Interreg Italy – Croatia

AcquaGuard

INTERREG ITALY-CROATIA PROGRAMME 2021 – 2027

D.1.1.1 Risk database – general risk database for the INTERREG IT-CRO region

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Document Information

Author(s)

Name	PartnerNo	Organisation	Primary Contact and Email
Miljenko Sedlar	2	REGEA	msedlar@regea.org
Tomislav Novosel	2	REGEA	tnovosel@regea.org
Karla Mlađen	2	REGEA	kmladen@regea.org
Elisa Furlan	4	CMCC	elisa.furlan@cmcc.it
Maria Katherina Dal Barco	4	CMCC	mariakatherina.dalbarco@cmcc.it
Caterina Dabala	5	CORILA	dabala@corila.it
Adele Testoni	5	CORILA	testoni@corila.it

Activity information

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Activity 1.1. Risk analysis	4	CMCC
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Executive summary

This document offers a summary and overview of the most relevant climate-related hazards based on geographical and hydrological characteristics for the INTERREG IT-CRO region. It serves as an accompanying document to the Excel file. It acts as a basis for further analysis of climate-related hazards for the pilot regions of the AcquaGuard Project – Veneto Region and Karlovac County.

A description of each climate-related hazard and the most relevant expected risks and impacts for each are provided. The document also includes an overview of the hazard megatrend analysis from existing sources and data. Finally, it lists compound climate-related hazards since the occurrence of one hazard often leads to the emergence or amplification of others.

1 Introduction

The Mediterranean region is considered a climate change hotspot due to its heightened vulnerability to warming temperatures, altered precipitation patterns, and increased frequency of extreme weather events. It is also known that the Mediterranean is warming 20% faster than the global average.[1]

The INTERREG IT-CRO region relies heavily on the Adriatic Sea as a cornerstone of its economy, primarily through tourism, which is a major economic driver. However, the region's dependence on the Adriatic Sea also presents numerous challenges and hazards, particularly in the context of climate change.

Climate change substantially threatens the INTERREG IT-CRO region, amplifying existing vulnerabilities and introducing new risks. Rising temperatures, altered precipitation patterns, and an increased frequency of extreme weather events exacerbate water scarcity, impact agricultural productivity, and threaten biodiversity. Coastal communities face additional risks from rising sea levels and more intense heatwaves, which can lead to flooding, erosion, damage to infrastructure, and adverse effects on human health (Dal Barco et al., 2024; Fogarin et al., 2023; Mysiak et al., 2018; Pham et al., 2023, 2024).

Given these challenges, it is crucial for the INTERREG IT-CRO region to prioritise climate change mitigation and adaptation strategies. Effective management of climate-related hazards is essential to safeguard the region's economy, environment, and communities. This document aims to provide an overview of the most relevant climate-related hazards in the

[1] United Nations Environment Programme / Mediterranean Action Plan: https://www.unep.org/unepmap/resources/factsheets/climate-change

INTERREG IT-CRO region and serve as a starting point for a more detailed risk assessment and the development of tailored adaptation measures.

2 Introduction to main risk concepts and terminologies

Climate change is accelerating and intensifying slow and rapid onset events across all environments. To develop effective strategies for mitigating these impacts, it is crucial to first characterise all key components interplaying in the risk definition, including hazard, exposure, vulnerability, and response. This step is fundamental to understanding how each socio-ecological system is featured and its ability to cope with climate change, thus developing an integrated framework to assess risks.

A comprehensive description of these key components is here provided highlighting their evolution across the assessment reports as released by the Intergovernmental Panel on Climate Change (IPCC) and the related scientific literature.

Over the past decades, the IPCC has produced several reports as part of a global and collective effort to gather all knowledge on climate change, its causes, potential impacts, and response options. A total of six assessments have been produced with the latest being the Sixth Assessment Report (AR6), released between 2021 and 2023.

The definitions of hazard, exposure, vulnerability, and risk were significantly expanded in The Fifth Assessment Report (AR5) which emphasised their broader implications for climate change impacts (IPCC, 2014). AR5 expanded the concept of hazard to include "physical impacts," emphasising climate-related events or trends with potentially adverse effects on human and ecological systems while broadening the definition of exposure to include species, ecosystems, and environmental functions. Moreover, the AR5 expanded the definition of vulnerability as well to emphasise its complexity and multidimensionality. All these changes were maintained in the AR6 which defined them as follows:

(a) hazards as natural or human-induced events or trends that can cause damage to social and ecological systems;

(b) exposure refers to the presence of human and ecological elements in vulnerable settings;

(c) vulnerability is the propensity to be adversely affected, encompassing sensitivity to harm and the capacity to cope adapt; and

(d) risk is defined as the probability of adverse consequences for human or ecological systems due to climate change and human responses to it.

It is in the latest AR6 that the concept of multi-risk, including compound and cascading risks was introduced, providing a more detailed and integrative perspective on how various risk factors interact and influence each other (IPCC, 2023). In particular, the report places a stronger emphasis on risk and solutions than previous reports (IPCC, 2023). Since the Special Report on Global Warming of 1.5 ºC, efforts have been made across Working Groups to develop a consistent risk framing for the IPCC's AR6 (Reisinger et al., 2020). This comprehensive framing spans all three Working Groups, considering risks from climate change responses, dynamic and cascading effects, and detailed geographic impacts on people and ecosystems. This new framework, as reported in the AR6, highlights the connections between climate responses, sustainable development, and transformation, as well as the governance implications for both public and private sectors (IPCC, 2023).

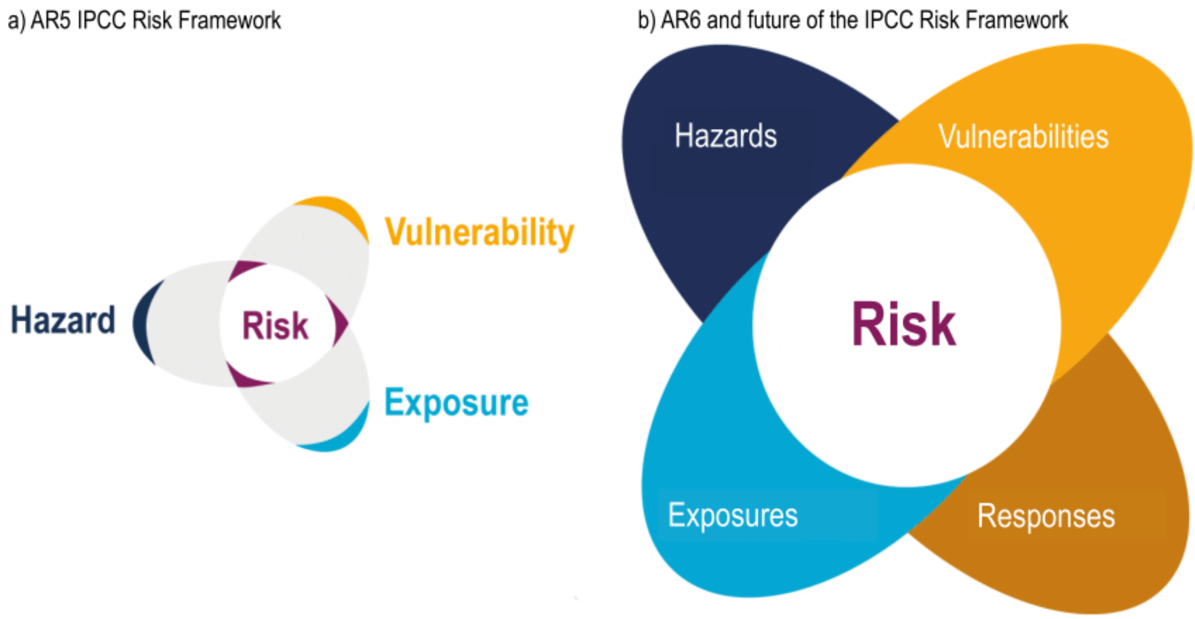

Figure 1: Evolution of the risk frameworks developed by the Intergovernmental Panel on Climate Change (IPCC) within the Fifth and Sixth Assessment Reports (AR5 and AR6; IPCC, 2014; 2023)

In addition to hazard, exposure, and vulnerability, AR6 introduces in the risk framework (e) responses as part of the main components of climate change risk (Figure 1). Including response in risk assessment enhances the understanding of the relationship between climate change risk and resilience, as responses are crucial for governance and understanding feedback that shapes social-ecological systems (Simpson et al., 2021). Considering response as a determinant of risk supports integrating climate-resilient development pathways and climate change risk concepts within assessments. Risk can emerge from various pathways shaped by interacting drivers. Understanding potential outcomes and their severity necessitates recognising this web of interactions stemming from anthropogenic climate change or human-induced events and pressures. These changes mark a significant advancement in understanding and addressing the complexities of climate change impacts. Despite numerous initiatives tackling this issue (Dal Barco, Maraschini, et al., 2024; Furlan et al., 2019; Gallina et al., 2016; IPCC, 2014; Terzi et al., 2019), there is no unified framework for assessing complex climate change risks.

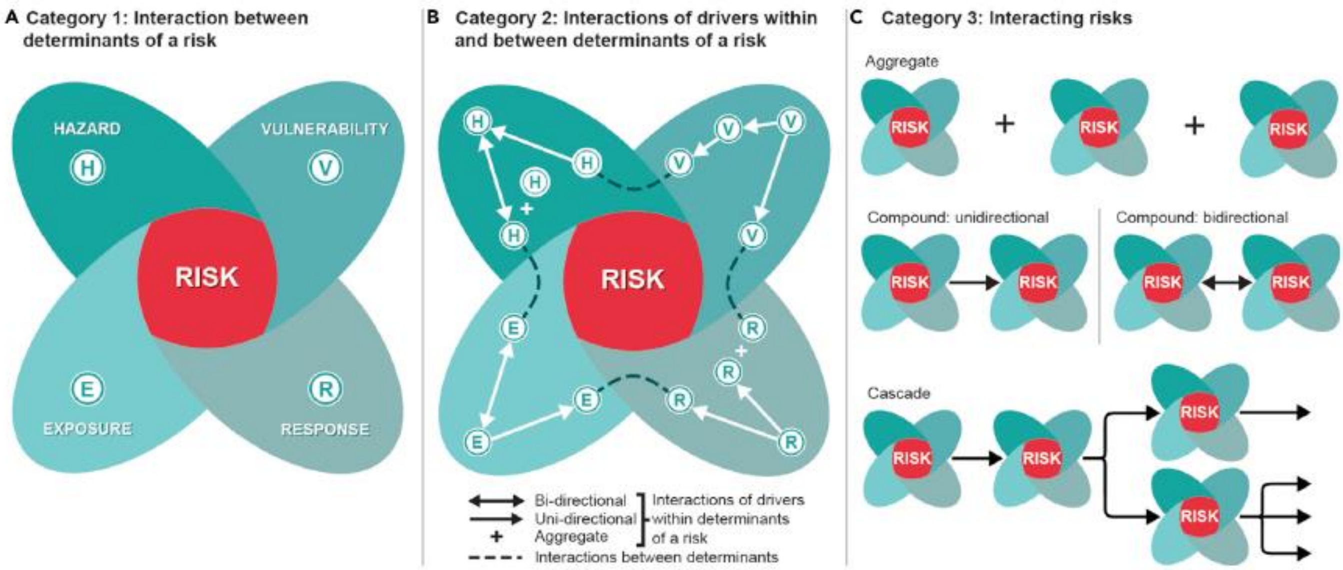

Figure 2: Risk framework proposed by Simpson et al. (2021) aimed at understanding and assessing complex climate change risks across three categories. (A) Category 1 – interactions between determinants of risk; (B) Category 2 – Interactions of drivers within and between determinants of risk; (C) Category 3 – Interactions of risks

To address this gap, Simpson et al. (2021) developed three categories to understand complex climate change risk (Figure 2):(A) interactions between determinants of risk (i.e., hazard, exposure, vulnerability, and response); (B) interactions of drivers within and between determinants of risk (e.g., as temperature and income); and (C) interactions of risks (e.g., as water scarcity and health).

An expanded assessment approach that considers responses as an additional determinant of risk and emphasises the types and origins of interactions (compound, cascade, and aggregate; Simpson et al., 2021). This approach clarifies the interactions within and among risk determinants and multiple risks, guiding more detailed and accurate risk assessments. Interactions among risks can be unidirectional or bidirectional (compounding interactions), while cascades occur when one risk triggers multiple other risks, resulting in a proliferation of interactions (Simpson et al., 2021).

Adopting a dynamic perspective of risk over time and space can help focus on interactions among various response options needed for recovery and risk management and preparedness (Simpson et al., 2021). Assessments that consider interacting risks are integral to anticipating complex risks and supporting more robust decision-making.

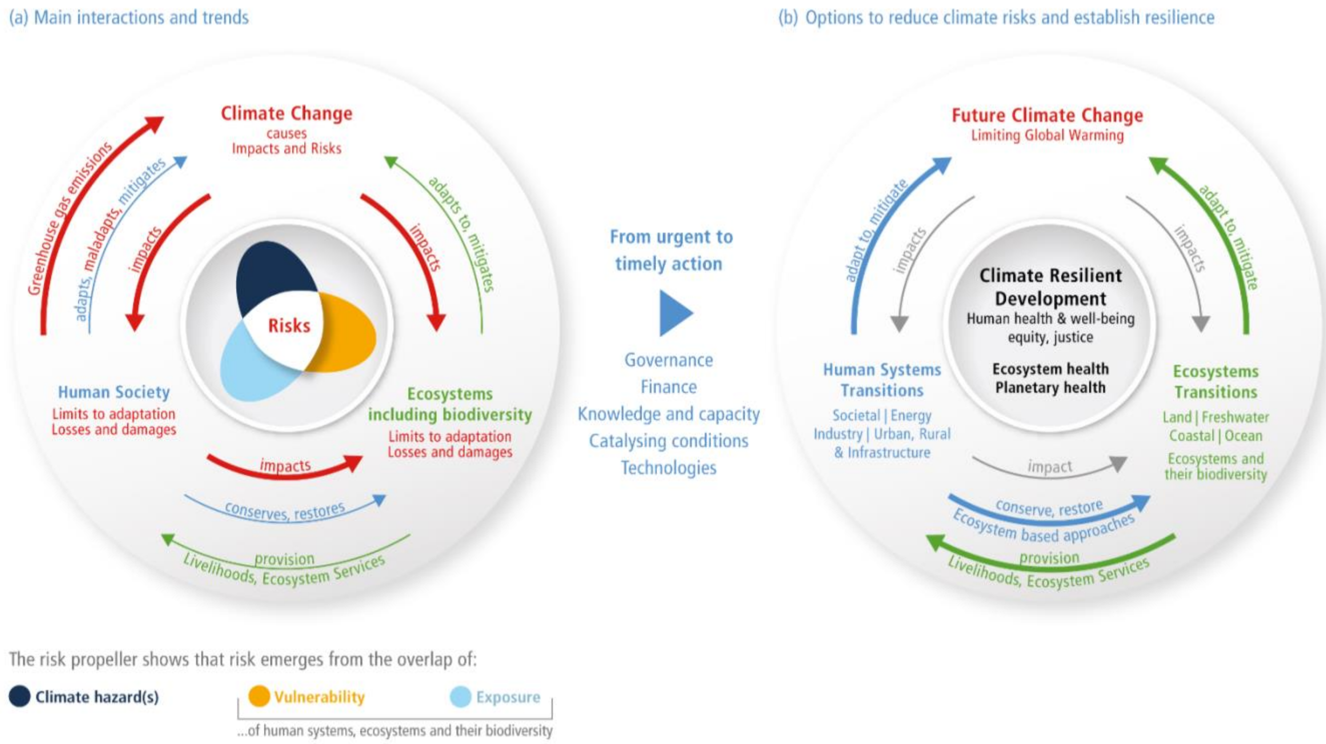

Figure 3: From climate risk to climate-resilient development: climate, ecosystems (including biodiversity) and human society as coupled systems (IPCC, 2022, Figure TS.2)

Knowledge of climate risks is essential for informing climate action aimed at achieving climate-resilient development. Climate actions can accelerate efforts toward developing climate resilience through effective policies, practices, and enabling conditions. In AR6, the term 'enabling conditions' is used to refer to factors that enhance the feasibility of adaptation and mitigation strategies for climate-resilient development, which is defined as the implementation of mitigation and adaptation measures to foster sustainable development.

Pathways to climate-resilient development are determined by collective social decisions and actions across various spheres including community, socio-cultural, political, ecological, knowledge and technology, and economic and financial domains. Key elements driving high climate resilience development include equity and justice, inclusion, knowledge diversity, and ecosystem management.

The analysis of multi-sectorial and cross-border systems (e.g., AcquaGuard pilot areas), natural hazards, and climate-related risks can make less easy the selection of climate-resilient development pathways. It, therefore, requires the development of a comprehensive (and multi-dimensional) risk portfolio which must include adaptation responses implemented to mitigate envisaged risks, without introducing new ones. The feasibility of implementing these adaptation measures should be assessed to support and ensure the accurate identification of climate-resilient development pathways, in line with the EU Mission Adaptation[2].

In conclusion, a better understanding of the interactions among all risk components is crucial for making informed decisions and creating effective strategies to mitigate and adapt to the changing climate. For this reason, hazard, exposure, vulnerability, risk, and response features have been introduced to address the importance of complex risks and their interactions in an integrated manner.

[2] EU Mission – Adaptation to Climate Change: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/adaptation-climate-change_en

These definitions and key concepts will be used as a basis for the collection and categorisation of data (D1.1.1 Risk database – general risk database for the INTERREG IT-CRO region), as well for the characterisation of the pilot cases (D1.1.2 Risk portfolios for the project regions).

3 INTERREG IT-CRO Region Overview

3.1 Geographical and demographic characteristics of the INTERREG IT-CRO region

The INTERREG Italy-Croatia region, located in the northern Adriatic Sea, includes the coastal areas and close hinterlands of Italy and Croatia. This area has diverse geographical and climatic features, as it sits at the conjunction of Mediterranean and Central European climate zones.

The program area includes 33 NUTS III statistical regions - 25 provinces in Italy and 8 counties in Croatia. In Croatia, the region comprises 65 towns and 177 municipalities, while in Italy, it includes 25 provinces and 1,267 municipalities. The Croatian part of the region is predominantly mountainous and dominated by the Dinaric Alps. In contrast, the Italian part consists mainly of plains, although some areas feature the mountain zones of the pre-Alps and the Apennines.

The INTERREG Italy-Croatia cooperation area covers the marine basin, coastal landscapes, and green and urban areas. The region is home to 30 UNESCO World Heritage sites, natural resources, and intangible heritage items.

The Adriatic Sea's surface area is 138,595 km^2, with a length of 783 km and an average width of 170 km. Its coastline and islands represent the most valuable natural ecosystem in the area. Such marine and coastal resources are of paramount importance for economic development. However, coastal regions are under considerable pressure from urbanisation, agriculture, industrial activities, and transportation.

The INTERREG IT-CRO region covers an area of 85,562 km² and has a population of 12,292,116 inhabitants, around 88% living in Italy.[3]

Major occupations in the region include manufacturing, wholesale and retail trade, and public sector jobs in education, social care, defence, health, and social care. The predominance of road transport on land routes and numerous small and large ports along the coast characterise the region.

[3] INTERREG Programme 2021 – 2027: https://www.italy-croatia.eu/documents/555109/576296/web_INTERREG_Italy_Croatia_Programme_2021_2027.pdf/24c91b1b-8715-134c-d239-74bb1f6b6f89?t=1711099425737

Figure 4: Map of INTERREG Italy – Croatia region[4]

On the Italian side, the Friuli-Venezia Giulia region is distinguished by its unique karst landscapes on the Karst Plateau, the shallow Gulf of Trieste with its rocky cliffs, and the alpine foothills in the north. Dominating the northern area are the Julian Alps, highlighting the contrast with the coastal plain. Transitioning to the Veneto region, the fertile Po Valley stretches to the Adriatic shores and contains vast lagoons, such as the Venetian Lagoon. A barrier of islands and peninsulas separates the aforementioned lagoon from the Adriatic Sea. The Po, Adige, and Piave river systems traverse the region, adding to its diverse hydrological landscape.

In the northern part of Emilia-Romagna lies an agriculturally rich plain of the Po River delta, which stretches to the Adriatic coast and contains sandy beaches and many wetlands. Moving to the central and southern parts of the region, the Apennines dominate the terrain, creating a varied landscape of rolling hills and valleys.

This diversity continues into the Marche region, characterised by several rivers that flow from the Apennines to the Adriatic Sea, such as Metauro, Tronto, and Potenza. These rivers create lush valleys that support agriculture, while the coastline combines sandy stretches and rocky outcrops.

The Abruzzo region, south of the Marche region, is well known for its rugged and mountainous terrain, with the Apennines dominating the landscape from north to south. This area extends to the Adriatic coast, which features a mix of sandy beaches and rocky promontories. The narrow but fertile coastal plain supports agriculture and viticulture. Major

[4] Italy Croatia cross-border cooperation programme: https://www.italy-croatia.eu/cooperation-area

rivers, such as the Pescara and Sangro, flow from the mountains to the Adriatic, forming deep valleys that outline the region topographically.

Further south lies Molise, a region of a diverse landscape that includes rugged mountains, rolling hills, and a narrow coastal sandy strip along the Adriatic. Many rivers, such as the Biferno and Trigno, cross the region and form fertile valleys.

Going down more to the southeast lies Apulia, a flat or gently rolling terrain with a long coastline along the Adriatic and Ionian Seas. The region features the extensive Tavoliere plain, one of Italy's largest plains, and is widely known for its agricultural productivity. Moving towards central Apulia, the Murge plateau rises with its karst landscapes, representing a distinguishing topographical feature of this region. The coastline has sandy beaches, rocky cliffs, and other diverse coastal scenery.

On the Croatian side, Istria is the largest Adriatic peninsula, and it has a diverse geography. Many bays, coves, and rocky beaches are along the western coast, whereas steep cliffs mark the eastern shore. Inland, the terrain transitions to rolling hills and fertile plains.

The County of Primorje-Gorski Kotar includes the Kvarner Gulf, a mixture of littoral and mountainous landscapes. Its seashore is usually formed by pebbly beaches, rocky shores, and steep cliffs, appropriately complemented by forested islands. On the other hand, the Dinaric Alps in the inland include lush forests and deep valleys, thereby forming a unique combination of the Mediterranean and Alpine elements.

Karlovac County belongs to the area of rounded hills, fertile valleys, and prominent river systems. Four rivers (Kupa, Korana, Mrežnica, and Dobra) converge near Karlovac, shaping a distinctive hydrological landscape. This terrain gently transitions from plains over low hills to the rugged Dinaric Alps in the south.

Moving southward, Lika-Senj County is predominantly mountainous, dominated by the Dinaric Alps and the Velebit range. The region features rugged terrain, extensive forests, and karst formations like caves and sinkholes.

Zadar County, part of Northern Dalmatia, shares similarities with Šibenik-Knin County's rugged coastline with islands, inlets, and bays. Coastal features include rocky cliffs and pebbly beaches, while karst landscapes with limestone plateaus and fertile valleys characterise inland areas. The Velebit mountain range is a natural barrier between the coast and the interior.

Further south, Split-Dalmatia County in central Dalmatia boasts coastal scenery and beaches, which are sandy and pebbly, next to steep cliffs. Inland, the landscape rises toward the Biokovo mountain range, starkly contrasting the coastal areas. The Cetina River flows through deep canyons.

Lastly, southern Dalmatia's Dubrovnik-Neretva County presents a varied coastline with rocky shores, sandy beaches, and secluded coves. Many of its islands have an insular landscape with hilly land covered by lush vegetation. Inland, the Dinaric Alps give way to rolling hills and fertile plains, where the Neretva River delta forms a significant ecological and geographical feature, blending mountainous areas with coastal plains.

3.2 Climate characteristics of the INTERREG IT-CRO region

The INTERREG IT-CRO region boasts a diverse climate shaped by its varied geography and proximity to the Adriatic Sea. The Adriatic Sea moderates temperatures, preventing extremes and adding humidity to the region. Inland areas exhibit more continental characteristics with greater temperature variability and higher precipitation levels, often including snowfall in winter. The regions topography creates numerous microclimates, especially in mountainous regions where valleys may experience different weather patterns than exposed coastal areas or high-altitude zones.

The coastal regions of Croatia, the Trieste Gulf coastal area, and the southern half of Italy experience a subtropical intermediate climate. This climate is characterised by mild winters where temperatures rarely fall below freezing and warm to hot summers. Precipitation levels are moderate throughout the year, with a slight tendency towards drier conditions during the summer months.

In contrast, Karlovac County and other inland regions of Croatia feature an intermediate warm temperate climate. Winters are moderately cold with occasional snowfall, while summers are warm to hot. Precipitation is evenly distributed across the year, with a slightly higher amount during the warmer months.

Further north, the northern half of the Italian coast exhibits a subtropical continental climate. This climate is defined by cold winters, often with temperatures dropping below freezing and hot summers. Overall precipitation levels are moderate, with a tendency towards drier conditions during the summer season (Figure 5).

Wind patterns, such as the cold Bora and warm Sirocco, further influence the climate, adding to the regions environmental complexity. This geographical and climatic diversity supports rich biodiversity and diverse human activities, making the INTERREG IT-CRO region a significant area for both natural and economic development.

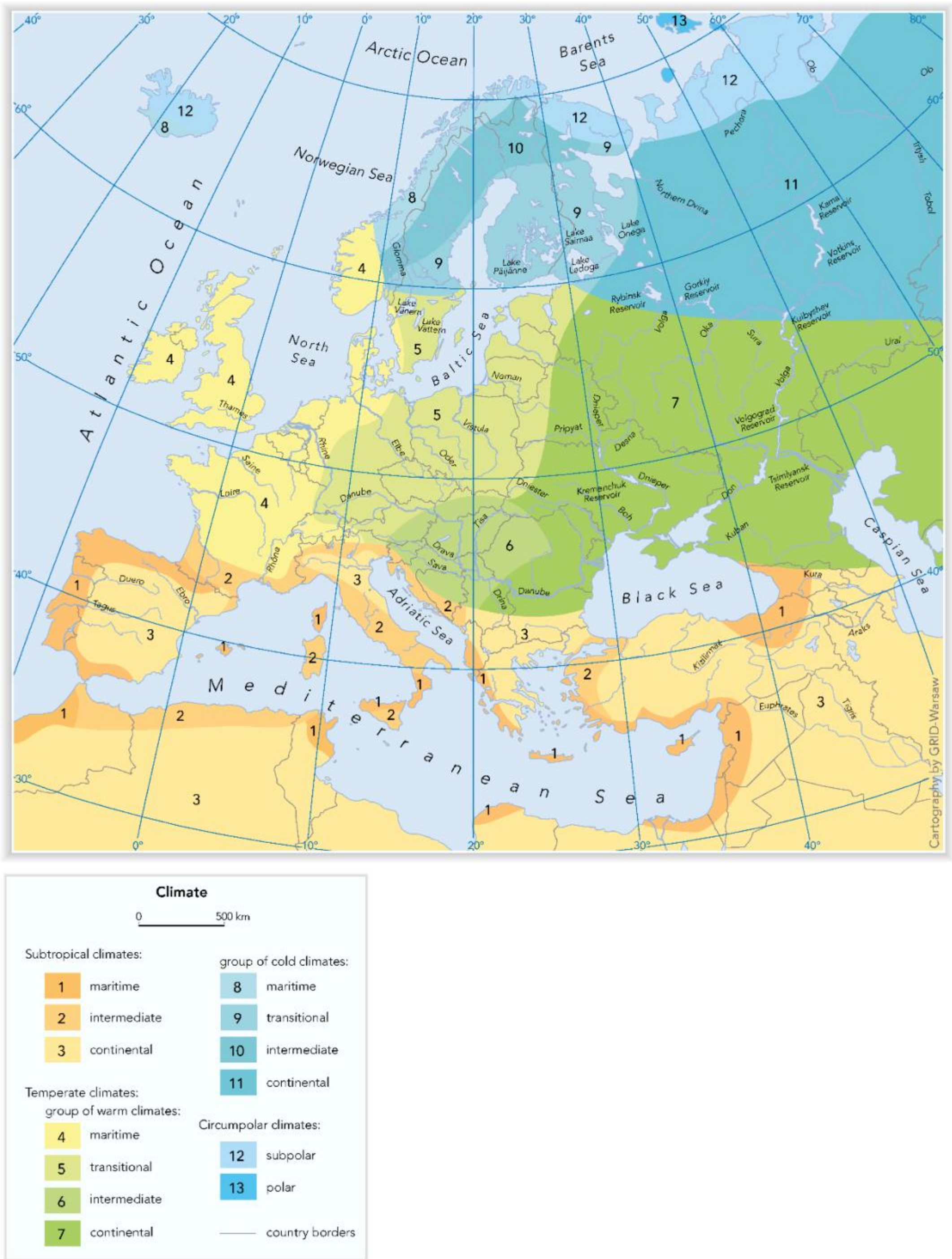

Figure 5: Division of climatic zones across Europe[5]

[5] European Environment Agency: https://www.eea.europa.eu/data-and-maps/figures/climate

4 Risk database development approach

Based on the geographical characteristics outlined in Section 3.1, the INTERREG IT-CRO region is at risk of various climate-related hazards due to its coastal features, geomorphology, and main economic activities centered around tourism, fisheries, and maritime transport. Climate-related hazards pose significant risks and can profoundly affect numerous sectors and aspects of life.

These hazards encompass a range of events, such as extreme weather phenomena, and each of which could disrupt ecosystems, infrastructure, economies, and human health and well-being. This document not only identifies the climate-related hazards specific to the observed region but also gives a full account of anticipated risks and impacts connected with them.

Therefore, this risk database gives an overview of existing megatrend analysis on hazards in the region under consideration through comprehensive assessment and data from the European Environment Agency which clearly shows the trends in terms of frequency, intensity and spatial distribution of these hazards.

Finally, accompanying Excel document lists compound climate hazard events. These events involve multiple hazards' simultaneous occurrence or interaction and can significantly amplify their impacts. For instance, convective storms can trigger floods and storm surges, increasing coastal vulnerabilities, including the erosion process. Heatwaves make droughts more intense hence increasing chances of wildfires outbreaks.

5 Risk database overview

This chapter provides an overview of the information in the accompanying Excel document, consolidating key data and analyses related to European hazard megatrends.

5.1 Extreme temperatures

5.1.1 Heat waves

With increasing global temperatures due to climate change, heat waves' frequency, duration, and intensity also increase. Given these extreme events, heat-related illnesses and fatalities will very likely result, along with the exacerbation of pre-existing medical conditions and the straining of energy and water resources. Continuous heat waves could further disrupt natural ecosystems and lower agricultural productivity while increasing the risks of wildfires.

The lower maps of Figure 6 illustrate the median number of heat waves projected by a combination of models for the near future (2020–2052) and the latter part of the century (2068–2100) using the RCP4.5 scenario. The lower maps depict the same time periods but under the RCP8.5 scenario.

According to the European Environment Agency's analysis, the frequency of heat waves in the INTERREG IT-CRO region will increase over the next couple of decades, particularly in its southern parts. Under the RCP4.5 scenario, an additional 4 to 6 heatwave days per year are expected in the region within the next 30 years. In contrast, the rise would be more substantial in severe scenarios such as the RCP8.5, with an additional 7 to 12 heat wave days per year within the same period.

The projections indicate that heat wave frequency will continue to rise through the end of the century. Under the RCP4.5 scenario, the number of heat wave days will increase to 13-15 per year, while under the RCP8.5 scenario, it could increase drastically to 16-33 days per year.

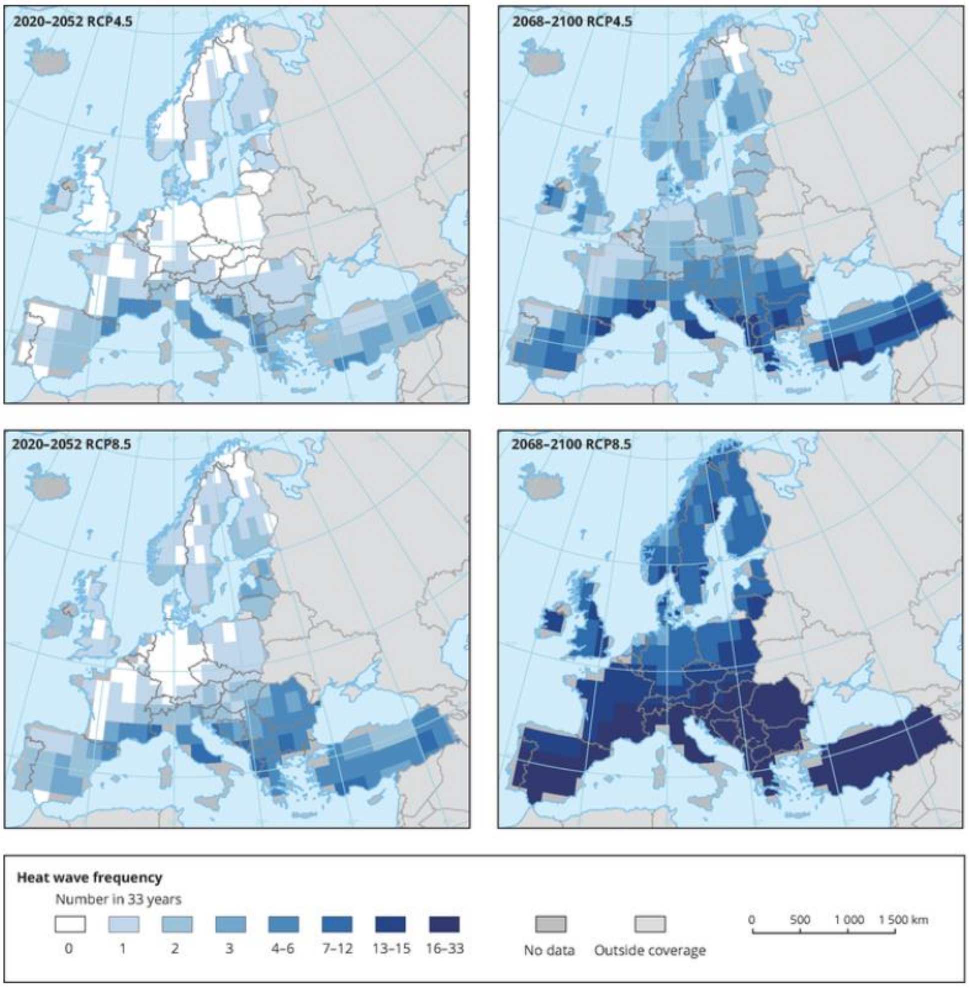

Figure 6: Comparison of heat wave frequency maps for the near future (2020-2052) (left) and the latter part of the century (2068-2100) (right) under the RCP4.5 (top) and RCP8.5 (bottom) scenarios[6]

[6] European Environment Agency: https://www.eea.europa.eu/data-and-maps/figures/number-of-extreme-heat-waves-1

5.1.2 Urban heat islands

The creation of an urban heat island (UHI) is a phenomenon characterised by significantly higher air temperatures in built-up areas compared to surrounding rural. There are so-called micro-urban heat islands, which most often occur in parts of the city associated with large asphalt surfaces or other impermeable materials such as parking lots, shopping centres, industrial facilities, etc. In a city, some places are cooler than the rest of the urban environment (so-called heat sinks), such as parks, green areas, open water surfaces, etc.

The difference between the temperature of the warmest urban zone and the temperature of the rural area represents a measure of the intensity of the urban heat island. The intensity of the UHI changes depending on the season and the time of day. Cities in temperate latitudes generally have UHIs with the greatest intensity in the summer and winter seasons, and the daily cycle shows that the UHI is mostly more pronounced at night. This is a consequence of the heat the city absorbs during the day, which is released at night and further warms the atmosphere.

The impact of UHI is evident in the following examples: UHI enhances the formation of smog and ozone (e.g., Fallmann et al., 2016) and increases the need for drinking water due to intensive household water usage. In general, UHI favourably impacts the length of the vegetative period and can also increase the frequency and intensity of heat waves.

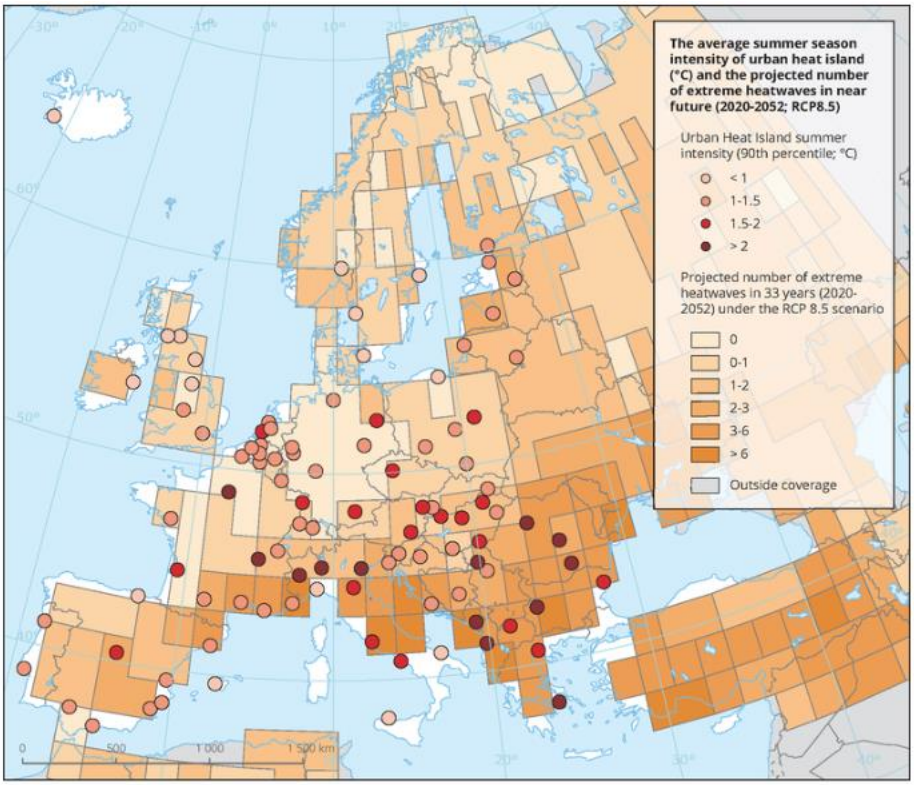

Figure 7: The average summer season intensity of urban heat islands and the projected number of extreme heat waves in 2020-2052 under the RCP8.5 scenario[7]

Figure 7 illustrates the average summer season intensity of urban heat islands and the projected number of extreme heat waves in the period 2020-2052 under the RCP8.5 scenario. According to the available analysis for the INTERREG IT-CRO region, the highest intensity is observed in Venice, exceeding 2 °C. In comparison, the intensity for the cities of Dubrovnik and Trieste is between 1 and 1.5 °C, and for Bari, it is less than 1°C.

5.1.3 Cold spells and frost

Cold spells and frost are relevant hazards to sectors like agriculture, construction, and transport. Their relevance and impacts largely depend on the affected climate zones. For

[7] European Environment Agency: https://www.eea.europa.eu/data-and-maps/figures/the-average-summer-season-intensity

example, cold spells can increase energy consumption due to heating, intensify respiratory and cardiovascular problems, and make the roads hazardous. In addition, frost days may disrupt agricultural production.

A cold spell is typically defined as a prolonged period of unusually low temperatures, often caused by the intrusion of cold Arctic air into temperate regions. Frost days, i.e., the number of days with a minimum daily temperature below 0 °C, are particularly common in late autumn and early spring, marking the transitions between warmer and colder seasons.

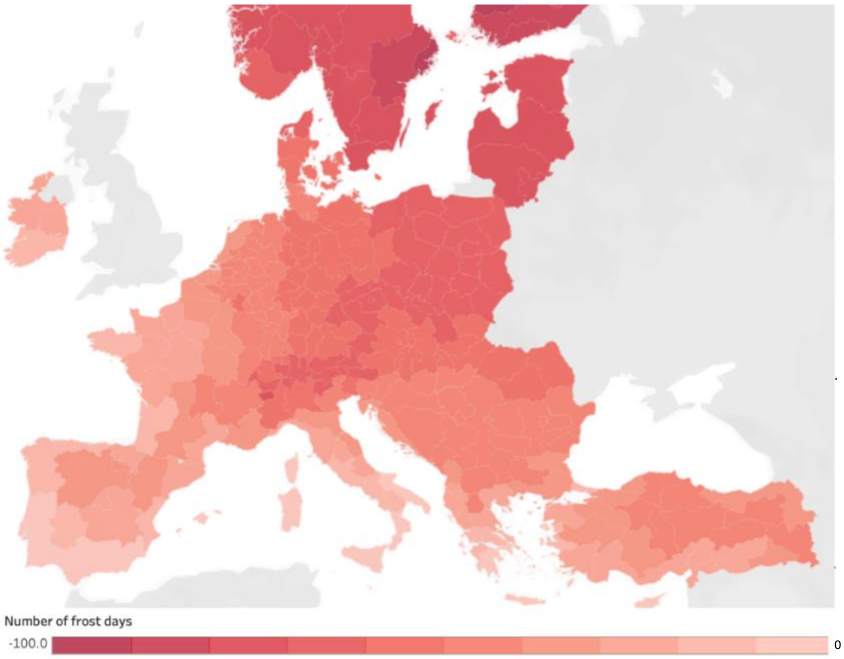

Figure 8: Projected number of frost days for 2071-2100 under the RCP8.5 scenario[8]

The European Environment Agency (EEA) provides projections of changes in the number of frost days. However, the indices regarding extreme cold weather, like cold spell duration,

[8] European Environment Agency: https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/heat-and-cold/frost-days

have not been considered in the analysis because of their limited use at the pan-European level.

According to the EEA, the number of frost days in Europe has decreased since the 1980s, but with considerable yearly variability. This trend is projected to continue throughout the 21st century (Figure 8), and the number of frost days is expected to decline by about half during the 21st century under the RCP8.5 scenario. The most significant change for the INTERREG IT-CRO region is expected in the Friuli-Venezia Giulia region, with a slightly more than 50-day reduction. In contrast, the smallest change is anticipated in the southernmost region, Apulia, with a reduction of 7 days. Emilia Romagna, Marche, and coastal Croatia are expected to experience a decrease of about 30 days during this period.

5.2 Heavy precipitation events

5.2.1 Flash flooding

Flash flooding is a rapid and extreme flow of high water into a normally dry area or a rapid rise in water level in a stream or creek above a predetermined flood level. It is usually the consequence of heavy rainfall over a short period of time, often from thunderstorms. It often happens within minutes or hours of excessive rainfall, dam or levee failure, or the sudden release of water held by an ice jam.

Flash floods are dangerous because a great deal of water comes on suddenly and powerfully, sweeping away vehicles, buildings, and even people. Urban areas are most prone to flash flooding because impervious surfaces, such as roads and parking lots, inhibit rainwater infiltration into the earth and increase runoff into drainage systems, often causing them to be overwhelmed.

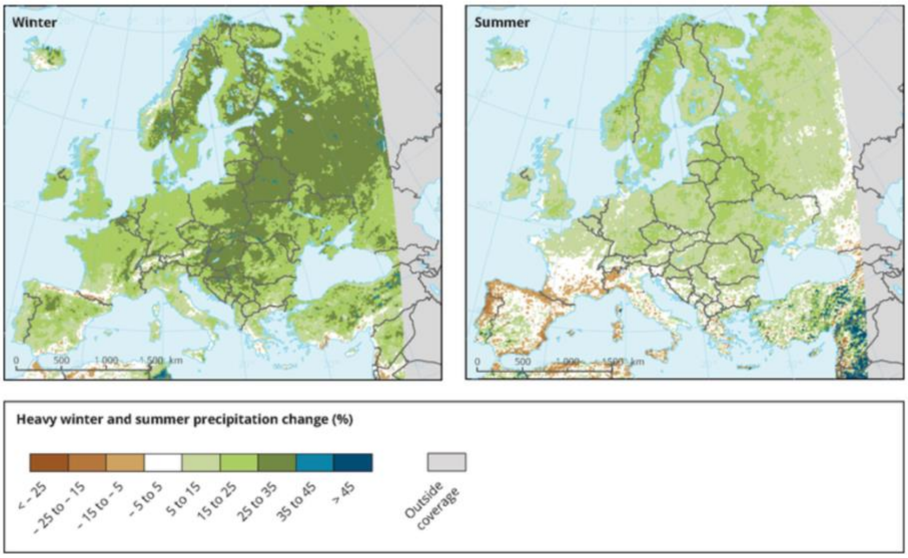

Figure 9: Projected changes in heavy precipitation in winter (left) and summer (right) from 1971-2000 to 2071–2100 for the RCP8.5 scenario[9]

Figure 9 illustrates the projected percentage change in heavy winter and summer precipitation for the period 2071-2100 under the RCP8.5 scenario. In winter, most of the INTERREG IT-CRO region is likely to experience an increase in heavy precipitation events by 5 to 15%, except for the coastal areas of the Marche, Abruzzo, and Molise regions. In summer, most of the territory is expected to change from -5 to 5%. However, coastal areas of Emilia Romagna, Abruzzo, and Apulia regions are expected to experience an increase in heavy precipitation by 5 to 15%.

5.2.2 Landslides

Numerous factors influence the downward movement of rock, debris, or earth along a slope, known as a landslide. Natural triggers, such as intense or prolonged rainfall, earthquakes, volcanic activity, and the natural weathering of rocks, saturate the soil and destabilise slopes.

[9] European Environment Agency: https://www.eea.europa.eu/data-and-maps/figures/projected-changes-in-20-year-2

Additionally, human activities contribute significantly to triggering landslides. Deforestation removes the root systems that help anchor the soil, making such an area very sensitive to erosion and landslides. Construction and urban development over unstable slopes, excavation, and mining activities drastically change the landscape. This further liberates slopes and raises the possibility of landslides.

The impact of landslides on communities, infrastructure, and the environment is profound. They can cause property damage, loss of life, and large economic costs. Infrastructure, including roads, bridges, and utility networks, may suffer heavy damage with long-lasting periods of inaccessibility and disruption. In general, landslides can continue to contribute to long-term environmental degradation through changes to freshwater habitats.

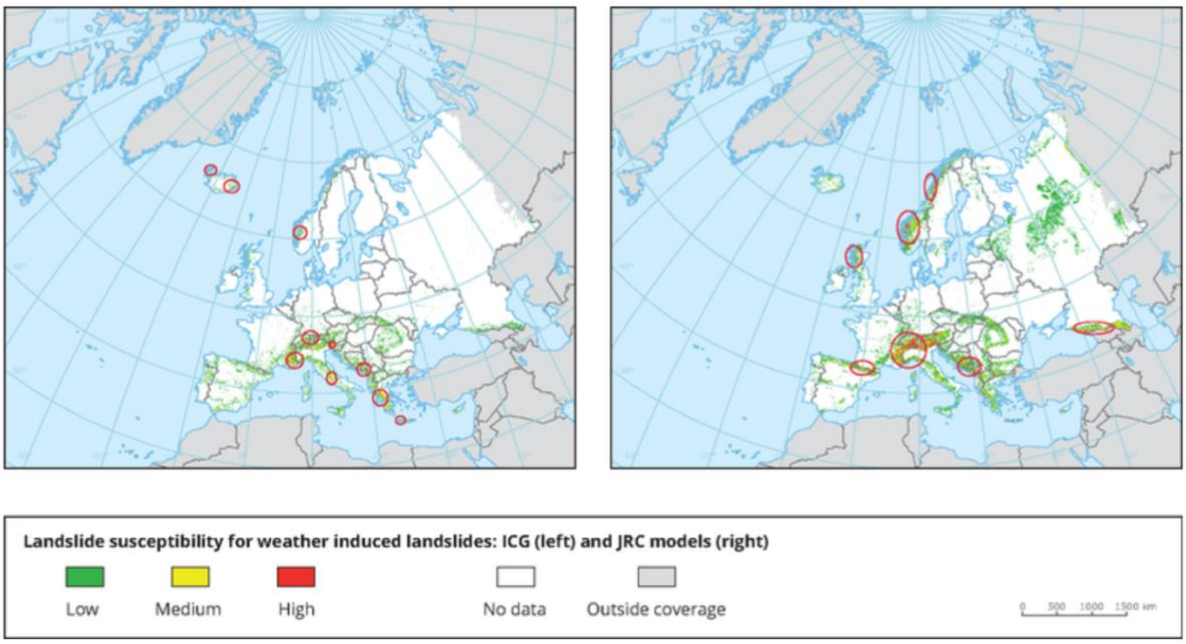

Figure 10: Landslide susceptibility in Europe due to weather-induced events, analysed using ICG (left) and JRC (right) models[10]

[10] European Environment Agency: https://www.eea.europa.eu/data-and-maps/figures/landslide-susceptibility-for-weather-induced-1/landslide-susceptibility-for-weather-induced

Figure 10 compares landslide susceptibility to weather-induced landslides using two distinct models developed independently by the International Centre for Geohazards (ICG) and the Joint Research Centre (JRC). Each uses the same datasets and focuses on the same geographical area.

The ICG model is heuristic, relying solely on expert judgment, and incorporates input parameters such as topography, geology, land cover, precipitation, and seismicity. In contrast, the JRC model is based on a statistical approach using logistic regression and is limited to analysing landslides of the slide and flow types. The JRC model generates a classified landslide susceptibility map, subsequently integrated with classified precipitation and seismic data (Jaedicke et al., 2014).

In the ICG model, the Marche and Abruzzo regions exhibit low susceptibility. Low to medium susceptibility is observed along Dalmatia's coastal and inland areas and northwestern Istria. Additionally, a hotspot has been identified on the eastern part of Friuli-Venezia Giulia, near the border with Slovenia.

Conversely, results from the JRC model are very similar for the Marche and Abruzzo regions. However, this method marks a broader area of the Croatian Adriatic coast and its hinterland as having low susceptibility. The northern parts of Friuli-Venezia Giulia are highly susceptible, although this area has not been identified as a hotspot in the JRC model.

5.3 Severe windstorms

Severe windstorms are an important hazard for various sectors and activities such as forestry, infrastructure, buildings, energy, and transport. However, data availability for this hazard is limited, and substantial discrepancies exist between different data sources, making extreme wind projections more uncertain than other climate hazards.

Storm location, frequency, and intensity have shown considerable decadal variability across Europe over the past century, so no significant long-term trends are apparent.

Wind data at the local or regional levels can show decreases and increases over several decades. Long wind speed records for various regions across Europe indicate that storm intensity has not significantly changed over the past 200 years.

Modeling studies show diverging results on changes in the number of storms across Europe, but they generally agree on increases in the strongest, most damaging storms in most European regions. A multi-model ensemble study projects a decrease in the wind speed of the strongest winter storms over southern Europe (Beniston et al., 2024).

Moreover, The Intergovernmental Panel on Climate Change's Sixth Assessment Report (IPCC, 2021: Climate change information for regional impact and risk assessment, Section 12.4.5) finds with medium confidence that the storm intensity will increase and storm frequency decrease for southern Europe.

5.4 Fluvial floods

One of the most prominent natural hazard events is fluvial floods, which result from river bank overflows owing to enormous rainfall, fast snowmelt, or ice jams. Such floods are characterised by water overflow of usually dry land, leading to destruction of infrastructure, agriculture, and ecosystems and posing great risks to human life and property.

A combination of meteorological, hydrological, and geomorphological factors influences the dynamics of fluvial flooding. Heavy or prolonged rainfall generally is the primary driver, commonly resulting in saturated soil conditions and increasing surface runoff. Rapid snowmelt, especially in mountainous regions, contributes significantly to the volume of water that reaches river systems.

Hydrological factors, including watershed characteristics, river channel capacity, and floodplain topography, significantly influence the extent of flooding. Human activities can either enhance or reduce the impacts of fluvial floods through activities such as urbanisation, deforestation, and constructing levees and dams.

The expected percentage changes in the 100-year return level of river discharge for the periods 2071-2100 compared to 1961-1991 are shown in Figure 11.

On the Italian side, significant increases are anticipated for the Po and Piave rivers, with projections indicating a 20-40% rise. The Tagliamento River is projected to experience a slightly lower increase, estimated between 10-20%. The Reno River is expected to see minimal change, with a variation ranging from -5% to +5%. Conversely, the Adige River is forecasted to decrease discharge from -10% to -20%.

Across the Adriatic Sea, rivers in Karlovac County are projected to see an increase in discharge ranging from 5% to 20%. In Dalmatia, the rivers Cetina and Krka are supposed to receive a more drastic increase in precipitation, ranging between 20% and 40%.

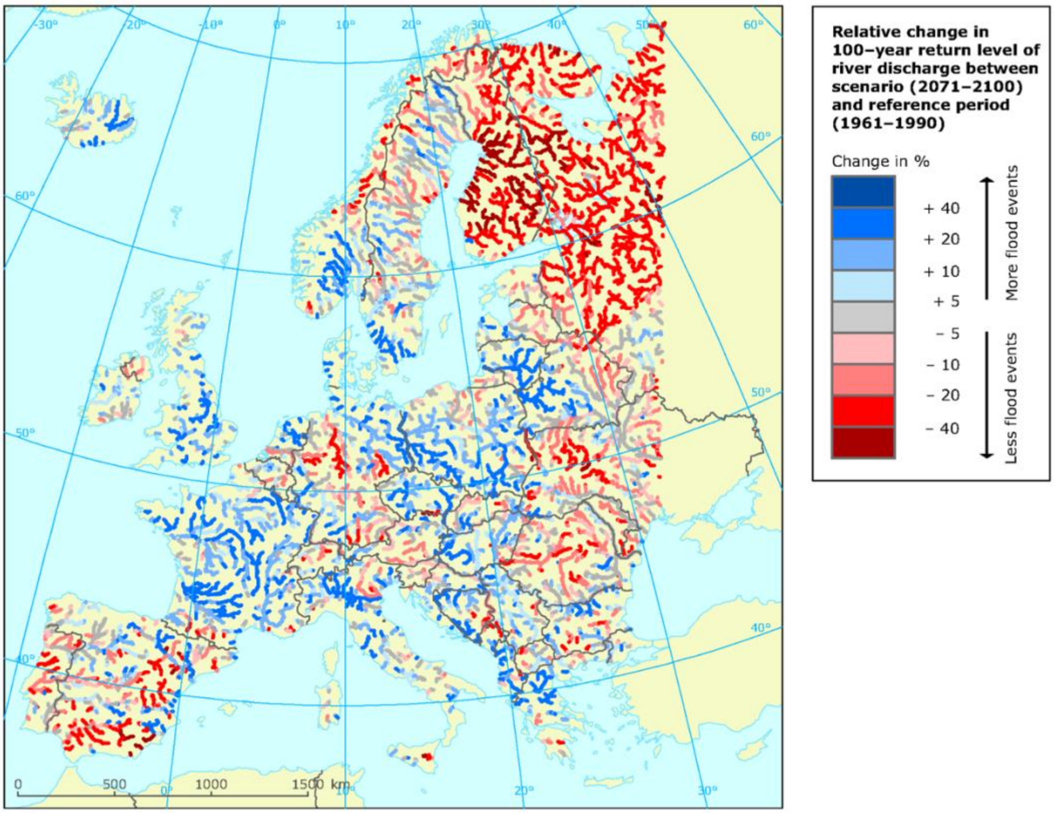

Figure 11: Projected change in the 100-year return level of river discharge between the periods 1961-1990 and 2071-2100[11]

[11] European Environment Agency: https://www.eea.europa.eu/data-and-maps/figures/projected-change-in-100-year-return-level-of-river-discharge-between-2071-2100-and-the-reference-period-1961-1990

5.5 Coastal hazards

5.5.1 Coastal flooding

Coastal flooding is increasingly recognised as a critical challenge facing communities worldwide. This phenomenon, characterised by the overflow of seawater onto adjacent land, poses a great danger to both natural and human systems. Storm surges are expected outcomes of sea level rise due to climate change, heightening coastal regions' vulnerability.

The impacts of coastal flooding are various, ranging from ecosystem and economic disruptions to community distortions. They extend beyond immediate damage to infrastructure and property, impacting vital ecosystems, such as wetlands and estuaries. Economically, coastal flooding can disrupt fishing, tourism, and shipping industries, leading to substantial financial losses for communities that rely on these sectors.

Socially, the greatest effect of coastal flooding is on low-income communities and marginalised groups living in those areas that are prone to flooding. Displacement of people, destruction of livelihoods, and damage to health and education institutions increase the gap between the social classes.

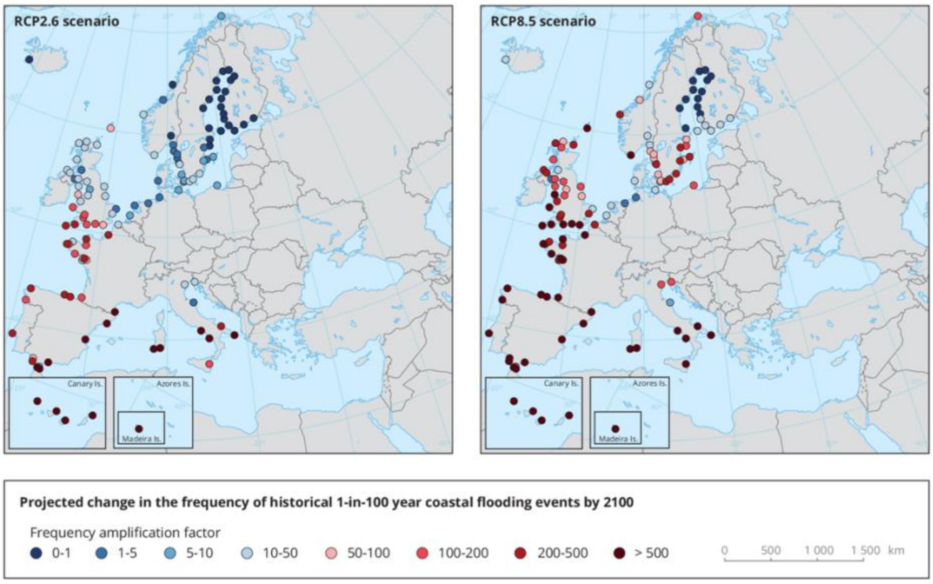

Figure 12: Projected change in the frequency of 1-in-100-year flooding events from 2010 to 2100 due to regional relative sea level rise, depicted RCP2.6 (left) and RCP8.5 scenarios (right)[12]

Under the RCP2.6 scenario, the frequency of historical 1 in 100-year coastal flooding events is anticipated to increase by 2100 (Figure 12). For tide gauge stations in the northern Adriatic, the amplification factor ranges from 10 to 50 for Venice and Trieste, 1 to 5 for Ancona, and 200 to 500 for Bari. For Otranto, an amplification factor of more than 500 is expected.

Under the RCP8.5 scenario, Trieste and Venice are projected to experience an amplification factor ranging from 100 to 200, Ancona from 5 to 10, and Bari and Otranto an amplification factor exceeding 500.

5.5.2 Erosion and coastal erosion

Erosion is a natural geological process where soil, rock, and other surface materials are worn away and transported by natural forces such as wind, water, and ice. This process plays a crucial role in shaping landscapes over time but can have significant negative impacts when

[12] European Environment Agency: https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/coastal/coastal-coastal-floods

accelerated by human activities. There are several types of erosion, each driven by different forces. The most common is water erosion, involving rainfall, riverbank erosion, and coastal erosion caused by the flow of water, which removes soil and rock. Wind erosion happens in arid and semi-arid areas with strong winds, picking up loose particles and blowing them away. Ice erosion, also known as glacial erosion, involves the movement of glaciers, cutting valleys out and carrying along with them whatever debris lies in their paths. Human-induced erosion, often increased by activities such as deforestation, construction, and improper farming, exaggerates natural erosion rates and increases its negative impacts.

The primary risks and impacts of erosion include loss of fertile topsoil, decreasing agricultural productivity, sedimentation of waterways, habitat destruction, and increasing vulnerability to natural disasters, such as floods and landslides.

Figure 13 illustrates the projected changes in vulnerability to water and wind erosion in the future, based on a comparison of long-term rainfall patterns between the periods 1970–2000 and 2061–2080 under the SSP2–4.5 scenario. The analysis indicates that soil erosion by water will likely increase in areas with consistently higher precipitation, while drier regions may face heightened vulnerability to wind erosion.

The Gulf of Venice area is expected to see increased erosion vulnerability due to rising precipitation and decreasing drought conditions. Conversely, parts of the Emilia Romagna and Abruzzo regions are projected to have reduced vulnerability owing to increasing drought. Regarding wind erosion, Apulia is anticipated to experience a rise in future wind erosion vulnerability due to more frequent droughts (Dal Barco et al., 2024).

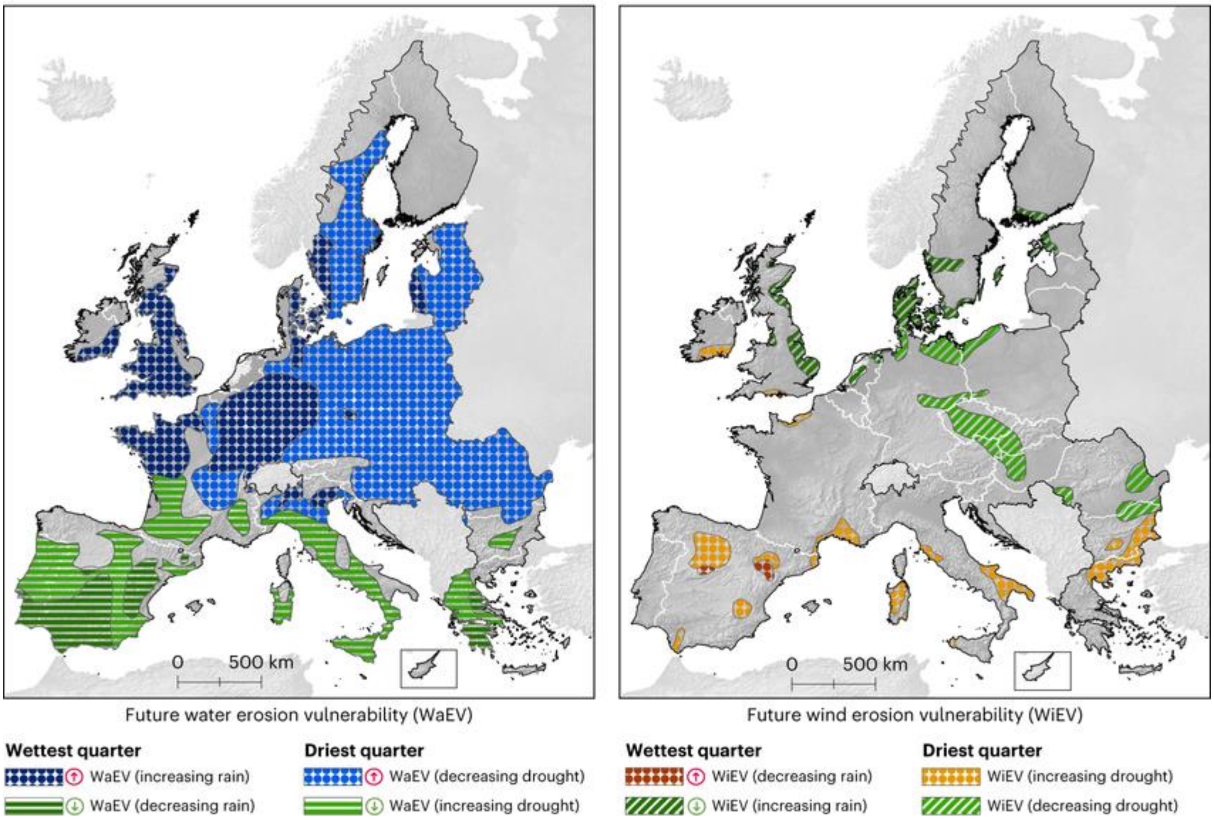

Figure 13: Projected changes in water (left) and wind (right) erosion vulnerability between 1970–2000 and 2061–2080 under the SSP2–4.5 scenario (Borrelli et al., 2022)

5.5.3 Sea level rise

Sea-level rise, driven primarily by the thermal expansion of seawater and the melting of glaciers and ice sheets, represents a significant and ongoing challenge. This process has fundamentally jeopardised coastal communities, ecosystems, and economies by increasing the risk of flooding, erosion, and storm surges.

Figure 14 illustrates historical trends at selected tide gauge stations since 1970 and projected changes in relative sea levels across Europe under the SSP5-8.5 scenario. By the end of the 21st century, the northern Adriatic Sea is projected to experience an increase in sea level of

0.5 to 0.6 meters. In comparison, the southern part is expected to experience a rise of 0.7 to 0.8 meters.

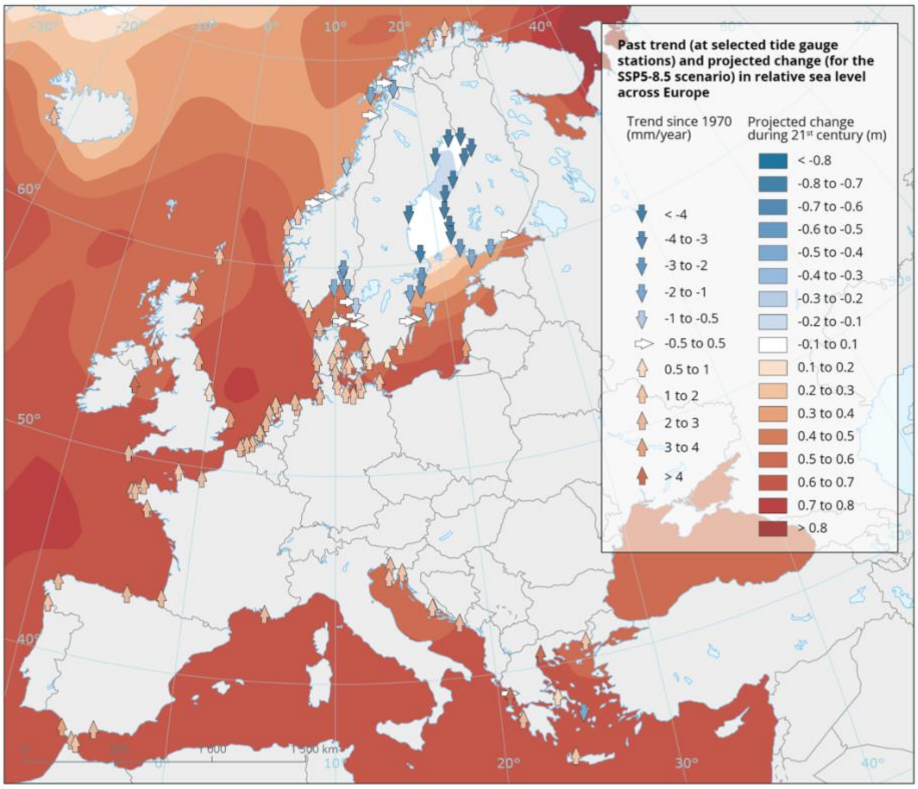

Figure 14: Trends in relative sea level at European tide gauge stations since 1970, overlaid with model projections for 2081-2100 under the SSP5-8.5 scenario[13]

5.6 Drought

Droughts are prolonged periods of abnormally low rainfall, leading to a water shortage. It is characterised by an extended period of below-average rainfall or snowfall, leading to reduced water availability in reservoirs, rivers, and groundwater. The effects of droughts can range from agriculture and water supply to energy production. In agriculture, droughts can result in crop failures and livestock losses, thus leading to a food shortage and economic

[13] European Environment Agency: https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/coastal/coastal-relative-sea-level

distress for farmers. Water supplies for domestic and industrial use may become reduced, leading to restrictions and the need for conservation measures. Energy production could be significantly reduced, especially hydropower. Ecosystems and wildlife suffer when the sources of water dry up, and there is an increase in the danger of wildfires.

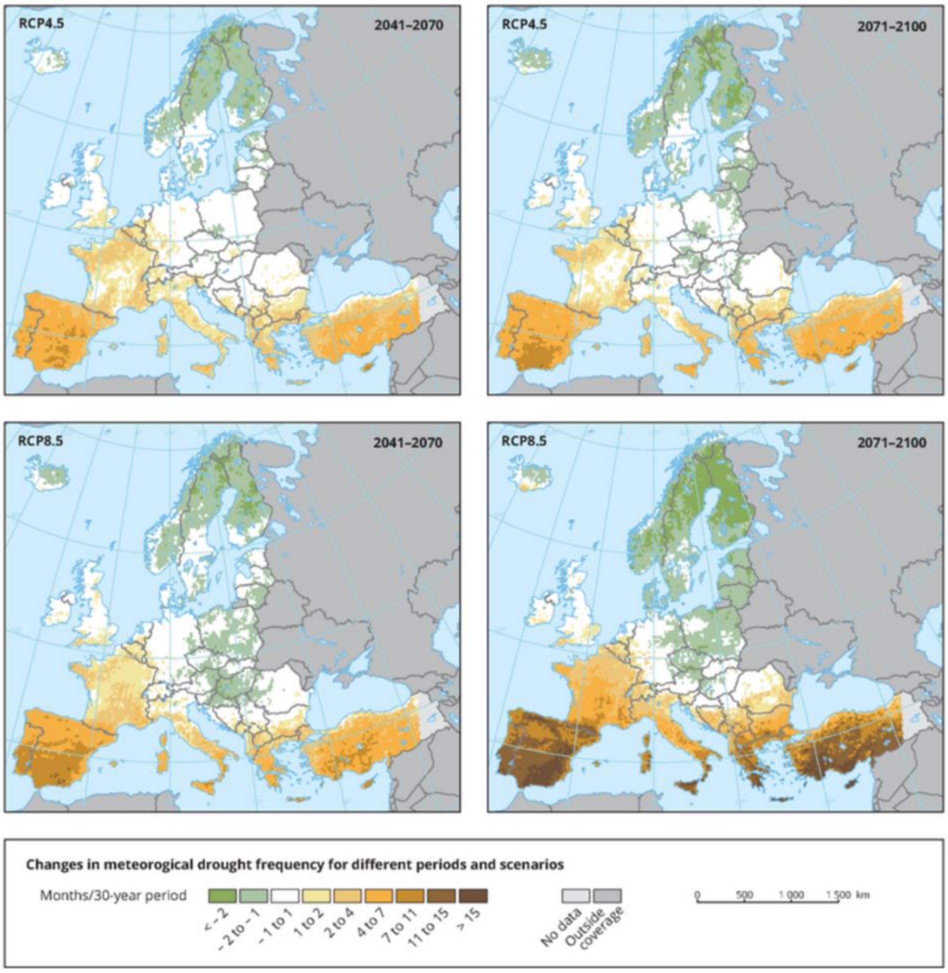

Figure 15: Cumulative changes in meteorological drought frequency for 2041-2070 (left) and 2071-2100 (right) under RCP4.5 (top) and RCP8.5 (bottom) emissions scenarios[14]

[14] European Environment Agency: https://www.eea.europa.eu/data-and-maps/figures/changes-in-meteorological-drought-frequency

Under the RCP4.5 scenario for the period 2041-2070, parts of Apulia and the Gulf of Venice and its hinterland are projected to experience an increase in dry months ranging from 1 to 4 months within a 30-year period. In contrast, parts of the Kvarner Gulf and southern Dalmatia are expected to increase by 1 to 2 months. For the same period, the RCP8.5 scenario predicts a reduction of dry months by 1 to 2 in the southwestern areas of Istria, parts of Lika-Senj and Karlovac Counties. Meanwhile, most of the Italian Adriatic coast from the Emilia-Romagna region is projected to experience an increase in the frequency of meteorological droughts, with a gradient intensifying towards the south.

Under the milder RCP4.5 scenario, an increase of 1 to 2 months within a 30-year period is expected over 2041-2070 in parts of Emilia-Romagna. In contrast, the southern half of the Adriatic coast will experience an increase of 2 to 4 months. However, under the more intense RCP8.5 scenario, during the period 2071-2100, the entire INTERREG IT-CRO region will see an increase in the number of dry days, except the Karlovac County area.

5.7 Wildfires

Wildfires are uncontrolled fires that occur in natural areas such as forests, grasslands, or prairies. Often powered by wind, dry vegetation, and heat, they are known to spread fast and cause huge damage to ecosystems, wildlife, and human communities. Intensifying factors include drought, lightning strikes, and human activities. Their effect can be devastating, such as loss of life, property destruction, and long-term destruction of the environment.

The hotter and drier it is, the more frequent and intense wildfires will be, posing a threat to ecosystems, communities, and air quality. Wildfires destroy homes, habitats, and natural resources, leading to economic losses through the destruction of both property and infrastructure, health complications due to smoke inhalation, and long-term environmental degradation.

Figure 16 depicts the Fire Weather Index (FWI), a numerical rating used to estimate fire risk in forested and grassland areas. The index considers wind speed, temperature, humidity, and precipitation factors. It includes data from the period 1981-2010 and projected changes under a 2 °C global warming scenario and the RCP8.5 scenario for 2071-2100.

In most regions, except for northern and central Dalmatia, Apulia, and Marche, the FWI increase is expected to lie between 0 and 2 in the case of the 2 °C global warming scenario. More significant changes are foreseen under the RCP8.5 scenario in the 2071-2100 period: an increase of 4 to 8 for most regions and 8 to 10 in northern Dalmatia, while in the case of Emilia Romagna and coastal parts of Apulia, an increase in FWI of 2 to 4 is foreseen.

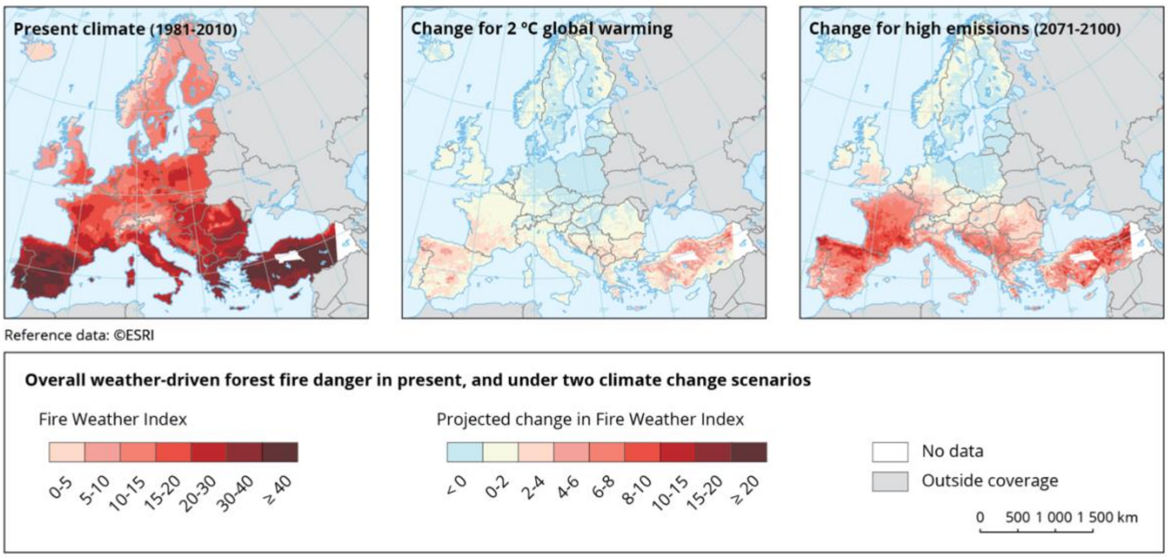

Figure 16: Fire Weather Index (FWI) for 1981-2010 (left), projected changes under a 2 °C global warming scenario (middle), and under RCP8.5 for 2071-2100 (right)[15]

[15] European Environment Agency: https://www.eea.europa.eu/en/analysis/indicators/forest-fires-in-europe

6 Conclusion

The purpose of the Risk database is to provide an overview of climate-related hazards in the INTERREG IT-CRO region. Considering the region's exposure and vulnerability, this document consolidates and defines the most relevant regional climate- related hazards in one place.

Furthermore, the accompanying Excel file provides a detailed overview of potential impacts on different sectors and aspects of life, facilitating informed decision-making and adaptation strategies. Including megatrend analysis and scenario projections for broader European contexts enhances our understanding of future trends and potential challenges in the INTERREG IT-CRO region.

Finally, recognising compound hazard events underscores the interconnected nature of these risks, emphasising the amplification and cascading effects that can result from their occurrence.

Overall, this risk database serves as a foundational resource and initiates further actions within the project, ensuring a strategic approach to addressing climate-related challenges in the region.

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