5 mil), Italy (cca. 4.4 mil), France (cca. 1 mil people) and Portugal (447 000 people).

Figure 10. Identification of hazard interaction -based on a theoretical framework (Gill and Malamud, 2016). The wildfire (WF) increase the probability of secondary hazards related to river flood or landslide.



Footnotes

[1A,D,E; 3A,P; 12D-F,M,P; 13P; 14D-F,P; 15D-F; 17D-F; 21A] The secondary hazards in these cases are all accepted to most likely occur as large numbers of events, and are thus analysed in this way.

[1C] There is disagreement in the literature about the nature of this relationship.

[2,6,12,14,15C] Water input triggers or increases the probability of a phreatic/phreatomagmatic eruption.

[3I] Volcanism increases the acidity of rain, promoting dissolution of carbonate material.

[12A] Low pressure systems have been shown to trigger or increase the probability of slow earthquakes on faults that are already close to failure (Liu *et al.*, 2009).

[17A, C-F] Secondary hazards triggered or have an increased probability over a range of time-scales, through snow and glacial melting.

[18C] Long term reductions in temperature can increase glaciation and thus decrease sea-levels. This reduction in sea-levels can reduce confining pressures, promoting volcanic eruptions.

Other analysis on primary hazards that both trigger or increase the probability of a secondary hazards could be provided also with a quantification of the population at risk (exposed).

3.3.2.2 Hazard Interactions: Spatial Overlap and Temporal Likelihood for triggered secondary hazard

Figure 11 (on the left.) depicts the LAU with high significance level (only hotspots region with > 90 % confidence interval) where Earthquake and Landslides are characterized by spatial overlap and temporal likelihood. **Figure 11** (on the right) depicts the population at risk (absolute values) in the regions with high significance level (only > 90 % confidence interval) where earthquake and landslides share high spatial overlap and temporal likelihood of triggering relationships. The total population living in these regions is close to 440000. Most of the population at risk (on the right) are found in Italy (225510 people), Slovenia (68225 people), Switzerland (60457) and France (37773).

Figure 11. On the left: regions with high spatial overlap and temporal likelihood for the Landslide as triggered secondary hazard and Earthquake as primary hazard. On the right: LAU with highest significance in multi-hazard landslide /earthquake spatial and temporal relationship. Population sum assessed at NUTS3 level (only for the region with > 90 % confidence interval)

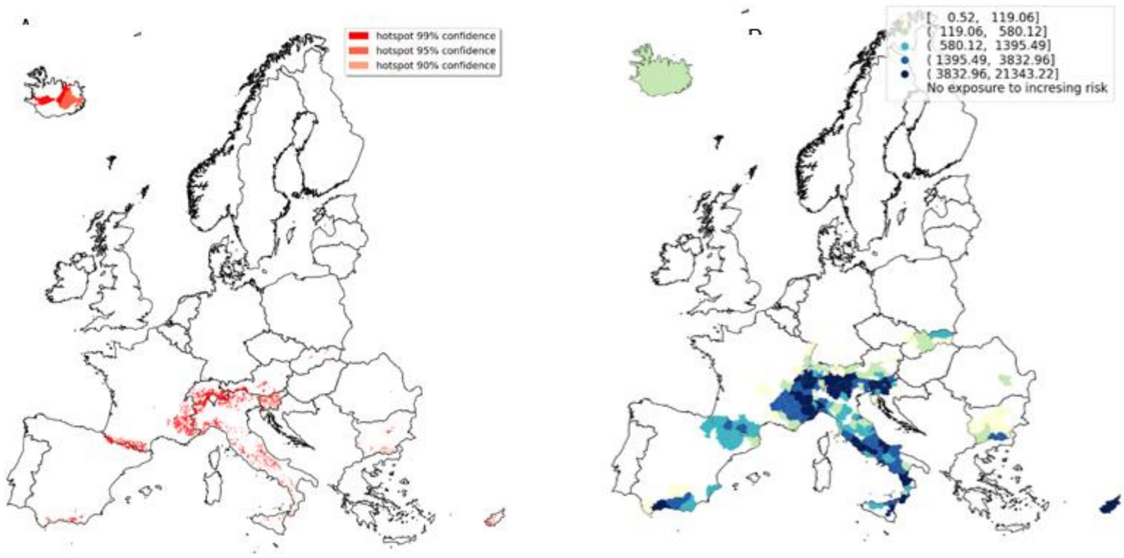


Figure 12 explains the range of the spatial overlap and temporal likelihood for the Landslide as triggered secondary hazard. The key of the range is presented below.

Spatial overlap:

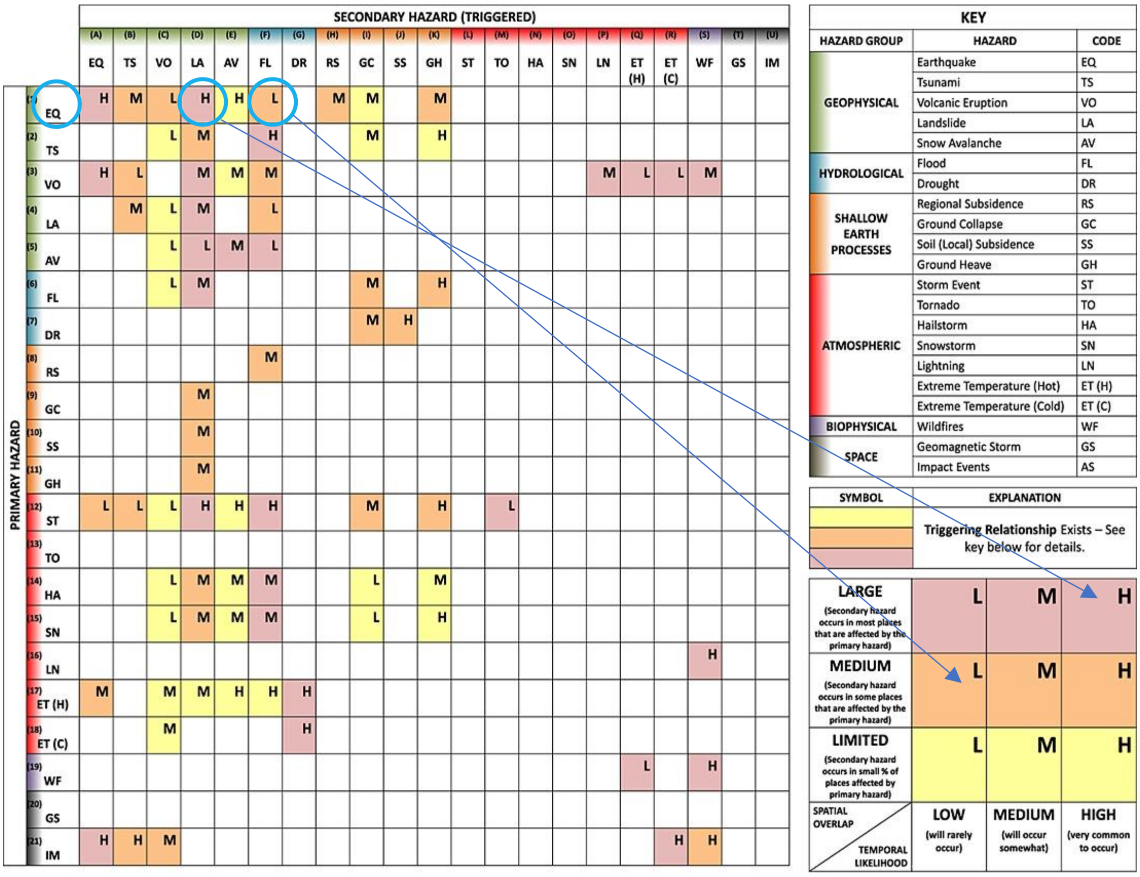
- Large (~70–100%): Secondary hazard occurs in most places that are affected by primary hazard.
- Medium (~30–70%): Secondary hazard occurs in some places that are affected by primary hazard.
- Limited (~0–30%): Secondary hazard occurs in a small percentage of places affected by primary hazard.

Temporal likelihood:

- High: Widespread case studies or examples of the primary hazard triggering the secondary hazard.
- Medium: Some case studies or examples of the primary hazard triggering the secondary hazard.
- Low: Occurrences in the literature of the primary hazard triggering the secondary hazard are either rare or non-existent but believed to be hypothetically possible.

The mark ''H'' for landslide as secondary hazard suggests that the landslides occurs in most places that are affected by primary hazard (Earthquake). Also, the landslide has a high probability of being triggered by the primary hazard.

Figure 12. Spatial overlap and temporal likelihood of triggering relationship matrix (Gill and Malamud 2016). The earthquake (EQ) as primary hazard has high temporal probability and spatial overlap with the secondary hazards Landslide and medium temporal and spatial relationship with secondary hazard River flood.



SECONDARY HAZARD (TRIGGERED)

PRIMARY HAZARD	(A) EQ	(B) TS	(C) VO	(D) LA	(E) AV	(F) FL	(G) DR	(H) RS	(I) GC	(J) SS	(K) GH	(L) ST	(M) TO	(N) HA	(O) SN	(P) LN	(Q) ET (H)	(R) ET (C)	(S) WF	(T) GS	(U) IM
(1) EQ	H	M	L	H	H	L		M	M		M										
(2) TS			L	M		H			M		H										
(3) VO	H	L		M	M	M										M	L	L	M		
(4) LA		M	L	M		L															
(5) AV			L	L	M	L															
(6) FL			L	M					M		H										
(7) DR									M	H											
(8) RS						M															
(9) GC				M																	
(10) SS				M																	
(11) GH				M																	
(12) ST	L	L	L	H	H	H			M		H		L								
(13) TO																					
(14) HA			L	M	M	M			L		M										
(15) SN			L	M	M	M			L		H										
(16) LN																			H		
(17) ET (H)	M		M	M	H	H	H														
(18) ET (C)			M				H														
(19) WF																	L		H		
(20) GS																					
(21) IM	H	H	M															H	H		

KEY

HAZARD GROUP	HAZARD	CODE
GEOPHYSICAL	Earthquake	EQ
	Tsunami	TS
	Volcanic Eruption	VO
	Landslide	LA
	Snow Avalanche	AV
HYDROLOGICAL	Flood	FL
	Drought	DR
SHALLOW EARTH PROCESSES	Regional Subsidence	RS
	Ground Collapse	GC
	Soil (Local) Subsidence	SS
	Ground Heave	GH
ATMOSPHERIC	Storm Event	ST
	Tornado	TO
	Hailstorm	HA
	Snowstorm	SN
	Lightning	LN
	Extreme Temperature (Hot)	ET (H)
	Extreme Temperature (Cold)	ET (C)
BIOPHYSICAL	Wildfires	WF
SPACE	Geomagnetic Storm	GS
	Impact Events	AS

SYMBOL	EXPLANATION
	Triggering Relationship Exists – See key below for details.

SPATIAL OVERLAP / TEMPORAL LIKELIHOOD	LOW (will rarely occur)	MEDIUM (will occur somewhat)	HIGH (very common to occur)
LARGE (Secondary hazard occurs in most places that are affected by the primary hazard)	L	M	H
MEDIUM (Secondary hazard occurs in some places that are affected by the primary hazard)	L	M	H
LIMITED (Secondary hazard occurs in small % of places affected by primary hazard)	L	M	H

Footnotes

[1A,D,E; 3A,P; 12D-F; 14D-F; 15D-F; 17D-F; 21A] The secondary hazards in these cases are all accepted to most likely occur as large numbers of events, and are thus analysed in this way.

[1B] Generally only applicable if earthquake has moment magnitude $M_w > 7$.

[1C] Generally only applicable if earthquake has moment magnitude $M_w > 8$.

[2,6,12,14,15C] Water input triggers a phreatic/phreatomagmatic eruption.

[3Q,R] Generally only applicable if height of eruption column is > 10 km.

[12A] Low pressure systems have been shown to trigger slow earthquakes on faults that are already close to failure (Liu *et al.*, 2009).

[17C-F] Secondary hazards triggered over a range of time-scales, through snow and glacial melting.

[18C] Long term reductions in temperature can increase glaciation and thus decrease sea-levels. This reduction in sea-levels can reduce confining pressures, promoting volcanic eruptions.

[21A,B,C,S] Generally only applicable if asteroid impact has energy > 10 Mt.

[21Q,R] Generally only applicable if asteroid impact has energy > 10^5 Mt.

Source: JRC, 2022

3.3.3 Data limitations

The identification of exposure or risk on the RDH is done generally from relating ***an asset*** to ***a hazard*** (vulnerability of assets is not yet addressed in this way, as it is a composite indicator, hazard independent). There is also the possibility to relate ***an asset*** to ***multiple hazards*** and have a multi-hazard assessment (of exposure or risk) on the single asset. This latter situation is the central aspect of this analysis and regards the relation of the asset population to multiple hazards: landslide, coastal flood, river flood, earthquake, wildfires and subsidence. Therefore, the regions with multi-hazard potential depicted in the present analysis are identified only due to the relation of the specific asset population and the multiple hazards (listed above). Meaning that relating other single assets to the multiple hazards could (and it is correct like this) identify different regions with multi-hazard potential.

The current analysis is not assessing the relation of other assets types (residential buildings, commercial, agriculture, infrastructure etc.) to the multiple hazards presented above. However, independent of current analysis, on the RDH these other assets are considered and related to multiple hazards. They are not presented here as they are the subject of more in depth, underlying analysis not present currently on the RDH, where we present only the aggregated information (i.e. the exposure and risk as normalized 0-10 values of the relations one to many or many to many selections among assets and hazards). That is why this (pilot) analysis is important for us as we can identify analysis (i.e. quantification of assets at risk in the regions with multi-hazard potential, identification triggered secondary hazard etc.) of multi-hazard assessments that will be implemented on the platform and made available for the general user. Please see below the assets and hazards present at present on the RDH for which the multi-hazard methodological approach is implemented.

Table 4. List of assets addressed currently on the RDH.

Source	**Assets (and categories)**	**Amount (metric)**	**Spatial layer/resolution**
	Infrastructure		
HARCI-EU[4]	Electricity distribution lines	Tonnes (k) of oil equivalent	Grid (1000m)
HARCI-EU	Gas pipelines	Tonnes (k) of oil equivalent	Grid (1000m)
HARCI-EU	Railways	Annual freight transported (k)	Grid (1000m)
HARCI-EU	Roads	Annual freight transported (k)	Grid (1000m)
HARCI-EU	Education facilities	Total expenditure (Mil. Eur)	Grid (1000m)
CORINE[5]	**Agriculture**	km2	Grid (100m)
CORINE	Arable (211,212,213)	km2	Grid (100m)
CORINE	Forest (311,312,313)	km2	Grid (100m)
CORINE	Pasture (231)	km2	Grid (100m)
CORINE	Permanent crops (221,222,223)	km2	Grid (100m)
	Buildings		
ESM[6]/CORINE	Commercial built-up	km2	Grid (100m)
ESM/CORINE	Residential built-up	km2	Grid (100m)
GHSL	**Population**	people no.	Grid
	Protected area		
WADP[7]	N2000_Birds_Directive	km2	Vector
WADP	N2000_Both_Directives	km2	Vector
WADP	N2000_Habitats_Directive	km2	Vector
WADP	N2000_Protected_areas	km2	Vector
WADP	Protected_area_WHS	km2	Vector

Source: JRC, 2022

[4] HARCI-EU HARmonized grids of Critical Infrastructures in EUrope - https://www.nature.com/articles/s41597-019-0135-1
[5] Corine land use code CORINE Land Cover — Copernicus Land Monitoring Service
[6] GHS_pop and GHS_Build/ESM and Urban Centres: Global Human Settlement - Download - European Commission (europa.eu)
[7] WDPA (WHS _CH): https://www.protectedplanet.net/c/world-database-on-protected-areas

Table 5. List of hazards addressed currently on the RDH

River flood	T = (10,50, 100, 200, 500)	Areal extent/intensities of the river flood (m)	EFAS
Landslide	T = (2, 5, 10, 20, 50, 100, 200, 500)	ELSUS_v2 - (200 m) and GPCC - (5km resolution) - with the return periods T = (2, 5, 10, 20, 50, 100, 200, 500).	ESDAC, GPCC
Coastal inundation	T = (10,50, 100, 200, 500)	Areal extent/intensities of coastal inundation as extreme total water level (TWL) result of the contributions from the mean sea level (MSL), the tide and the combined effect of waves and storm surge.	Vousdoukas, et al., 2016
Earthquake	T = (250,475, 975, 1500)	Areal extent of PGA >= 0.18 (g), equivalent of 'Moderate', 'Moderate to heavy' 'Heavy'', ''Very heavy' potential damage level of USG Intensity Scale	GAR
Subsidence	Soils with clay content greater than 35%.	Areal Extent of fine and very fine soil texture (particle < 2 mm size) and with clay content greater than 35%.	ESDAC, IPL project
Forest fire	Wildland–Urban Interface area (WUI)	WUI areas within 10 km limit range from the historical burned areas (2000-2016)	CORINE/EFFIS based

Source: JRC, 2022

3.4 Assumption and uncertainty

The regions with multi-hazard potential are the regions with high statistical significance (p-value < 0.10) when combining statistics and probabilities (z-scores and p-values) from single clustering analysis. By addressing the significance of the common estimation (i.e. combined clusters through meta-analysis) it introduces an objective "statistical proof" of the multi-hazard clustering potential. In this way the uncertainty is also addressed.

4 Identifying European regions with Emerging and Increase in risk

The analysis proposed is set to identify: newly exposed assets to emerging risk and increase in risk as a result of unforeseen events caused by low probability of hazard occurrence. This situation happens when the frequency distribution of extreme events is altered, under the climate change, and the unlikely/unforeseen events become likely/probable in the near future.

The asset for this first analysis is population, and the analysis is based on identifying the population at risk (exposure) to hazards with various probability of occurrence (e.g. various return period). The hazard considered are: coastal floods, river floods and landslides.

Hazard exposure is aggregated at administrative levels (LAU, NUTS3, and Country) following the overlapping of the population (asset) and the hazard gridded layers. The exposure can be seen as the maximum that can be lost in an area, maximum risk.

4.1 Methodology

The methodological approach used for identifying areas with emerging and increased risk is based on a comparison between the exposure to low probability hazard occurrence (or low frequency hazard extremes) and high probability hazard occurrence (or high frequency occurrence of hazard extreme).

This comparison will define:

- River flood, coastal flood, landslides as ***Emerging*** risks - when they are new, unforeseen risk that are not normal within an area (e.g., LAU administrative unit in our case), are not common across European regions because they are absent as medium or frequent extreme events. They are though present in these regions as very unlikely/improbable extremes only. The probable change from an unlikely to a likely event is generally linked to climate change (which brings change in the frequency distribution of the extreme events). When this situation happens, these regions are considered as regions/areas prone to emerging risks. Within these regions it is possible to quantify the assets exposure as being new, emerging.
- Areas with rapid ***Increase*** in risk - when hazard's exposure to medium or frequent extreme events is common within an area but additionally, experience considerable increase particularly due to very unlikely/improbable extremes' exposure. This situation is arguably expressing a High Impact Low Probability situation. The population at risk above the 0.5 percentile, for the frequent hazards, and below 0.5 percentile, for unlikely hazards occurrence, is not considered. This threshold was established in order to depict the significant increase in risk. The probability levels and exposure thresholds used to define both emergent and increased risk are presented in **Error! Reference source not found.**.

The identification of the areas/regions for both increase and emergent risk was first done at the level of Local Administrative Units. The relative or absolute emerging or increased population at risk were aggregated further to NUTS3 level (see **Figure 13** and **Figure 14**) or Country level (see the Annex 1 and 2).

Table 6.. Levels of probability/likelihood and exposure thresholds used to define the emergent and increased risk

	River flood		Landslides		Coastal flood	
	Likely	Very unlikely	Likely	Very unlikely	Likely	Very unlikely
	Level definition		Level definition		Level definition	
	> 1% in 1 year, 100 years RP	< 0.2% in 1 year, 500 years RP	> 0.5% in 1 year, 100 years RP	< 0.2% in 1 year, 500 years RP	> 1% in 1 year, 100 years RP	< 0.2% in 1 year, 500 years RP
Emerging risk defined when:	Likely = 0 (people exposed)	Very unlikely > 0 (people exposed)	Likely = 0 (people exposed)	Very unlikely > 0 (people exposed)	Likely = 0 (people exposed)	Very unlikely > 0 (people exposed)
Rapid increase defined when:	< 0.5 percentile (people exposed)	> 0.5 percentile (people exposed)	< 0.5 percentile (people exposed)	> 0.5 percentile (people exposed)	< 0.5 percentile (people exposed)	> 0.5 percentile (people exposed)

Source: JRC, 2022

4.2 Data sources

4.2.1 Population

Population gridded used from GHSL, population density (Sergio Freire et al., 2016). The GHSL settlement model grid (model that classify the human settlements on the base of the built-up and population density) was used to assess the "degree of urbanisation" and it is available at: http://ghsl.jrc.ec.europa.eu/.

4.2.2 Hazards

Table 7: Dataset used for the present emergent and increase in risk assessments

Hazards	Dataset		Link
	Definition	**Probabilities compared**	
River flood	Flood inundation maps	(T= 100 & 500 years)	http://data.jrc.ec.europa.eu/collection/floods
Coastal flood	Coastal inundation maps	(T= 100 & 500 years)	
Landslide	The landslide probabilistic hazard layer (ELSUS_v2/GPCC)	(T= 100 & 500 years)	https://climatedataguide.ucar.edu/climate-data/gpcc-global-precipitation-climatology-centre. .

Source: JRC, 2022

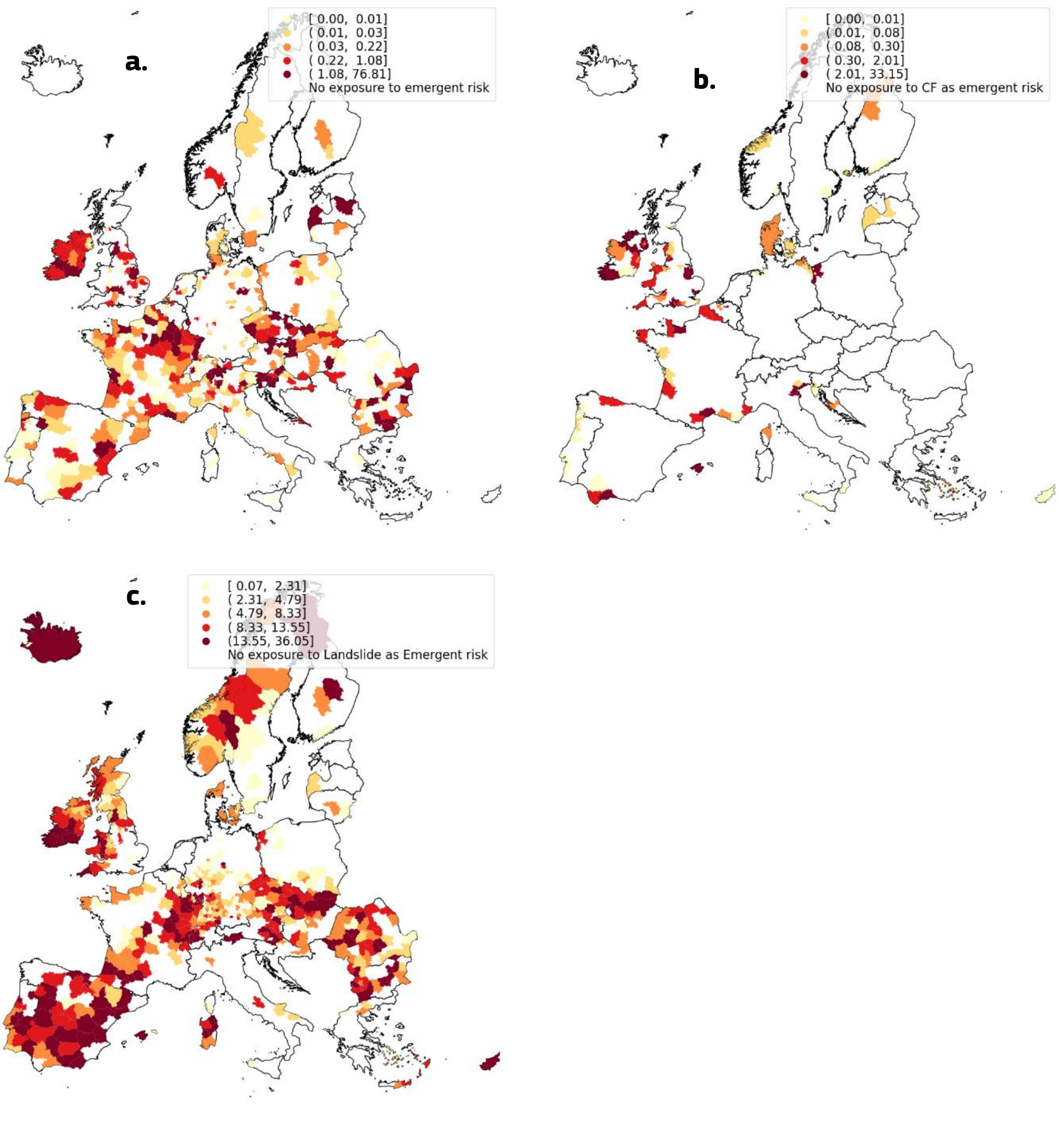
4.3 Results

The results are structured for three hazards: river flood, coastal flood and landslides and for the emerging and increasing risk. They depict new and additional people at risk to hazards from areas with emerging risk and increasing risk.

4.3.1 Emerging risk – population newly at risk

Figure 13 and Annex 2 presents at NUTS3 level and Country aggregation respectively, emerging population to risks from river flood, coastal flood and landslide. These regions are not known as being at risk from the river flood, as there is no exposure to the hazard with return period of 10yr, 50yr, 100yr (frequent/possible events). They emerge of being at risk because exposure is present for the 500-year return period hazard (the very unlikely/improbable hazard extremes).

Figure 13. Emerging areas (NUTS 3 level) with newly exposed population to risk from river flood (a.), coastal flood (b) and landslide (c). Values expressed as percentage (%) form the region's (NUTS3) total.



Source: JRC, 2022

4.3.1.1 River floods

At European level, there are 661 regions (LAU) that are emerging as new areas of risk. These regions are home to a total of close to 60 000 people which represent 1.4% of their total population as newly exposed for River flood risk for those regions. By far most affected will be UK with 34614 more people at risk followed by the Nederland with 11704, Austria 2703 and Germany 1745 people.

4.3.1.2 Coastal flood

European wide, coastal flood is considered as an emerging risk for 175 more regions (LAU). They sum up a total close to 43 200 people that are exposed to this emerging risk in these regions for Costal flood. This total represents 2.5% of the population of the above LAU. Ranked second and third are France and UK with 14 606 and 7026 people respectively. From the total, 17 398 (40%) live in Spain but they only represent 3% of the population of the regions with emerging risk. Poland seems to be heavily exposed as in the newly emerged area are at risk, 33% of the population are exposed.

4.3.1.3 Landslides

At European level, landslides will emerge as a new risk for 4281 regions (LAU). More than 1.6 million people or 4.1 % of the population of the above LAU are emerging as being at risk in these regions. Countries with high number of people newly at risk are: Germany (474 497 people), UK (304 906 people), Spain (194 885 people), Portugal (85 344 people) or Romania (85 161 people).

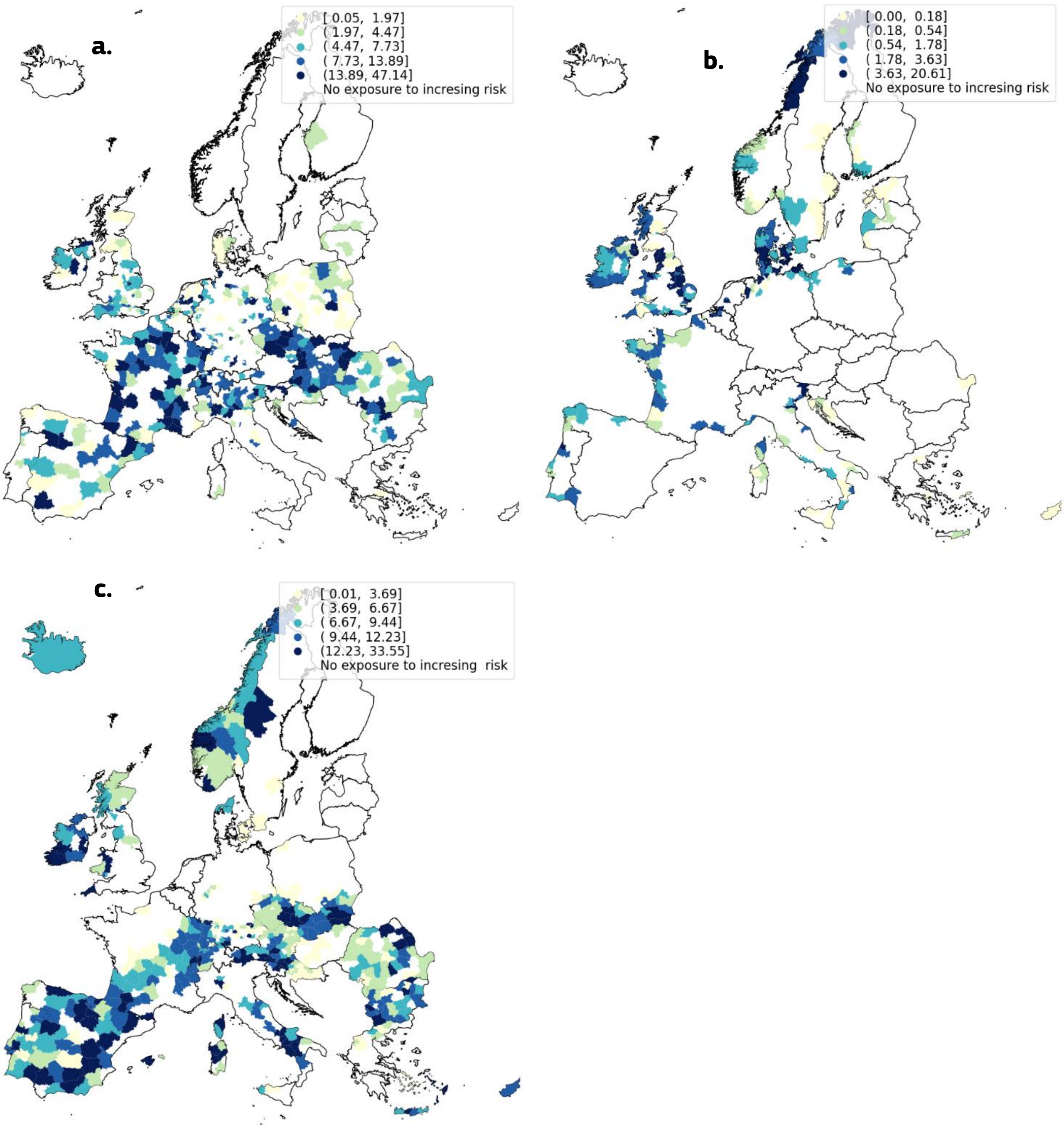
4.3.2 Regions with increased risk – increase of population at risk

Figure 14 and Annex 3 present the regions (NUTS3 and Countries) with increase (%) in population at risk from river flood, coastal flood and landslide. These regions are known as being at risk from the three hazards when considering frequent extreme events, but what is quantified here is the additional amount of people at risk from the very unlikely/improbable hazard extremes (hazards with 500yr RP) to the total figures.

4.3.2.1 River floods

At European level, there are 743 regions (LAU) where an increase of population at risk has been identified due to very low probability river flood hazard occurrence. They sum up a total of close to 519 454 people which represent 5.9% population additionally at risk from low probability events. Most increase in terms of absolute values are identified in Nederland (118 936 people), Hungary (79 313 people), Germany (73 289 people) and UK (78 344 people). In terms of relative increase Slovakia, Ireland, UK, Switzerland and Slovenia show > 10% of population being additionally at risk.

Figure 14. Increasing of population at risk (%) to River Flood (A.), Coastal flood (B.) and Landslides (C.) as addition due to low probability hazard occurrence (unlikely hazards)



Source: JRC, 2022

4.3.2.2 Coastal flood

European wide, there are 571 regions (LAU) where an increase of population at risk has been identified due to very low probability coastal flood hazard occurrence. There are close to 139834 people representing a 1.4% increase of the population at risk. Most increase in terms of absolute values are identified in UK (69 989 people), Belgium (37 441 people), Nederland (11 601). In terms of relative increase Belgium and UK have an increase in the population at risk of more than 5%.

4.3.2.3 Landslides

At European level, there are 5518 regions (LAU) where an increase of population at risk has been identified due to very low probability landslides hazard occurrence. They sum up a total of close to 1.6 million people which represent 5.7% population additionally at risk from low probability events. Most increase in terms of absolute values are identified in Spain (245 318 people), Germany (222 522 people), France (210 588 people). In terms of relative increase Slovenia, Ireland, Cyprus, UK, show > 8% of population being additionally at risk.

4.4 Data and methodological limitations

The hazard data and the assets (socio-economic) data currently present on the RDH platform are analysis which represent present baselines (e.g. hazard floods result of frequency analysis of modelled floods form 1980-2015; GHLS data covering assessment of the period 2000-2015). Future projections of these analysis are not available so far on the RDH. This limits the detection of the regions with emergent risk by only comparing ‘infrequent events’ (long return periods) with ‘frequent events’ (short term return periods) of the baseline analysis. The influence of the climate change in changing the probability from an infrequent towards a more frequent extreme event is therefore possible, but a correspondence in the change of frequency cannot be obtained (e.g. for a certain region it is not possible to link a return period of future under the climate change with one of the present based on baseline as the projected analysis is not available). The same for the quantification of the emerging population at risk, due to the absence of the project demographic parameter.

The current analysis is quantifying the emerging risk and increase in risk only at the level of population. Is not assessing the other assets types (residential buildings, commercial, agriculture, infrastructure etc.). Nevertheless this (pilot) analysis is important for us as it is possible to identify analysis (i.e. regions with emerging and increase in risk, quantification o the emerging and increase in risk) that can be further applied on the rest of the socio-economic parameters present on the RDH platform (**Table 8**).

Table 8: List of assets addressed currently on the RDH

Source	Assets (and categories)	Amount (metric)	Spatial layer/resolution
	Infrastructure		
HARCI-EU[8]	Electricity distribution lines	Tonnes (k) of oil equivalent	Grid (1000m)
HARCI-EU	Gas pipelines	Tonnes (k) of oil equivalent	Grid (1000m)
HARCI-EU	Railways	Annual freight transported (k)	Grid (1000m)
HARCI-EU	Roads	Annual freight transported (k)	Grid (1000m)
HARCI-EU	Education facilities	Total expenditure (Mil. Eur)	Grid (1000m)
CORINE[9]	**Agriculture**	km2	Grid (100m)
CORINE	Arable (211,212,213)	km2	Grid (100m)
CORINE	Forest (311,312,313)	km2	Grid (100m)
CORINE	Pasture (231)	km2	Grid (100m)
CORINE	Permanent crops (221,222,223)	km2	Grid (100m)
	Buildings		
ESM[10]/CORINE	Commercial built-up	km2	Grid (100m)
ESM/CORINE	Residential built-up	km2	Grid (100m)
GHSL	**Population**	people no.	Grid
	Protected area		
WADP[11]	N2000_Birds_Directive	km2	Vector
WADP	N2000_Both_Directives	km2	Vector
WADP	N2000_Habitats_Directive	km2	Vector
WADP	N2000_Protected_areas	km2	Vector
WADP	Protected_area_WHS	km2	Vector

Source: JRC, 2022

4.5 Uncertainty

By considering the 0.5 percentile thresholds in order to depict the significant increase in risk an objective statistic to measure the magnitude of increase is introduced. The uncertainty assessment is therefore limited to this statistic, in absence of the probabilistic or significance analysis for the present study.

8 HARCI-EU HARmonized grids of Critical Infrastructures in EUrope - https://www.nature.com/articles/s41597-019-0135-1

9 Corine land use code CORINE Land Cover — Copernicus Land Monitoring Service, https://land.copernicus.eu/pan-european/corine-land-cover

10 GHS_pop and GHS_Build/ESM and Urban Centres: Global Human Settlement - Download - European Commission (europa.eu), https://ghsl.jrc.ec.europa.eu/download.php

11 WDPA (WHS _CH): https://www.protectedplanet.net/c/world-database-on-protected-areas

5 Identifying drivers of vulnerability and disaster risk

In this section an index is proposed for the assessment of vulnerability to disasters across Europe. It portrays the structural vulnerability of a community in relation to socio-economic and general environmental factors which are not linked to any hazard. Furthermore, the method allows the identification of individual drivers of vulnerability such as economic, social, political or environmental aspects. For deeper insights into the indicators, dimensions and trends at different geographical scale, refer to the online story map on vulnerability (https://drmkc.jrc.ec.europa.eu/risk-data-hub/#/interactivereports) and the interactive dashboard (https://drmkc.jrc.ec.europa.eu/risk-data-hub/#/dashboards).

5.1 Introduction

The current report shows an example of analysis that can be performed through the vulnerability framework developed within the RDH. The choice of the indicators derives from an extensive literature review and it is based on open data sources. Additionally, it is also related to availability of data for each administrative level considered.

The set of indicators here presented is specifically defined for the RDH project in order to represent the vulnerability of the communities as a whole with an exhaustive view. For this reason, the indicators can vary from other projects/reports/researches which consider vulnerability at country level only (such as the resilience scoreboards). Therefore, the vulnerability framework developed within the RDH can provide an estimation of the vulnerability at multiple levels that are country, NUTS2 and NUTS3.

Since the composite index is also described through four main dimensions (Social, Political, Economic and Environmental) over a time frame which goes from 2005 to 2030, it is also able to provide information on possible vulnerability drivers directly related to the characteristics of the communities. In other words, it is possible to asses if a dimension is going to contribute in a positive or negative way to the vulnerability of country or a region.

An important aspect is related to the fact that the implemented framework assesses only the hazard independent dimensions of the vulnerability. The hazard-related component represents a further development and it is in the plan for the RDH to add it.

Currently there is an ongoing review of the framework, which is going to end in the next weeks, aimed to add new indicators to better describe the four dimensions at each level. The review will come with a report containing all the details related to the implemented workflow. Therefore, at the end of this report three annexes will show the indicators that are both already implemented and that will be implemented in the framework with the review, as well as the description and the logic behind each indicator. Furthermore, there is also the whole list of references that support that indicator (they can directly mention the indicator or provide the logic that supports the indicator).

Given that the exposure is a fixed parameter in the risk equation on the RDH, the vulnerability represents a main variable capable to describe possible risk drivers. This because the projection of the exposure depends on multiple assumptions making it particularly susceptible to subjective choices. In addition, its development requires specific studies.

5.2 Methodology

Our methodological approach provides a composite index derived from multiple indicators with intermediate steps at three geographical levels that are countries, NUTS2 and NUTS3. This allows to capture different location-dependent factors that may influence the overall vulnerability indicator.

The index is defined through a hierarchical structure across the three main geographical levels. Each of them results in one of the three key components of the index: *Country Component*, *NUTS2 Component* and *NUTS3 Component*. Each component is described by a set of pillars that are the principal factors that can drive vulnerability in a defined area. There are four main pillars across the key components: *Social*, *Economic*, *Political* and *Environmental*. Pillars are further broken down into sub-pillars that define specific facets of the broader domain. Sub-pillars in turn, are composed by raw indicators (**Table 9**).

Table 9: The hierarchical structure of the components

Indicator	Sub-Pillar	Pillar	Key Component
Population change	Population	Social	Country
Children at-risk-of-poverty	Social Participation		
Disabled people with need for assistance			
Long-term care (health) expenditure			
Change in Age-dependency	Dependency		
Self-reported unmet need for medical care	Health		
Perceived Good Health			
Gross National Saving	Financial Resources	Economic	
GDP per capita			
Income Inequality	Inequality		
Cultural heritage	Cultural heritage		
Governmental efficiency	Government	Political	
Political Stability	Political Situation		
National Adaptation Strategies	Strategy		
Environmental vulnerability index	EVI	Environmental	
Natura 2000 protected areas	Natura 2000		

Indicator	Sub-Pillar	Pillar	Key Component
Life expectancy	Health	Social	NUTS2
Hospital beds per 100'000 population			
Participation in Social Networks	Social Participation		
Information			
People at risk of poverty or social exclusion			
People with tertiary education	Education		
Severe material deprivation rate	Financial Resources	Economic	
Household income			
Motorways	Access		
Employment rate	Employment		
Regional Quality of Government index	Government	Political	
Population density	Population	Social	NUTS3
Net migration			
Old Dependency	Dependency		
Young Dependency			

The estimation of the index is carried out by averaging the key components. The Vulnerability Index is normalized at both European level and at sub-national level in order to simplify the comparison between countries and their administrative units.

The indicator is estimated from panel data covering each year from 2005 to 2030. That is, 26 values of vulnerability for each spatial unit are computed. This allow to estimate, not only the current state of a system, but also to estimate a trend[12]. In practice, it is possible to observe how the vulnerability evolves over time and how different countries behave across the time-horizon considered.

Accordingly, we perform a cluster analysis[13] that allows to detect groups of countries that exhibit a comparable trend and similar fluctuations of the vulnerability over time. The analysis allows detection of the vulnerability drivers through an inspection of the index components. Through the comparison of the index's mean within each group against the average of each component, it is possible to observe which one affects most the vulnerability.

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12 Missing data are imputed through linear regression.

13 The cluster analysis is performed by using the k-means algorithm. It classifies the observations into *n* clusters in which each observation belongs to the cluster with the nearest mean, with the aim to minimize the within-cluster variance. It is one of the most used cluster algorithms due to its high efficiency, however it requires some explorative analysis in order to define the number of clusters it has to detect.

5.3 Data sources

Table 10 shows a comprehensive list of the data source of all the 29 indicators used to estimate the vulnerability.

Table 10: List of the indicators and their data sources

Indicator	Source	Link
Population change	Eurostat	https://ec.europa.eu/eurostat/web/main/data/database
Children at-risk-of-poverty		
Disabled people with need for assistance		
Change in Age-dependency		
Self-reported unmet need for medical care		
Perceived Good Health		
GDP per capita		
Income Inequality		
Natura 2000 protected areas		
Life expectancy		
Hospital beds per 100'000 population		
Participation in Social Networks		
Information		
People at risk of poverty or social exclusion		
People with tertiary education		
Severe material deprivation rate		
Household income		
Motorways		
Employment rate		
Population density		
Net migration		
Large families		
National Adaptation Strategies		
Cultural heritage	UNESCO	https://whc.unesco.org/en/syndication
Regional Quality of Government index	University of Gothenburg	https://www.gu.se/en/quality-government/qog-data/data-downloads/european-quality-of-government-index
Governmental efficiency	Worldwide Governance Indicators	https://info.worldbank.org/governance/wgi/
Political Stability		
Environmental vulnerability index	Wikipedia (SOPAC)	https://en.wikipedia.org/wiki/Environmental_Vulnerability_Index
Gross National Saving	World Bank	https://data.worldbank.org/indicator/NY.GNS.ICTR.ZS

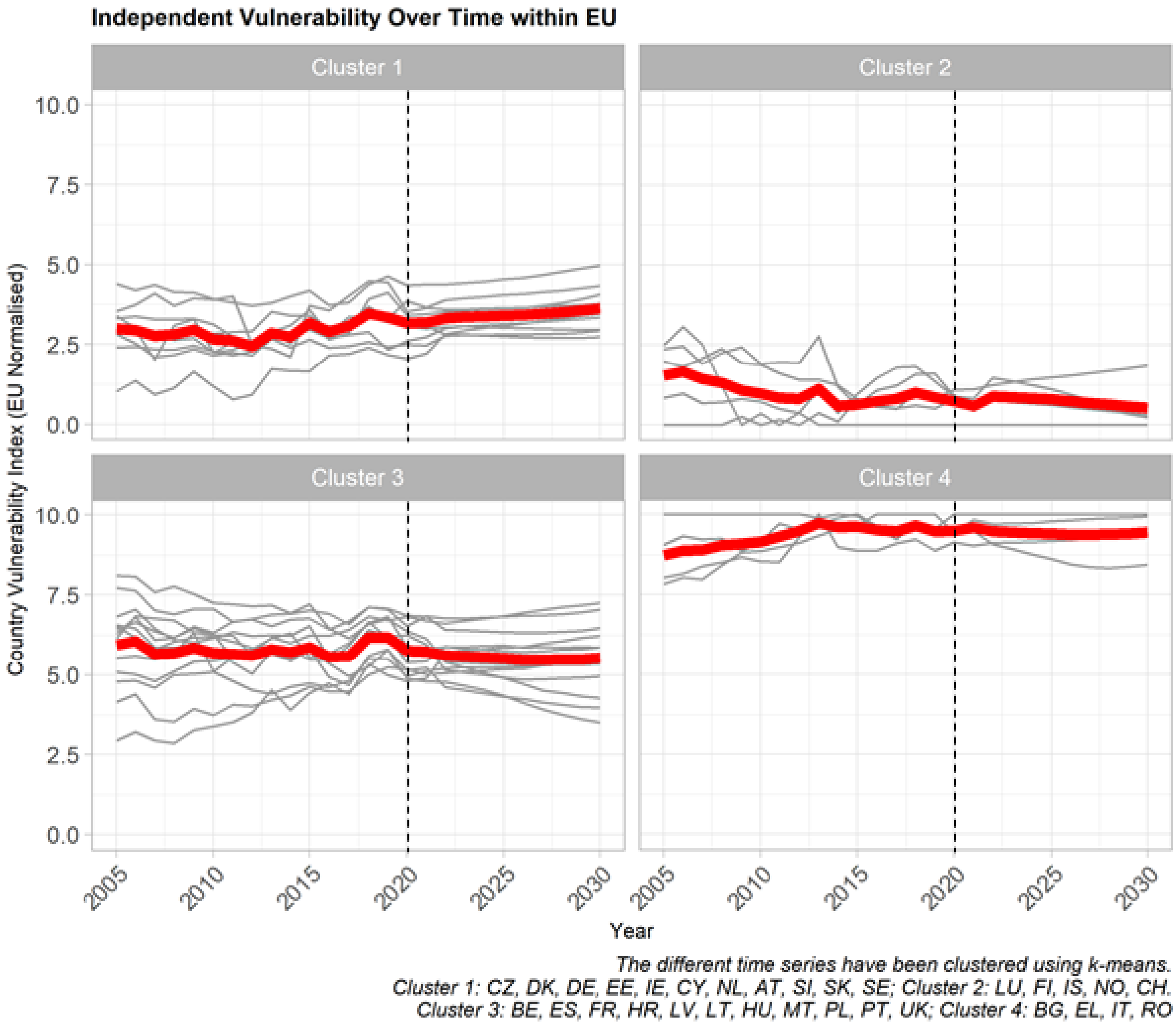
Source: JRC, 2022

5.4 Results

In Figure 15 the outcomes of trend analysis of the Vulnerability Index 2005-2030 are presented. Four clusters of countries are detected based on their vulnerability over time. Clusters can be classified as

- Cluster 1: countries with a medium vulnerability that increases over time;
- Cluster 2: countries with a low vulnerability;
- Cluster 3: countries with a medium vulnerability which is stable over time.
- Cluster 4: countries with a high vulnerability;

Figure 15: Outcomes of trend analysis of the Vulnerability Index 2005-2030 (clusters of countries)

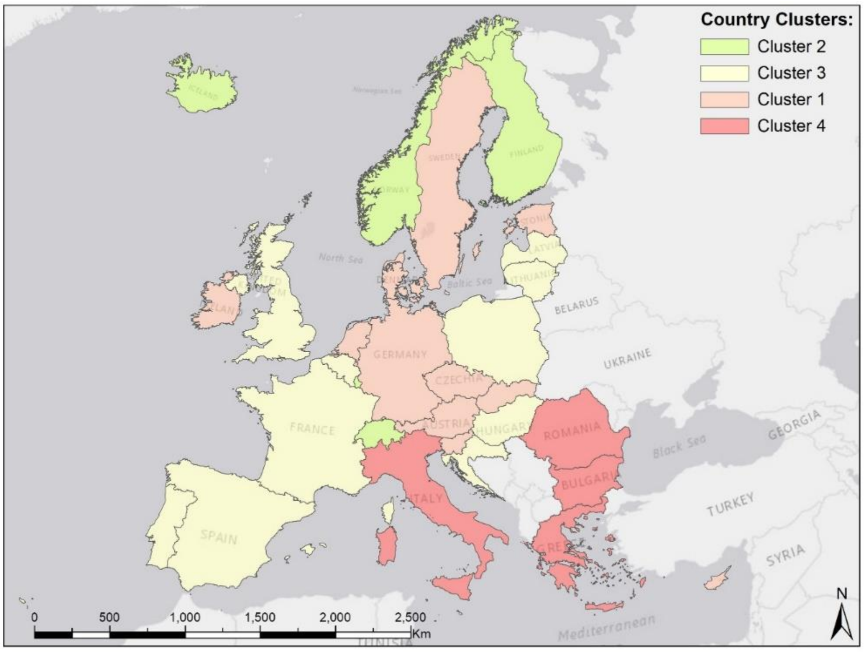


Source: JRC, 2022

The black dashed line identifies the split between calculated and projected values. The 2020 is the latest available year in the data, hence vulnerability values are projected starting from 2021.

By looking at the geographic distribution of clusters (Figure 16), it is possible to observe that there are spatial patterns across Europe. Countries in the north are the ones with a low vulnerability overall, while on the contrary the south-east of Europe appears to be the most vulnerable area. Central and west Europe is split between Cluster 1 and 3 that are the ones with medium vulnerability values.

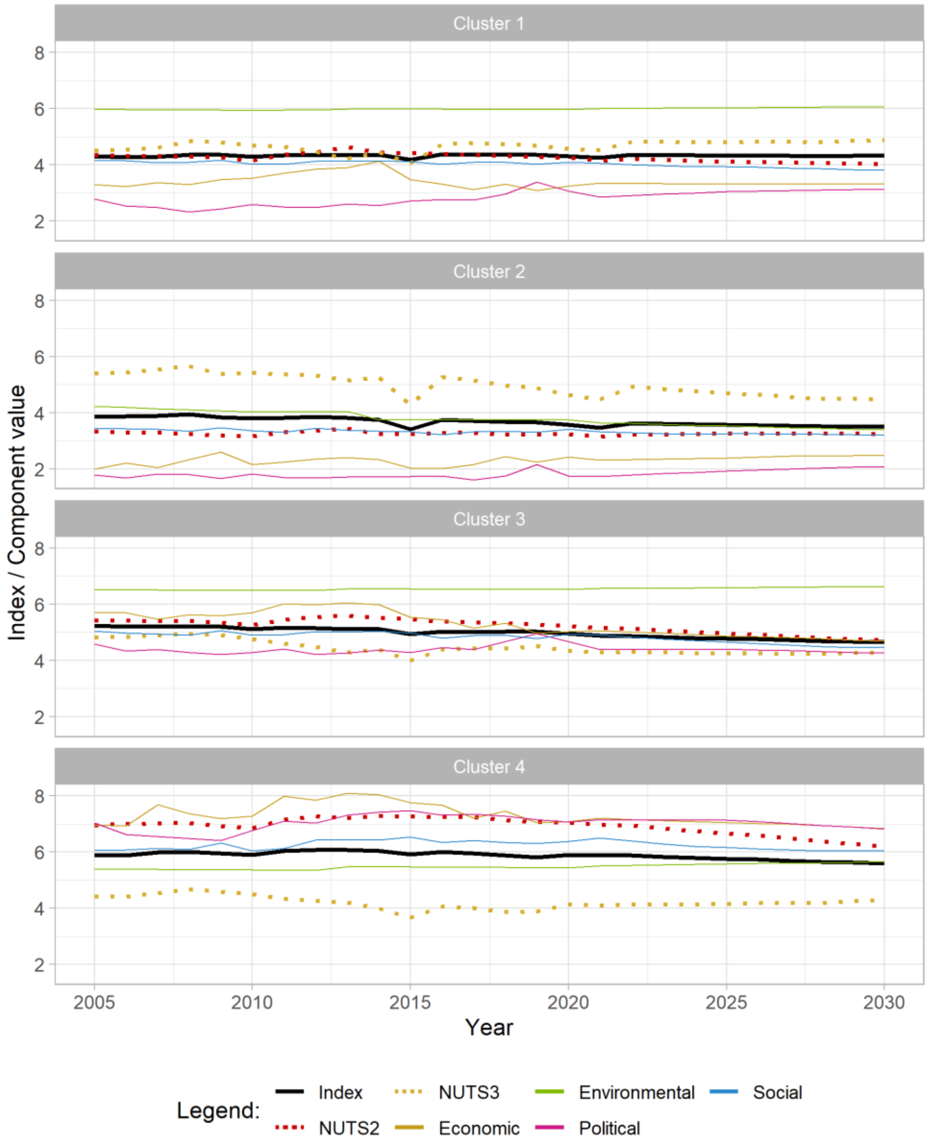
Figure 16: Spatial distribution of the clusters detected through the analysis



Source: JRC, 2022

In Figure 17, the definition of the aspects that affect the vulnerability within the identified clusters is presented. The comparison of the average Vulnerability Index with the average score of each component allows to identify which are the components that affect the vulnerability over time. The ones that lay above the index are the ones of interest.

Figure 17: Definition of the aspects that affect the vulnerability within the identified clusters



Source: JRC, 2022

5.5 Key Outcomes

The analysis allows to identify the overall trend of the vulnerability within the European area over a period of 26 years starting from 2005. In addition, the process is able to detect countries with a similar tendency over time by grouping them in four clusters. Eventually, it highlights the aspects which affect the vulnerability within each group.

Countries with a high vulnerability over time (Cluster 4) appear to be affected mainly by the political and the environmental components which lie around high values for the whole period considered. Those are followed by the sub-national (NUTS2) and the social components that seems to give a significant contribution to the vulnerability of these countries as well.

Within Cluster 2 (Countries with a low vulnerability over time), the factor that mainly affect the vulnerability is the sub-national component at NUTS3 level. However, its contribution is not so relevant given that all the other components maintain low and medium values for the whole period considered.

Cluster 1 and Cluster 3 are rather similar: in both of the cases the environmental component is the one that affect vulnerability in a relevant way. However, within Cluster 3 all the other components are rather stable with a slight decrease in the near future; while Cluster 2 shows a kind of opposite trend.

6 Country Reports

Country reports aim to provide an overview of all the risk-related aspects within a Member State. They are compound of multiple analysis and show results related to both the risk analysis and the loss data. In the current example the country considered is Italy and the asset selected is "residential buildings"14. Charts related to the risk analysis consider earthquakes, landslides, coastal floods and river floods as hazards, since those are the ones currently included in the RDH.

This in a not exhaustive selection of data available on the RDH. Users are able to choose between a variety of Hazards and Assets as first choices as well as the geographical area and the spatial aggregation of interest (currently countries, NUTS2 and NUTS3). Furthermore, they can choose to visualize different measures computed by the platform: risk, exposure, vulnerability, and single hazard layers. Additionally, they can choose projected exposure at different year intervals as well temporal aggregations of past losses (2, 5, 10, 15, 25 years). Finally, for loss data, they can choose the measure of losses and damages as: area at risk, economic impact, fatalities, people affected, and people injured.

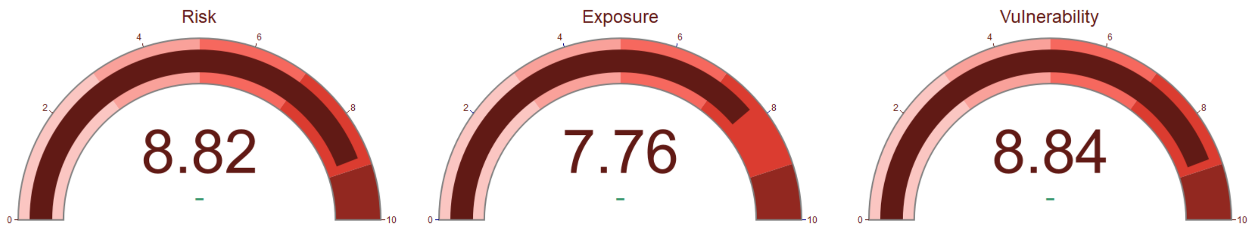
A comprehensive table of all available hazards, assets and metrics for both risk estimation and losses is available in chapter 2 of this report, Table 1 and Table 2. Accordingly, the platform is able to generate insights on all combinations of said hazards and assets.

The implementation of the outputs from this report are found in the Facts and Figures module of the RDH.

6.1 Infographics

The following figures (**Figure 18** - **Figure 22**) display results related to the risk analysis.

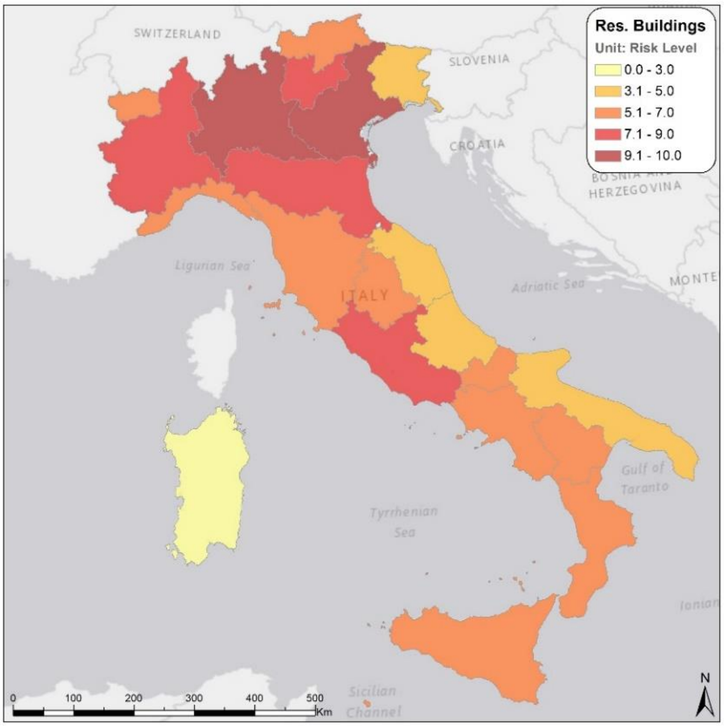
Figure 18. Metrics related to the risk and its components within a country for a selected asset (residential building) and hazard/s (earthquake, landslide, coastal flood and river flood) for a timeframe of 2 years.



Source: JRC, 2022

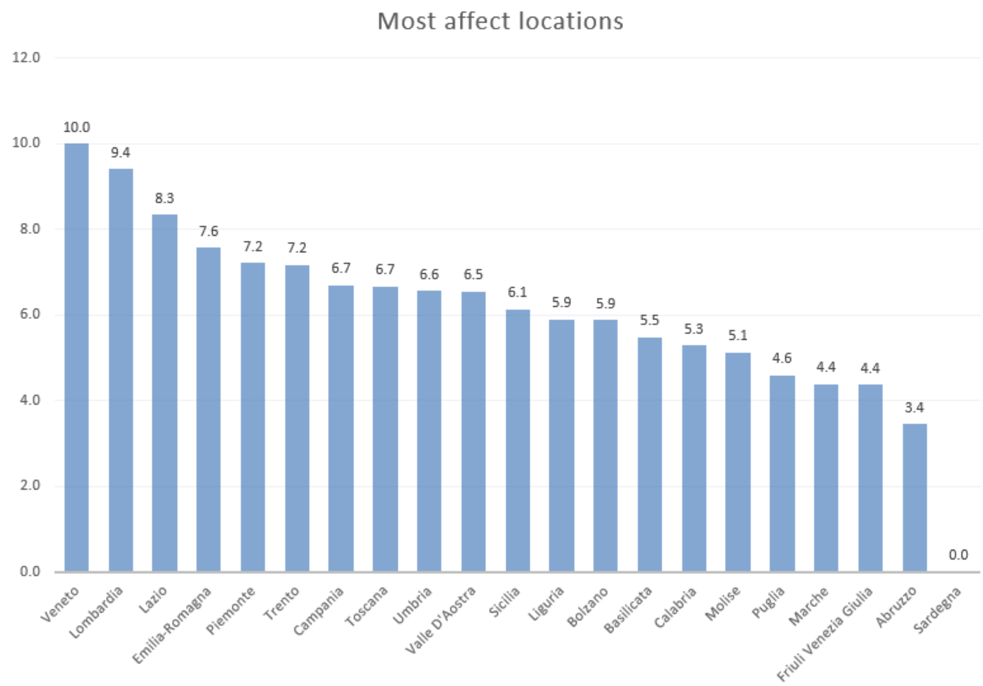
14 The RDH supports 4 macro-categories of assets: population, buildings, critical services and environment. Each category contains a variety of specific assets.

Figure 19. Estimated risk for residential buildings in Italy (selected timeframe: 2 years, hazards selected: earthquake, landslide, coastal flood and river flood).



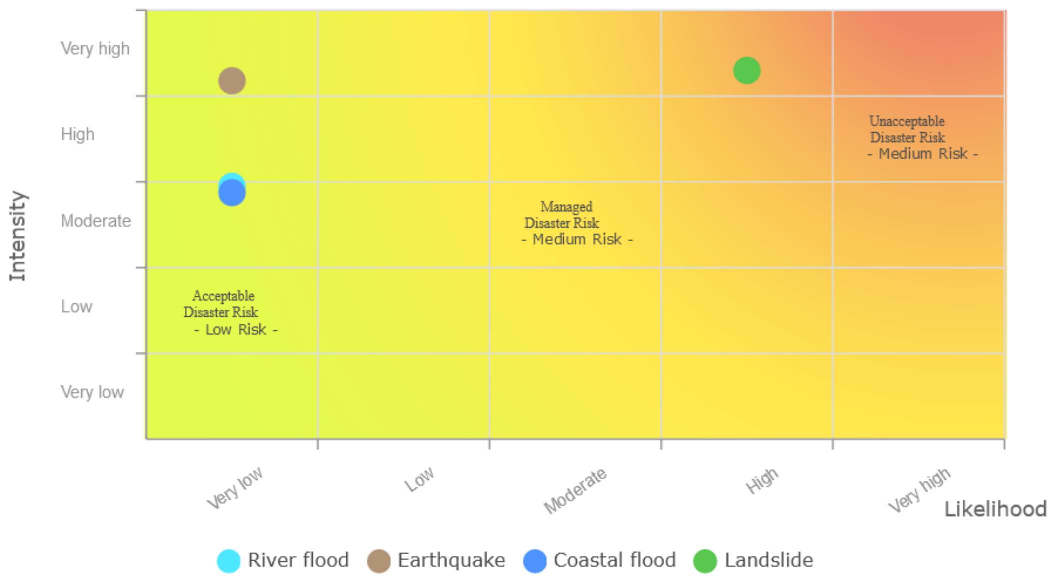
Source: JRC, 2022

Figure 20. Ranking of the Italian regions (NUTS2) by risk for residential buildings (selected timeframe: 2 years, hazards selected: earthquake, landslide, coastal flood and river flood).



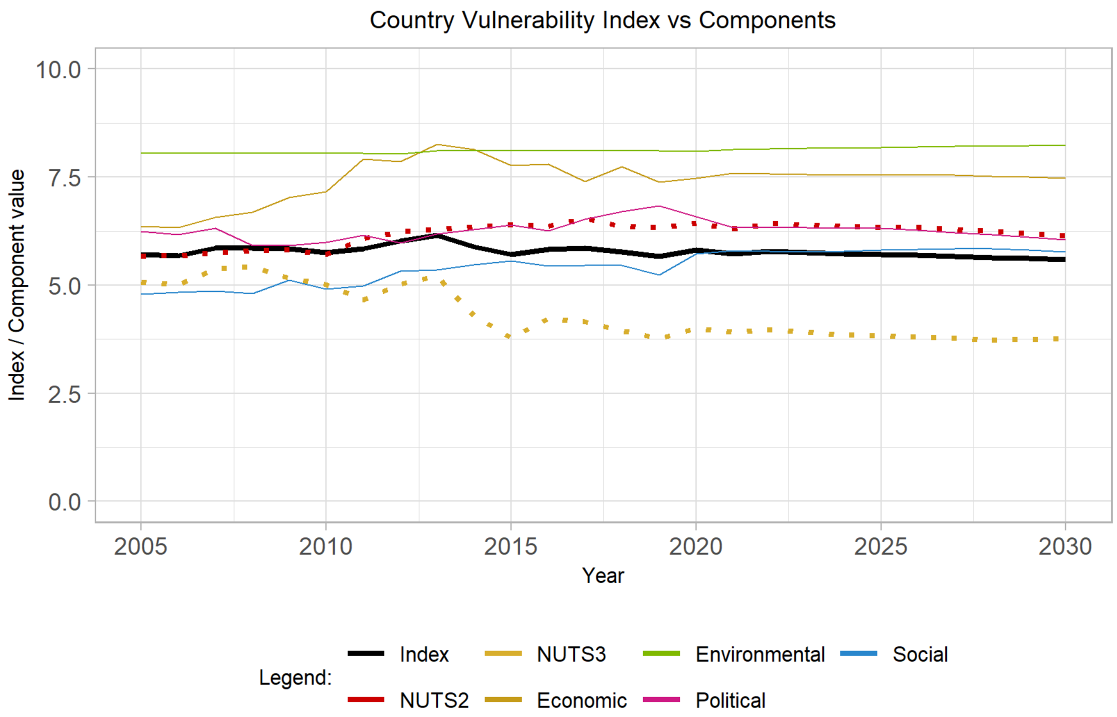
Source: JRC, 2022

Figure 21. The risk matrix for the residential buildings with a timeframe of 2 years (in Italy). It shows potential impact intensity of hazard on said assets, along with probabilities for the next 2 years



Source: JRC, 2022

Figure 22. Vulnerability trend and its components for the selected country, 2005-2030



Source: JRC, 2022

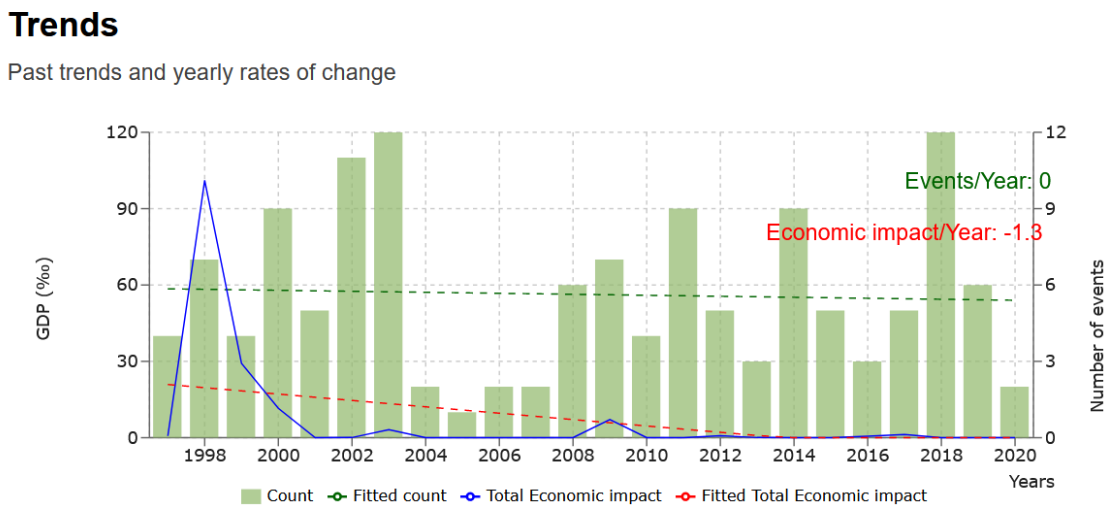
The analysis provides also information about the components which give a higher contribution to the vulnerability. Those are the ones with a value higher than the composite Vulnerability Index.

Figure 23 through Figure 25 show results related to loss data.

Figure 23. Overall loss by hazard category. The example shows losses on residential buildings in Italy by considering all the hazards within the last 25 years

Source: JRC, 2022

Figure 24. Trends and yearly range of change for both the number of events and the total losses, 1997-2020



Source: JRC, 2022

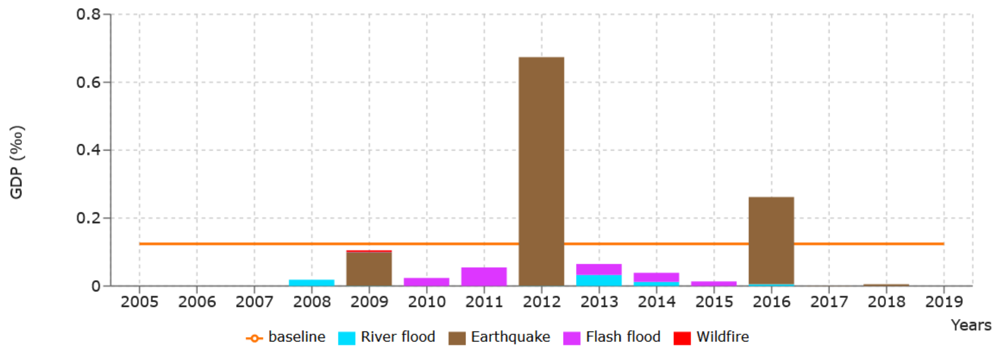
Example related to the residential buildings in Italy. The spike in total economic impact shown in 1998 refers to a prevalence of Floods and Flash Floods occurred in the area of Naples, Treviso and Padova (Campania and Veneto regions respectively).

Figure 25. Disaster damage data based on SENDAI indicators aggregation

Sendai Indicator C-4

Direct economic loss in the housing sector attributed to disasters. Data would be disaggregated according to damaged and destroyed dwellings.

Reference Value for years 2005-2015 (baseline): 0.12417



Source: JRC, 2022

The aggregation has a yearly timeframe and shows the stacked share per hazard type from the total yearly damage (residential buildings in Italy). The baseline (computed 2005 – 2015 in compliance with Sendai methodology) represents the average yearly GDP variation (in %) due to direct economic losses from multiple hazards (shown below the graph).

7 Conclusions

In this report five analytical reports based on the analysis of the data available within the RDH were presented. This compendium provides a glimpse of the multiple analysis that can be derived from crossing the different datasets on hazard, exposure, vulnerability and disaster risk and disasters losses hosted on the platform.

The analysis performed using the data hosted on the RDH provides some insights into EU risk landscape and the impacts of disasters over the past 30 -40 years, emerging new areas of risk, and vulnerability profiles across Europe:

- Most of the economic losses in Europe, were mainly due to river floods, flash floods and earthquakes with over 42%, 12%, and 10% shares of total losses respectively.
- The Countries most affected by natural hazards have been Italy, Germany and Spain.
- The year 2013 recorded the worst economic losses from floods while 2012 has had the largest economic losses overall across all hazards available in RDH.
- Despite the significant amount of damages and losses, the trend analysis seems to suggest a rather descending trend in impact of river floods in recent years. Observing the trend, the EU civil protection mechanism – implemented in 2001 – and the Flood Directive (2007/60/EC)[15] appear to have been an important contribution in the descending trend.
- At European level, there are 661 regions (LAU) that are emerging as new areas of risk. These regions are home to a total of close to 60 000 people which represent 1.4% of their total population as newly exposed for River flood risk for those regions. By far most affected will be UK with 34614 more people at risk followed by the Nederland with 11704, Austria 2703 and Germany 1745 people.
- In terms of disaster vulnerability profiles, by looking at the geographic distribution of vulnerability clusters, we observe that there are spatial patterns across Europe: Northern countries are the ones with a low vulnerability overall, while South-eastern countries appear to be the most vulnerable Central and Western Europe are characterized by medium vulnerability values.

The analyses presented are not an exhaustive selection of data available on the RDH. Users are able to select between a variety of Hazards and Assets as first choices as well as the geographical area and the spatial aggregation of interest (currently countries, NUTS2 and NUTS3). Furthermore, they can visualize different measures computed by the platform: risk, exposure, vulnerability, and single hazard layers. Additionally, they can opt for using projected exposure at different year intervals as well temporal aggregations of past losses (2, 5, 10, 15, 25 years). Finally, for loss data, they can select the measure of losses and damages as: area at risk, economic impact, fatalities, people affected, and people injured.

The platform is able to generate insights on all combinations of hazards and assets, as well as on damages to physical assets and fatalities pertaining to different types of disasters and for different geographical scales and time frames. The final aim is to produce periodic highlights on DRM- relevant issues in the form of online story maps (https://drmkc.jrc.ec.europa.eu/risk-data-hub/#/interactivereports) and through the interactive dashboards (https://drmkc.jrc.ec.europa.eu/risk-data-hub/#/dashboards). These tools allow to explore in a more user-friendly and accessible way the many insights the platform is able to offer for different application areas for reporting needs (e.g. supporting local/national authorities with the commitments in the framework of the Sendai agreement or the National Risk Assessments reports).

The future enhancements planned for the Risk Data Hub (RDH) encompass several aspects. These include revising the vulnerability composite indicator to incorporate hazard-specific components, updating the baseline exposure data, integrating the latest hazard data that aligns with EU standards, and incorporating validated risk information generated by research projects. Additionally, one of the key objectives is to provide improved accessibility to the baseline data, such as hazard and exposure layers, vulnerability indicators, and information pertaining to individual disaster events. These new features aim to enhance the overall user experience within the RDH.

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32007L0060

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List of abbreviations and definitions

CEDRE	Centre of Documentation, Research and Experimentation on Accidental Water Pollution
CF	Coastal Flood
CH	Chemical Spill
CORINE	Coordination of information on the environment
CW	Cold wave
DFO	Dartmouth Flood Observatory
DRMKC	Disaster Risk Management Knowledge Centre
DR	Drought
DRM	Disaster Risk Management
EC	European Commission
EDII	European Drought Impact Report Inventory
EFFIS	European Forest Fire Information System
EFAS	European Flood Awareness System
EM-DAT	Emergency Events Database
EMSR	Emergency Management Service
EMM	European Media Monitor
EQ	Earthquake
ESM	European Settlement Map
ESDAC	European Soil Data Centre
EU	European Union
FF	Forest Fire
FL	River Flood
FLSH	Flash Flood
GAR	Global Assessment Report on Disaster Risk Reduction
GDP	Gross domestic product
GHSL	Global Human Settlement Layer
GIS	Geographic Information System
GLC	Global Landslide Catalog
GPCC	Global Precipitation Climatology Centre
HANZE	Historical Analysis of Natural Hazards in Europe
HARCI-EU	HARmonised grids of Critical Infrastructures in EUrope
HW	Heat wave
IN	Industrial
IPL	International Panel on Land Subsidence
JRC	Joint Research Centre
LAU	Local Administrative Unit
LS	Landslides
MARS	The Mariners' Alerting and Reporting Scheme

MO	Miscellaneous Other
NCEI/WDS	National Centers for Environmental Information / World Data Service
NOAA	National Oceanic and Atmospheric Administration
NUTS	Nomenclature of territorial units
RDH	Risk Data Hub
RP	Return Period
TS	Tsunami
VO	Volcano
WADP	World Database on Protected Areas
WISC	Windstorm Information Service
WF	Wildfire
WS	Windstorm
WUI	Wildland Urban Interface

List of figures

List of tables

Annexes

Annex 1. Increase in population at risk due to low probability hazard occurrence

Increase in population														
River flood					**Coastal Flood**					**Landslide**			
Country	No. LAU	Increase (%)	Increase absolute		Country	No LAU	Increase (%)	Increase absolute		Country	No LAU	Increase (%)	Increase absolute
NL	34	5.8	118937		UK	193	6.5	69990		ES	401	5.5	245319
HU	57	3.7	79314		BE	19	9	37442		DE	395	6.4	222523
UK	97	10	78345		NL	8	4.5	11602		FR	1502	7.4	210589
DE	107	2.5	73290		IT	43	0.9	5081		CH	516	7.3	152115
FR	118	4.1	47070		DK	64	2.4	4332		IT	169	6.6	95167
IT	55	5.4	25427		FR	83	0.8	3519		RO	335	5.9	87784
SK	42	11.1	22296		DE	52	0.7	3323		PL	112	3.4	83080
ES	37	3.6	19148		ES	12	0.7	1718		CZ	395	3.1	67802
PL	41	1.5	13358		NO	15	0.8	608		BG	232	7	59860
RO	50	4.2	11397		IE	26	1.2	499		PT	261	7.5	57124
BE	11	1.2	7839		PT	14	0.4	477		EL	25	7.7	49657
CZ	23	8	5434		PL	5	0.9	459		NO	86	3.4	49593
IE	5	11	3874		SE	9	0.2	360		SK	201	5.2	45602

CH	11	11.1	3146		EL	5	0.2	213		AT	239	1.6	35689
AT	8	7.5	3084		FI	4	0.4	123		UK	81	8.3	27781
HR	11	5.3	2948		HR	7	0.2	41		HU	27	1.3	27437
SI	11	29.3	1682		LV	5	0.1	28		HR	56	2.2	24426
BG	10	3.1	1325		LT	1	0.1	22		IE	221	9.1	22535
PT	5	5.2	629		CY	2	0.1	5		SI	224	9.5	12297
DK	3	1.3	364		EE	3	0.1	2		CY	22	8.7	1762
LT	3	2.3	253		RO	1	0.1	1		SE	3	6.2	1452
FI	2	2.4	163							DK	11	2	740
LV	1	3.7	81							IS	4	8	682
EL	1	0.3	62										
Summary	743	5.98	519 466			571	1.4	139845			5518	5.8	158 1016

Annex 2. Population newly at risk due to emerging risk

River flood					Coastal flood					Landslide			
Country	Emergent absolute	No. LAU	Emergent relative (%)		Country	Emergent absolute	No. LAU	Emergent relative (%)		Country	Emergent absolute	No. LAU	Emergent relative (%)
UK	34615	60	7.07		ES	17399	22	1.59		DE	474497	896	3.3
NL	11705	12	2.28		FR	14606	48	0.99		UK	304906	729	7.1
SK	3059	33	3.23		UK	7027	38	3.71		ES	194885	332	6.7
AT	2703	16	4.20		BE	2264	4	0.63		PT	85345	209	5.4
DE	1746	50	0.89		IT	1213	11	1.17		RO	85161	237	3.8
IE	1009	27	3.14		PL	328	1	33.15		SK	83366	361	7.4
IT	996	52	0.25		IE	314	10	1.97		FR	75601	301	4.4
FR	699	163	0.30		DK	62	12	0.27		IE	50877	255	9.2
CH	678	15	1.01		HR	8	2	0.15		CZ	44597	228	2.7
HU	656	22	1.32		SI	7	1	0.07		NO	33852	46	5.5
BG	595	26	1.01		EL	6	2	0.07		AT	26802	142	4.4
SI	559	33	6.07		LV	3	2	0.04		CH	26206	113	7.8
ES	327	32	0.32		FI	3	3	0.02		PL	25967	72	2.2
RO	262	23	0.31		DE	3	7	0.04		IT	25917	60	4.3

PL	159	17	0.11		NO	2	2	0.01		BG	25036	91	1.5
CZ	154	19	1.60		PT	2	8	0.00		HU	12916	53	2.8
PT	119	28	0.08		SE	0	1	0.00		SE	10806	16	1.4
BE	99	6	0.19		CY	0	1	0.00		BE	10100	33	1.8
HR	73	9	0.24							CY	7684	51	4.2
NO	55	1	0.23							EL	6018	10	2.8
LV	50	2	2.26							IS	3191	4	2.6
SE	20	4	0.05							HR	2960	8	4.5
FI	5	2	0.04							FI	2356	7	1.6
LT	1	2	0.06							DK	2168	15	3.4
DK	1	6	0.01							SI	829	8	8.6
EL	0	1	0.00							LT	488	2	1.5
										LU	90	1	2.1
										LV	68	1	2.4
Summary	60345	661	1.40			43247	175	2.44			1622690	4281	4.12

Annex 3. Indicators included in the vulnerability framework.

The implemented field show the indicators already implemented and the ones that will be added with the framework review.

Scale	Dimension	Sub-dimension	Hazard-independent Indicator	Vulnerability	Data Provider	Implemented	Timeframe	
							Actual values	Projected
Country	Social	Population	Projected population change	(+)	Eurostat	✓	2014-2020	2005-2013; up to 2050
Country	Social	Population (Social Participation)	Children at-risk-of-poverty	(+)	Eurostat	✓	2003-2020	2021-2030
Country	Social	Population (Social Participation)	Disabled people with need for assistance	(+)	Eurostat	✓	2012	-
Country	Social	Population (Social Participation)	Long-term care (health) expenditure	(-)	Eurostat	✓	2008-2019	2005-2007; 2020-2030
Country	Social	Dependency	Change in Age-dependency	(+)	Eurostat	✓	2014-2020	2005-2013; up to 2050
Country	Social	Health	Self-reported unmet need for medical care	(+)	Eurostat	✓	2008-2020	2005-2007; 2021-2030
Country	Social	Health	Perceived Good Health	(-)	Eurostat	✓	2010-2020	2005-2009; 2021-2030
Country	Economic	Financial resources	Gross National Saving	(-)	WBG	✓	≈1970-2020	2021-2030
Country	Economic	Financial resources	GDP per capita	(-)	Eurostat	✓	2000-2020	2021-2030
Country	Economic	Inequality	Income Inequality	(+)	Eurostat	✓	1995-2020	2021-2030
Country	Economic	Environmental	Cultural heritage	(+)	Unesco	✓	1978-2021	-
Country	Political	Government	Governmental efficiency	(-)	WGI	✓	1996-2020	2021-2030
Country	Political	Political situation	Political Stability	(-)	WGI	✓	1996-2020	2021-2030
Country	Political	Government (Strategy)	National Adaptation Strategies	(-)	ClimateAdapt	✓	2018	-
Country	Environment	Environmental / Government	Environmental protection expenditure	(-)	Eurostat		2008-2018	2005-2007; 2019-2030
Country	Environment	Environmental /	Climate related economic losses	(+)	Eurostat / EAA		1980-2020	-

Scale	Dimension	Sub-dimension	Hazard-independent Indicator	Vulnerability	Data Provider	Implemented	Timeframe	
							Actual values	Projected
		Government					(aggregated)	
Country	Environment	Environmental / Government	Production, value added and exports in the environmental goods and services sector	(-)	Eurostat		2000-2020	2021-2030
Country	Environment	Environmental	Common farmland bird index	(-)	Eurostat		1990-2020	2021-2030
Country	Environment	Environmental	Natura 2000 protected areas	(-)	Eurostat	✓	2011-2020	-

Scale	Dimension	Sub-dimension	Hazard-independent Indicator	Vulnerability	Data Provider	Implemented	Timeframe	
							Actual values	Projected
NUTS2	Social	Health	Life expectancy	(-)	Eurostat	✓	1990-2019	2020-2031
NUTS2	Social	Health / Access	Hospital beds per 100'000 population	(-)	Eurostat	✓	1993-2020	2021-2030
NUTS2	Social	Access (Social Participation)	Participation in Social Networks	(-)	Eurostat	✓	2006-2021	2005; 2022-2030
NUTS2	Social	Access (Social Participation)	Information (Frequency of internet access: once a week (including every day))	(-)	Eurostat	✓	2006-2021	2005; 2022-2030
NUTS2	Social	Access (Social Participation)	People at risk of poverty or social exclusion	(+)	Eurostat	✓	2003-2020	2021-2030
NUTS2	Social	Population (Education)	Primary and lower secondary education (levels 1 and 2)	(+)	Eurostat		2012-2019	2020-2030
NUTS2	Social	Population (Education)	People with tertiary education (levels 5-8)	(-)	Eurostat	✓	2000-2020	2021-2030
NUTS2	Economic	Financial resources	Severe material deprivation rate	(+)	Eurostat	✓	2003-2020	2021-2030
NUTS2	Economic	Financial resources	Household income	(-)	Eurostat	✓	1995-2020	2021-2030
NUTS2	Economic	Access	Motorways	(-)	Eurostat	✓	2008-2019	2005-2007; 2020-2030
NUTS2	Economic	Access	Railways	(-)	Eurostat		2008-2019	2005-2007; 2020-2030
NUTS2	Economic	Inequality (Employment)	Employment rate	(-)	Eurostat	✓	2009-2020	2021-2030
NUTS2	Political	Government	Regional Quality of Government index	(-)	QoG	✓	2010-2021	2005-2009; 2022-2030
NUTS2	Environment	Environmental	Urban area classified as green space	(-)	CORINE		2000-2018	2019-2030
NUTS2	Environment	Environmental	Urban land cover	(+)	CORINE		2000-2018	2019-2030
NUTS3	Social	Population	Population density	(+)	Eurostat	✓	1990-2019	2020-2030

Scale	Dimension	Sub-dimension	Hazard-independent Indicator	Vulnerability	Data Provider	Implemented	Timeframe	
							Actual values	Projected
NUTS3	Social	Population	Net migration	(+)	Eurostat	✓	2000-2020	2021-2030
NUTS3	Social	Dependency	Young dependency	(+)	Eurostat	✓	2014-2020	2005-2013; 2021-2030
NUTS3	Social	Dependency	Old dependency	(+)	Eurostat	✓	2014-2020	2005-2013; 2021-2030
NUTS3	Economic	Financial resources	NUTS3 GDP per capita vs country average	(-)	Eurostat		2000-2020	2021-2030
NUTS3	Economic	Financial resources	Gross Value Added (at basic prices)	(-)	Eurostat		1995-2020	2021-2030
NUTS3	Economic	Access (Technology)	Power plants per 100'000 inhabitants	(-)	WRI		≈1900-2021	-
NUTS3	Economic	Access (Technology)	Patent applications to the EPO	(-)	Eurostat		1977-2012	2013-2030
NUTS3	Environment	Environmental	Soil erosion	(+)	Eurostat		2000-2016	2017-2030

Annex 4. Description of the indicators included in the framework.

The column Reference IDs refers to the IDs of the bibliographic sources contained in Annex 3. Each time an indicator is mentioned or its conceptualisation is defined in an article then it is linked to that specific source.

Scale	Hazard-independent Indicator	Description	Type	Sub-type°	Reference IDs
Country	Projected population change	Population change in the future will increase the vulnerability if the population growths. This indicator presents the dynamic of vulnerability. Future projection is used since the current situation is covered by population density and future change has a great impact on vulnerability.	Sensitivity	Cohesion	5, 10, 11, 15, 21, 36, 55, 65
Country	Children at-risk-of-poverty	Children at risk of poverty also indicate a future trend: for children already being at risk of poverty, the likelihood that they will be more vulnerable in terms of financial resources and/or social exclusion should be considered. This can further have an influence on political structures.	Sensitivity	Housing / Cohesion	5, 10, 42, 45, 65
Country	Disabled people with need for assistance	People with need for assistance are more vulnerable because of their dependency. This indicator takes disabled people and people who reported the need for assistance into account since young and old dependency is covered by age-dependency it only covers the working age population (15-64 years).	Sensitivity	Housing / Cohesion	10, 11, 12, 15, 41, 45, 52, 54, 65
Country	Long-term care (health) expenditure	A higher expenditure for long-term care identifies the capability of a country to take care of people who need medical assistance. Thus, it is related to the economic welfare of a community: higher expenses are related to a lower vulnerability. The indicator is related to the expenses dedicated to health functions, excluding capital investment.	Adapt. Capacity	Cohesion	5, 24, 32, 41, 45, 46, 55, 65
Country	Change in Age-dependency	Demographic change in the future will increase the vulnerability: a positive demographic change increases the population with age-dependency. This indicator presents the dynamic of vulnerability. Future projection is used since the current situation is covered by age-dependency and future change has a great impact on vulnerability.	Sensitivity	Housing / Cohesion	6, 9, 10, 11, 12, 15, 16, 20, 33, 41, 45, 65
Country	Self-reported unmet need for medical care	This indicator explains the vulnerability of people that are unable to afford medical needs. In case of a disaster and the need for medical service they will be more economically vulnerable and it can have an effect on their health.	Sensitivity	Cohesion	10, 15, 43, 45
Country	Perceived Good Health	People with perceived good health are less vulnerable due to their ability to manage themselves and help others.	Sensitivity	Cohesion	5, 15, 43, 45
Country	Gross National Saving	The national savings represents the countries' economic vulnerability.	Adapt. Capacity	Economic resource	5, 7, 10, 22, 32, 65
Country	GDP per capita	The GDP per capita is a measure of the wealth of the population. The higher is the indicator the lesser is the vulnerability.	Adapt. Capacity	Economic resource	5, 7, 8, 10, 11, 13, 16, 19, 22, 24, 27, 30, 32, 33, 35, 36, 40,

Scale	Hazard-independent Indicator	Description	Type	Sub-type°	Reference IDs
					45, 46, 47, 65
Country	Income Inequality	The Gini-coefficient describes the inequality of incomes in a country. The greater the gap between low and high salaries is, the more people are vulnerable.	Sensitivity	Economic resource	7, 10, 11, 20, 24, 27, 30, 33, 41, 42, 43, 45, 46, 47, 65
Country	Cultural heritage	The indicator is a mix of structural, economic and social aspects. Buildings included in the list of Unesco Heritage Sites are usually more vulnerable to extreme events due to their age and the way they are bult. Consequently, if a site is heavily damaged, it will have a high cost of re-construction. In addition, heritage sites are landmarks and their lost has a social impact on the communities.	Sensitivity	Institutions / Environment	37, 38
Country	Governmental efficiency	Governmental efficiency is an important indicator for calculating the efficiency on national level before, during and after a hazard strikes.	Adapt. Capacity	Institutions	6, 8, 11, 15, 24, 32, 36, 45, 46, 55
Country	Political Stability	Political Stability can imply the efficiency of a government, their international cooperation and their focus on needs of the country.	Sensitivity	Institutions	6, 11, 36, 45, 46, 55
Country	National Adaptation Strategies	National Adaptation strategies can represent the effort and mind-setting of the national government for DRR actions.	Adapt. Capacity	Institutions / Environment	5, 10, 11, 17, 24, 32, 42
Country	Environmental protection expenditure	The environmental protection expenditure quantifies the millions of Euros invested in equipment and plant for pollution control and in equipment and plant linked to cleaner technology ('integrated technology') by the activities under the economic activities identified by the NACE Rev. 2 classification. Higher investments lead to a lower environmental impact from those activities, therefore to a lower pressure. As a result, the ecosystems can increase their resilience against other stressful events.	Adapt. Capacity	Institutions / Environment	5, 6, 7, 10, 22, 32, 42, 45, 46, 55
Country	Climate related economic losses	The economic losses that come from weather and climate-related disasters are a good indicator of the coping capacity of a country. The vulnerability of a country will be higher if it has to dedicate a lot of economic resources to that kind of events.	Adapt. Capacity	Institutions / Environment	5, 6, 7, 10, 17, 22, 24, 32, 42, 45, 46, 55
Country	Production, value added and exports in the environmental goods and services sector	The indicator provides the quantity of resources that come from products for environmental protection prevent, reduce and eliminate pollution or any other degradation of the environment. They include measures undertaken to restore degraded habitats and ecosystems. Examples are electric vehicles, catalysts and filters to decrease pollutant emissions, wastewater and waste treatment services, or noise insulation works. A country capable to produce more services of this kind can create a less vulnerable environment.	Adapt. Capacity	Institutions / Environment	5, 6, 7, 10, 17, 22, 24, 32, 42, 45, 46, 55

Scale	Hazard-independent Indicator	Description	Type	Sub-type°	Reference IDs
Country	Common farmland bird index	Birds are high in the food chain; hence they can be considered as a good indicator for the overall state of health of ecosystems and biodiversity. The farmland bird indicator acts as a proxy to assess the biodiversity status of agricultural environments across Europe. A high level of biodiversity is related to a more resilient environment, since the diversification of the ecological niches guarantees the subsistence of the main environmental processes.	Sensitivity	Environment	10, 11, 17, 22, 39, 40, 42, 46, 55
Country	Natura 2000 protected areas	The Natura 2000 network is composed by special protection areas (SPA) and proposed sites of Community importance (pSCI) that are subsequently designated under the Habitats Directive as special areas of conservation (SAC). Protected areas identify ecosystems with a high ecological value which should include a high level of biodiversity as well. Since a well-diversified environment is less vulnerable, countries that have a high % share of Natura 200 areas have a less vulnerable environment.	Sensitivity	Environment	10, 11, 17, 20, 22, 24, 27, 28, 39, 40, 41, 42, 45, 46, 55
NUTS2	Life expectancy	Life expectancy in this context takes only the overall health situation of the population into account. Thus, the higher the expectancy the better is the health situation.	Sensitivity	Cohesion	6, 24, 33, 45, 46, 55
NUTS2	Hospital beds per 100'000 population	The number of hospital beds per 100,000 inhabitants is measure of the adaptive capacity of a community. A higher value is related to the capability of an area to aid people affected by events, therefore it is related to a lower vulnerability overall.	Adapt. Capacity	Access	4, 5, 6, 7, 10, 12, 13, 15, 21, 30, 32, 36, 37, 42, 54, 55, 65
NUTS2	Participation in Social Networks	This indicator transmits a picture on social interaction. Nowadays, interactions in social networks can present one part of social interactions. To bear in mind: it does not replace social interactions in persons.	Adapt. Capacity	Cohesion	2, 15, 27, 32, 36, 41, 52, 55
NUTS2	Information (Frequency of internet access: once a week (including every day))	The more people are connected to information services the better early warning can be disseminated.	Adapt. Capacity	Cohesion	2, 15, 27, 32, 36, 41, 52, 55
NUTS2	People at risk of poverty or social exclusion	This indicator is based on economic indicators (People living in households with very low work intensity; severe material deprivation rate; at risk of poverty rate) which can lead to social exclusion.	Sensitivity	Cohesion	5, 7, 8, 9, 15, 27, 36, 65
NUTS2	Primary and lower secondary education (levels 1 and 2)	A higher rate of people with lower level of education tend to increase the vulnerability due to a low level of awareness. It's inversely proportional to the tertiary education indicator.	Sensitivity	Education	3, 4, 6, 7, 8, 9, 12, 15, 16, 19, 20, 21, 23, 26, 30, 33, 36, 40, 43, 45, 46, 47, 52, 54, 55

Scale	Hazard-independent Indicator	Description	Type	Sub-type°	Reference IDs
NUTS2	People with tertiary education (levels 5-8)	People with higher obtained education are believed to be less vulnerable due to their degree of knowledge and capable to react faster in case of an event.	Adapt. Capacity	Education	3, 4, 6, 7, 8, 9, 12, 15, 16, 19, 20, 21, 23, 26, 28, 30, 32, 33, 36, 40, 43, 45, 46, 47, 52, 54 ,55
NUTS2	Severe material deprivation rate	The material deprivation rate stands for existing poverty. Poverty is traditionally defined on the availability of financial means.	Sensitivity	Economic resource	5, 7, 9, 10, 12, 26, 27, 42, 45, 55, 65
NUTS2	Household income	The household income is calculated as the balance of primary household income calculated in PPS. This anticipates the effect of commuting on regional differences and is calculated in context with the country. Household income describes a household's possible financial resources which make them less vulnerable.	Adapt. Capacity	Economic resource	2, 5, 7, 10, 15, 16, 20, 26, 27, 32, 41, 45, 49, 65
NUTS2	Motorways	The access to major road network describes the connectivity and remoteness of places. The shorter the distance, the lower the vulnerability.	Adapt. Capacity	Access	2, 7, 8, 9, 12, 15, 16, 21, 22, 24, 27, 30, 32, 35, 36, 41, 42, 45, 49, 52, 54, 55, 65
NUTS2	Railways	The access to major railways describes the connectivity and remoteness of places. The shorter the distance, the lower the vulnerability.	Adapt. Capacity	Access	2, 7, 21, 22, 27,32, 36, 42, 45, 49, 52, 55, 65
NUTS2	Employment rate	Higher employment rates present a population with more individuals having financial resources stability for recovery.	Adapt. Capacity	Economic resource	3, 9, 10, 11, 12, 15, 20, 27, 32, 35, 36, 41, 42, 43, 45, 46, 47, 52, 54, 65
NUTS2	Regional Quality of Government index	The EQI is a result of novel survey data on regional level governance within the EU. The data focusses on both perceptions and experiences with public sector corruption, services and their allocation and quality. This indicator represents citizens opinions and therefore implies their trust in the government.	Sensitivity	Institutions	2, 6, 8, 11, 15, 24, 27, 33, 36, 45, 55
NUTS2	Urban area classified as green space	Green spaces, such as parks, trees and gardens, can help city's resilience to the effects of climate change and extreme weather events. They have a cooling effect during period of hot temperatures and decrease the effect of the superficial run-off in case of extreme precipitations in urban areas. In addition, green areas are also related to the more developed areas of a city, hence they can highlight the more prosperous districts which usually are the most resilience.	Sensitivity	Environment	4, 5, 6, 7, 10, 11, 15, 19, 22, 35, 36, 41, 43, 49

Scale	Hazard-independent Indicator	Description	Type	Sub-type°	Reference IDs
NUTS2	Urban land cover	Built up urban area based on CORINE data. There is robust evidence that the amount of artificial areas, such as buildings and other structures, intensifies heat and can exacerbate the urban heat island (UHI) effect (EEA 2012). This will make an area more sensitive to the effects of high temperatures and heatwave.	Sensitivity	Environment	5, 6, 7, 10, 11, 15, 16, 19, 22, 35, 36, 41, 43, 49, 54
NUTS3	Population density	Population density can be seen as an indicator for, firstly, the total population that may be exposed and, secondly, the denser places are the higher is the vulnerability.	Sensitivity	Housing / Cohesion	4, 6, 9, 10, 11,12, 13, 21, 24, 26, 33, 35, 36, 37, 43, 49, 55, 65
NUTS3	Net migration	Net migration from the previous year indicates the tendency of (inter-)national immigration and therefore, the amount of people living in the NUTS 3 less than 1 year. People living in a place less than one year can have a higher vulnerability which can be reasoned by less local knowledge for disaster risk, preparedness and response or due to language issues.	Sensitivity	Housing / Cohesion	10, 11, 15, 36, 65
NUTS3	Young dependency	Young people can be more sensitive and less responsive to extreme weather events.	Sensitivity	Housing / Cohesion	2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 15, 16, 20, 21, 23, 24, 30, 33, 35, 41, 43, 45, 47, 48, 52, 54, 55, 65
NUTS3	Old dependency	Old people are more susceptible to harm during extreme events.	Sensitivity	Housing / Cohesion	2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 15, 16, 20, 21, 23, 24, 28, 30, 33, 35, 41, 43, 45, 47, 48, 52, 54, 55, 65
NUTS3	NUTS3 GDP per capita vs country average	The indicator compares the local GDP per capita to the country one. It is a measure of the local variability of the vulnerability in terms of economic resources.	Adapt. Capacity	Economic resource	5, 7, 8, 10, 11, 13, 16, 19, 22, 32, 33, 35, 36, 40, 42, 45, 65
NUTS3	Gross Value Added (at basic prices)	Gross Value Added (GVA) is defined as output value at basic prices less intermediate consumption valued at purchasers' prices. GVA is calculated before consumption of fixed capital. The resources that a city has can be a good indicator of a city's sensitivity in terms of extreme weather events and climate change. If a city has a lower than average GVA, then it may have been more susceptible to damage from all types of extreme weather events. A city with low resources may not be able to adequately address climate change adaptation due to other pressures.	Adapt. Capacity	Economic resource	5, 7, 10, 11, 32, 36, 40, 42, 45, 65

Scale	Hazard-independent Indicator	Description	Type	Sub-type°	Reference IDs
NUTS3	Power plants per 100'000 inhabitants	This indicator shows the power plants per head of population in the NUTS3 unit. The more power plants that there are, the greater the chance that there may be redundancy. Redundancy is an important concept in resilience. Redundancy demonstrates that there is excess capacity in given system means that during crises, the system may still be able to retain functionality. If there are more power plants in a NUTS3 area than the EU average, this may mean that alternative ways of providing energy to a given population may be found.	Adapt. Capacity	Economic resource	17, 23, 32, 36, 37, 55, 65
NUTS3	Patent applications to the EPO	This indicator shows the number of patent applications to the European Patent Office (EPO) per 1000 population. Technology and innovation are important in helping a city to adapt to climate change e.g. investment in new flood technologies or building technologies that can help to mitigate heat. The ability of a country or urban area to invest in technological solutions, is thought to be an indicator of its adaptive capacity. Therefore, number of patents per year is used as a proxy indicator reflecting this issue.	Adapt. Capacity	Economic resource	15, 17, 24, 27, 30, 32, 36, 37, 40, 47
NUTS3	Soil erosion	Given that the soil erosion by water is one of the most widespread forms of soil degradation in Europe, the indicator is a local measure of the environmental vulnerability of an area.	Sensitivity	Environment	10, 11, 22, 23, 26, 40

Annex 5. Bibliographic sources used for the identification of the indicators used within the vulnerability framework

The IDs mentioned in the first column are linked to the respective indicator in Annex 3.

Reference ID	Title	Citation & Link
1	How to construct and validate an Integrated Socio-Economic Vulnerability Index: Implementation at regional scale in urban areas prone to flash flooding	Aroca-Jiménez, E., Bodoque, J. and García, J., 2020. How to construct and validate an Integrated Socio-Economic Vulnerability Index: Implementation at regional scale in urban areas prone to flash flooding. Science of The Total Environment, 746, p.140905. https://doi.org/10.1016/j.scitotenv.2020.140905
2	Measuring Household Resilience in Hazard-Prone Mountain Areas: A Capacity-Based Approach	Tan, J., Peng, L. and Guo, S., 2020. Measuring Household Resilience in Hazard-Prone Mountain Areas: A Capacity-Based Approach. Social Indicators Research, 152(3), pp.1153-1176. https://doi.org/10.1007/s11205-020-02479-5
3	Integrated flood vulnerability assessment of villages in the Waimanu River Catchment in the South Pacific: the case of Viti Levu, Fiji.	Begg, S., De Ramon N'Yeurt, A. and Iese, V., 2021. Integrated flood vulnerability assessment of villages in the Waimanu River Catchment in the South Pacific: the case of Viti Levu, Fiji. Regional Environmental Change, 21(3). https://doi.org/10.1007/s10113-021-01824-9
4	Socio-economic and environmental vulnerability to heat-related phenomena in Bucharest metropolitan area	Grigorescu, I., Mocanu, I., Mitrică, B., Dumitraşcu, M., Dumitrică, C. and Dragotă, C., 2021. Socio-economic and environmental vulnerability to heat-related phenomena in Bucharest metropolitan area. Environmental Research, 192, p.110268. https://doi.org/10.1016/j.envres.2020.110268
5	Connecting people and place: a new framework for reducing urban vulnerability to extreme heat	Wilhelmi, O. and Hayden, M., 2010. Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. Environmental Research Letters, 5(1), p.014021. http://dx.doi.org/10.1088/1748-9326/5/1/014021
6	Urban Vulnerability Indicators. A joint report of ETC-CCA and ETC-SIA	Swart, Rob & Fons, Jaume & Geertsema, W. & Hove, Bert & Jacobs, C.M.J., 2012. Urban Vulnerability Indicators. A joint report of ETC-CCA and ETC-SIA. https://www.researchgate.net/publication/283419662_Urban_Vulnerability_Indicators_A_joint_report_of_ETC-CCA_and_ETC-SIA
7	Map book urban vulnerability to climate change: Factsheets	Timmerman, JG, Bacciu, V, Coninx, I, Fons, J, Gregor, M, Havranek, M, Jacobs, CMJ, Loehnertz, M, Peltonen, L, Sainz, M & Swart, RJ 2015. Map book urban vulnerability to climate change: Factsheets. European Environment Agency, Copenhagen. https://research.wur.nl/en/publications/map-book-urban-vulnerability-to-climate-change-factsheets
8	Dynamics of Socioeconomic Exposure, Vulnerability and Impacts of Recent Droughts in Argentina	Naumann, G., Vargas, W., Barbosa, P., Blauhut, V., Spinoni, J., Vogt, J., 2019. Dynamics of Socioeconomic Exposure, Vulnerability and Impacts of Recent Droughts in Argentina. Geosciences 9, 39.

		https://doi.org/10.3390/geosciences9010039
9	Development of a Matrix Based Statistical Framework to Compute Weight for Composite Hazards, Vulnerability and Risk Assessments	Kabir, Akter, Karim, Haque, Rahman and Sakib, 2019. Development of a Matrix Based Statistical Framework to Compute Weight for Composite Hazards, Vulnerability and Risk Assessments. Climate, 7(4), p.56. https://doi.org/10.3390/cli7040056
10	Vulnerability assessments of coastal river deltas - categorization and review	Wolters, M. and Kuenzer, C., 2015. Vulnerability assessments of coastal river deltas - categorization and review. Journal of Coastal Conservation, 19(3), pp.345-368. https://doi.org/10.1007/s11852-015-0396-6
11	Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks	Preston, B., Yuen, E. and Westaway, R., 2011. Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks. Sustainability Science, 6(2), pp.177-202. https://doi.org/10.1007/s11625-011-0129-1
12	Spatial vulnerability assessment of floods in the coastal regions of Bangladesh	Roy, D. and Blaschke, T., 2013. Spatial vulnerability assessment of floods in the coastal regions of Bangladesh. Geomatics, Natural Hazards and Risk, 6(1), pp.21-44. https://doi.org/10.1080/19475705.2013.816785
13	Temporal and spatial variation characteristics of disaster resilience in Southwest China’s mountainous regions against the background of urbanization	Huang, P., Pan, H., Peng, L., Chen, T. and Xu, J., 2020. Temporal and spatial variation characteristics of disaster resilience in Southwest China’s mountainous regions against the background of urbanization. Natural Hazards, 103(3), pp.3783-3802. https://doi.org/10.1007/s11069-020-04155-w
14	Operationalizing a concept: The systematic review of composite indicator building for measuring community disaster resilience	Asadzadeh, A., Kötter, T., Salehi, P. and Birkmann, J., 2017. Operationalizing a concept: The systematic review of composite indicator building for measuring community disaster resilience. International Journal of Disaster Risk Reduction, 25, pp.147-162. https://doi.org/10.1016/j.ijdrr.2017.09.015
15	Top-down assessment of disaster resilience: A conceptual framework using coping and adaptive capacities	Parsons, M., Glavac, S., Hastings, P., Marshall, G., McGregor, J., McNeill, J., Morley, P., Reeve, I. and Stayner, R., 2016. Top-down assessment of disaster resilience: A conceptual framework using coping and adaptive capacities. International Journal of Disaster Risk Reduction, 19, pp.1-11. https://doi.org/10.1016/j.ijdrr.2016.07.005
16	Is resilience capacity index of Chinese region performing well? Evidence from 26 provinces	Wu, Y., Que, W., Liu, Y., Cao, L., Liu, S. and Zhang, J., 2020. Is resilience capacity index of Chinese region performing well? Evidence from 26 provinces. Ecological Indicators, 112, p.106088. https://doi.org/10.1016/j.ecolind.2020.106088

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