CLIMAAX
climate ready regions

Deliverable Phase 2 – Climate risk assessment

Extended multi-risks analysis for forecasting, monitoring, mitigation and adaptation strategies in Molise - CLIMoL

Italy, Molise

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Abbreviations and acronyms

Abbreviation / acronym	Description
CLIMol	Extended multi-risks analysis for forecasting, monitoring, mitigation and adaptation strategies in Molise (CLIMol)
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolboX
CRA	Climate Risk Assessment
ERA5	ECMWF Reanalysis 5th Generation Dataset
FWI	Fire Weather Index
WUI	Wildland Urban Interface
D.L.	Decreto legislativo
RCP	Representative Concentration Pathway
EURO-CORDEX	Coordinated Regional Climate Downscaling Experiment - European Domain
GCM	General Circulation Model
CAE	CAE S.p.A
RCM	Regional Climate Model

Executive summary

This document presents the results of **Phase 2 of the CLIMol Project**, carried out within the framework of the **CLIMAAX project** for the **Molise Region, Italy**. The report addresses the critical need to systematically assess potential climate-related risks, primarily arising from the vulnerability of the territory and its adaptive capacity, in order to support informed decision-making processes and strengthen regional resilience to climate change.

The document provides an in-depth analysis of the main climate hazards affecting the Molise Region, namely **intense rainfall events (from 3 to 24 hours, including both short-duration convective and long-duration persistent events)** and **wildfires**, through the use of high-spatial-resolution datasets.

During this phase, two methodologies were applied. The first methodology was provided by the **CLIMAAX project** and relied on two calculation algorithms developed in the Python environment. The second methodology was developed at the **regional meso-climatic scale**.

The objective of this phase of the project was to analyse data from the official regional meteorological monitoring networks concerning accumulated precipitation (the sum of liquid and solid precipitation) over periods ranging from 3 to 24 hours, as well as the **Canadian Fire Weather Index (FWI)**, used as a predictive tool for assessing wildfire behaviour.

This dual methodological approach enables a more detailed characterization of each risk, thereby supporting improved territorial analyses and the identification of more effective mitigation strategies.

Regarding intense precipitation, as anticipated, the first methodology used two different data sources: the dataset derived from meteorological stations distributed throughout the region (**Regional Monitoring Network dataset**) and a dataset obtained through the downscaling of the **ERA5 model**, providing an approximate spatial resolution of 3 km and subsequently reprojected (**CHAPTER/RISICO dataset**). The CLIMAAX algorithm was applied to both datasets.

The second methodology relied on the regional rainfall dataset, which was interpolated using **multiple regression statistics** and projected across the entire regional territory, together with more detailed vulnerability-related data.

A dual methodological approach was also adopted for the FWI analysis. In the first method, following the recommendations of the CLIMAAX project, a regional-scale FWI simulation was carried out using the **CHAPTER/RISICO dataset** and the **WRF (Weather Research and Forecasting) meteorological model**. The downscaling process allowed for a more detailed representation of the variables of interest. The simulation covered the period **1981-2022**. In this case as well, the model provided through the CLIMAAX Toolbox was used to perform the same analyses previously conducted during Phase 1.

In the second method, hazard and risk analyses were conducted using methodologies and datasets provided by the Regional Administration. The results of these applications, together with a critical assessment, are presented in the following chapters.

Overall, the main findings can be summarized as follows:

Wildfire Sector

Future climate projections confirm the findings that emerged during the previous phase, namely a general deterioration of meteorological and climatic conditions that may lead to very high FWI values and an increasingly frequent occurrence of extreme wildfire events. The second methodology made it possible to characterize, from a spatial and altitudinal perspective, the areas most exposed to this risk.

Extreme and Heavy Rainfall Sector

The first methodology highlights a situation that remains only partially defined, as future projections are not homogeneous and strongly depend on the initial input data used in the climatological calculations. Applying the algorithm to two different datasets (simulated model outputs and observed data) produced divergent results. The model applied to the CHAPTER/RISICO dataset suggests future conditions characterized by more conservative rainfall thresholds for the different return periods compared to those obtained from the Regional Monitoring Network dataset.

The second methodology, on the other hand, provides a more consistent picture for both 3-hour and 24-hour precipitation events, clearly identifying the areas most exposed to the associated risks.

A detailed cross-analysis of the risk maps derived from the second methodology was subsequently performed in order to assess risk priorities and identify the macro-areas where dedicated mitigation measures should be planned and implemented, considering different spatial and temporal scales.

1 Introduction

1.1 Background

The **Molise Region** is located in south-central Italy, bordered by the regions of **Abruzzo, Lazio, Campania, and Apulia (Puglia)**. It has a population of approximately **289,224 inhabitants**, most of whom are concentrated in the main urban centers of **Isernia, Campobasso, and Termoli**, within a territory characterized by widespread hilly and mountainous landscapes. The topography becomes gentler in the coastal areas near the Adriatic Sea.

Molise consists of approximately **55.3% mountainous areas** and **44.7% hilly terrain**. The climate is generally **semi-continental**, with typically cold and snowy winters and hot, humid summers. However, in recent years, winters have become milder and less snowy, while summers have become drier.

The region's rivers are generally characterized by a **torrential regime**, with flows that decrease significantly, and in some cases almost completely, during the summer season.

Several protected natural areas are located within the region, including the **National Park of Abruzzo, Lazio and Molise** and the **Matese National Park**, both characterized by highly biodiverse forest ecosystems.

Molise is also home to two **UNESCO Man and the Biosphere (MAB) Reserves**: **Collemeluccio** and **Montedimezzo**.

Social Sector

The distribution of the population across the territory reflects its geomorphological characteristics. Major urban centers are located in flatter and more gently sloping areas; however, population density remains relatively high in rural areas as well.

A significant migration trend continues to drive younger generations toward larger cities, resulting in two major consequences: the abandonment of rural areas, which leads to an expansion of forested land, and the progressive ageing of the population remaining in these areas.

Population ageing is not only a consequence of the migration of younger generations but is also driven by declining birth rates. Together, these factors are altering the region’s social and economic balance, with impacts affecting the entire Molise Region.

Economic Sector

The economy of the **Molise Region** is primarily based on **agriculture, tourism, and small-scale industry**. These sectors, particularly the first and the third, are highly vulnerable to the impacts of climate change, as changes affecting the territory directly influence productive activities and economic performance.

Tourism, being largely concentrated in the summer season and along coastal areas, is generally less exposed to these effects, except during peak holiday periods when adverse weather and climate conditions may significantly impact tourist activities.

Other smaller yet still important economic sectors include **livestock farming** and **high-quality local craftsmanship**, such as **leather processing** and the **textile industry**.

Infrastructure and Built Environment Sector

The **Molise Region** is connected to the rest of the country primarily through **major state highways**, as no motorways directly connect **Campobasso** or **Termoli** with the other regional capitals. The layout of this transport network is necessarily constrained by the region's geomorphological characteristics: river valleys represent the main transportation corridors and communication routes, but they are also among the areas most vulnerable to extreme events such as intense rainfall and its associated impacts.

1.2 Main objectives of the project

As stated in the Molise Regional Adaptation Strategy, the primary objective of the Regional Administration is to improve climate risk assessment by adopting state-of-the-art scientific methods and incorporating the latest research findings. The use of the CLIMAAX methodological framework contributes to making this objective operational. The multi-risk approach introduced by the CLIMol Project represents a significant advancement, enhancing the level of detail of vulnerability analyses, updating risk maps, and integrating future scenario modelling into policy development. This process has also enabled the development and refinement of a regional methodology for risk assessment, building upon and improving previous approaches.

These analytical results are intended to support local authorities and communities in the development of evidence-based adaptation plans and in the implementation of targeted and appropriate actions. Enhancing response capacity and strengthening regional resilience require the adoption of structured analytical tools at the local level, enabling the establishment of continuous climate risk monitoring systems. These improvements are particularly relevant for the effective management of wildfire and hydrogeological risks.

During **Phase 1** of the project, future projections (2041-2070) of the impacts of climate change on **intense rainfall events (3-hour and 24-hour durations)** and **wildfires** were analysed using the dataset provided by **Copernicus**. The results highlighted a high degree of regional sensitivity to climate change and its associated impacts.

Phase 2 of the CLIMol Project aims to analyse higher spatial-resolution datasets through both methodologies employed, thereby providing a more detailed understanding of the future impacts of climate change. The objectives of this phase are:

- To identify the areas most vulnerable to the risks analysed, understand the underlying vulnerability factors, and assess how these risks threaten the territory and population.
- To provide an initial framework for identifying areas requiring protection based on their exposure to multiple risks.
- To evaluate and analyse the regional meteorological data collection system.

In summary, the main expected benefits of the project include a comprehensive assessment of the risks associated with **intense rainfall events** and **wildfires**, achieved through the application of both standardized and innovative methodologies.

1.3 Project team

Following the stakeholder involved in the project:

Table 1-1 – Project Team

Name	Description	Role
Regione Molise	Public authority with multiple responsibilities, including the management of the forestry sector and civil protection activities.	Project recipient and coordinator. Main point of contact with European institutions and the CLIMAAX coordinators. Responsible for stakeholder engagement activities. Responsible for project communication and dissemination activities. Provider of part of the data used for the analyses.
Beta 80	Company specializes in big data management	Provider of highly specialized technical experts in data management and processing for the execution of project algorithms.
D.R.E.Am Italia	A forestry cooperative specialized in environmental engineering and wildland fire prevention and management.	Organization providing technical expertise in wildland fire management and meteorology for civil protection operations and risk management.

1.4 Outline of the document's structure

This report is organized as follows. The **first section (Chapter 1)** introduces the second phase of the **CLIMol Project**, revisiting and building upon key aspects presented during the previous phase.

The **second section**, which constitutes the core of the project, describes the materials, methodologies, and results achieved during the implementation phase. **Chapter 2** is divided into several subsections, each addressing the two risks analysed within the CLIMol Project in parallel, namely **wildfires** and **intense rainfall events**.

The **third section (Chapter 3)** presents the concluding part of the report, providing a concise summary of the main findings together with a discussion of their significance and validity.

2 Climate risk assessment – phase 2

The **scoping phase** is necessary to define the subsequent steps following Phase 1. After the execution, during Phase 1, of the algorithm provided by the **CLIMAAX project** through its dedicated Toolbox, it is now necessary, before planning practical actions for the mitigation of the identified risks, to validate the results obtained and adapt them to local conditions through the use of higher-spatial-resolution datasets within the two methodologies applied.

The objective is to improve the reliability and applicability of the analyses by integrating detailed local-scale information, thereby ensuring that the risk assessments accurately reflect the specific environmental, geographical, and socio-economic characteristics of the Molise Region.

This approach makes it possible to refine the understanding of the identified hazards and vulnerabilities and provides a stronger scientific basis for the design and implementation of targeted risk mitigation and climate adaptation measures.

2.1 Scoping

The second deliverable of the CLIMol Project is developed within a framework that remains largely unchanged from that of the first phase. The primary objective continues to be the identification and quantification of climate-related risks affecting the regional territory through the use of higher spatial-resolution datasets.
The implementation of this second phase encountered several challenges related to the availability of locally sourced data. In particular, the regional meteorological monitoring network has been progressively expanded since the 1990s, resulting in certain limitations for climate risk assessment. These limitations can be summarized as follows:

1. **The temporal coverage of the available datasets is insufficient to ensure full statistical robustness**, and the various meteorological stations were installed at different times, leading to inconsistencies in the length of observational records.
2. **The spatial coverage of the monitoring network does not yet extend across the entire regional territory**, as the deployment of additional meteorological stations is still ongoing.

2.1.1 Objectives

The primary objective of the Climate Risk Assessment (CRA) within the second phase of the CLIMol Project is consistent with that pursued during Phase 1, namely to provide a clear understanding of the climate hazards relevant to the Molise Region, based on two different datasets and focused on two key hazards: **intense precipitation** and **wildfires**.

To achieve this objective, two distinct methodologies have been adopted. The first follows the methodology and tools provided by the **CLIMAAX Climate Risk Assessment framework**, with the aim of delivering an operational tool to support policy-making and management processes for multi-risk mitigation. The second methodology has been developed at the regional level and follows a substantially different approach.

More specifically, the CLIMol Project seeks, on the one hand, to produce a series of maps, including risk maps, that will serve as the basis for **Phase 3** of the project, supporting the design and implementation of **small-scale, targeted, and efficient interventions**. On the other hand, it aims to identify additional effective measures capable of mitigating the risks under investigation.

The focus on interventions that are small-scale, targeted, and efficient stems from the urgent need to safeguard the Region's population, cultural heritage, and natural assets, as well as from the limited resources available for the comprehensive management of the entire regional territory. Furthermore, among the project's objectives is the need to plan future maintenance activities, ensuring that the efforts and resources invested during the project implementation phase generate benefits over the medium and long term.

The main limitations encountered during this phase may be summarized as follows:

- The availability of datasets that are sufficiently extensive, both spatially and temporally, to ensure statistical robustness and practical applicability.
- The involvement of additional stakeholders, particularly local communities and the general population.
- The applicability and reliability of the datasets used as the basis for mapping future intervention priorities.

2.1.2 Context

The regional Civil Protection System is governed by **Legislative Decree No. 1 of 2 January 2018**, which defines the responsibilities and duties of both the central Government and the individual Regions. However, this legislation does not establish specific social and territorial planning procedures for addressing civil protection issues related to climate risks. Furthermore, the Regions are fully responsible for wildfire prevention, forecasting, and active fire suppression activities. They may delegate these responsibilities to their Civil Protection or Forestry departments. In Molise, wildfire management falls under the jurisdiction of the Civil Protection Service, particularly with regard to forecasting and active fire suppression activities.

The **CLIMol Project** operates within a regional context in which the Civil Protection Service oversees both wildfire management and intense rainfall events. However, while a dedicated planning and management document for wildfires exists, based on national legislation and guidelines (the *Molise Region Wildfire Operational Plan*), the legal framework concerning intense rainfall events focuses exclusively on forecasting and monitoring activities and does not address the operational management of emergencies (*Molise Regional Multi-Risk System*, Cardillo, 2018).

This situation, combined with the region's limited resources, has resulted in the absence of comprehensive risk planning and integrated multi-risk strategies (Figure 2.1).

The current political and institutional framework tends to promote an emergency-oriented response to environmental crises, emphasizing prevention primarily through the training of operators and emergency personnel at different levels.

A widespread belief still persists that environmental emergencies should be addressed mainly through emergency response interventions rather than preventive measures. However, this approach is not considered the most effective pathway toward comprehensive multi-risk mitigation. Although the training of operators has recently gained greater importance, representing a positive step forward, it remains insufficient on its own. A preventive approach based on robust data and sound scientific analyses, translated into concrete territorial management actions, appears to be the most effective solution. Thanks to the CLIMol Project, the Molise Region now has the opportunity to adopt such an approach.

The sectors most vulnerable to extreme weather and climate events are those that support the region's rural economy, particularly agriculture and livestock farming, as well as rural communities themselves. Nevertheless, it is important to emphasize that almost the entire population is exposed to environmental risks, especially those associated with heavy rainfall events, due to the region's topographical characteristics.

The CLIMol Project aims to coordinate the management of multiple risks and to foster a proactive approach to emergency management, supported by the essential involvement of local communities and a wide range of stakeholders, including professional associations and local authorities.

2.1.3 Participation and risk ownership

The range of stakeholders involved is broad and diverse. The following groups have been identified as the main stakeholders for the CLIMol Project:

- Trade associations
- Regional authorities and agencies
- Educational institutions
- Public institutions
- Media organizations
- Non-Governmental Organizations (NGOs)
- Research and training institutions (Academia)
- Healthcare sector organizations

2.1.4 Application of principles

The fundamental principle on which prevention measures should be based, particularly those related to environmental risks, is that all stakeholders within a territory should be actively involved. A territory is, by its very nature, a shared space experienced daily by its inhabitants; however, only a limited number of people are fully aware of its characteristics, vulnerabilities, and value.

Within this context, one of the objectives of the CLIMol Project is to develop, among other initiatives, an awareness-raising and communication campaign aimed at promoting the importance of the sustainable use and active management of the territory. To achieve this goal, it has been necessary to engage a broad range of stakeholders, including schools, environmental volunteer associations, and professional and trade organizations.

A second pillar of environmental risk prevention is risk assessment and the effectiveness of the resulting actions. This aspect, which will be explored in greater detail during Phase 3, is based on the principle that all stakeholders involved must agree upon, share, and implement the proposed actions, ensuring maximum transparency throughout the process.

Indeed, it is believed that purely top-down interventions are often economically inefficient and, in many cases, may even prove counterproductive. Conversely, a participatory approach that combines scientific evidence, local knowledge, and stakeholder engagement is considered essential for the successful mitigation of climate-related risks and for the long-term resilience of the territory.

2.1.5 Stakeholder engagement

In line with the objectives of Deliverable 2, this section complements the systematic stakeholder mapping process aimed at comprehensively identifying all institutional and private actors who will be involved, in various capacities, in the subsequent consultation phases. This stakeholder inventory is intended to support the planning of future meetings for the presentation of project results and to facilitate the co-design of adaptation strategies with key territorial stakeholders.

It should be noted, however, that the direct involvement of these stakeholders had not been formally initiated by the June 2026 deadline. This strategic and scheduling decision was driven by the need to allocate the available resources to an extensive and high-priority research effort.

More specifically, activities focused on the analytical study of the regional monitoring network and the complex processing of environmental data. The work concentrated on the reconstruction of historical precipitation series through the collection, validation, and normalization of raw data recorded by the meteorological stations distributed throughout the regional territory.

The statistical analysis of these historical records made it possible to identify long-term precipitation trends, assess changes in rainfall regimes, and evaluate the frequency of extreme weather and climate events at the local scale. This empirical dataset required a considerable methodological effort in order to perform a rigorous comparison with the predictive outputs and risk models generated by the algorithms of the European **CLIMAAX (Climate Risk and Vulnerability Assessment)** framework.

This calibration and scientific validation phase proved essential for verifying the consistency between algorithm-based estimates and observed ground data. It therefore constituted a necessary technical prerequisite for the subsequent sharing and discussion of resilience policies with stakeholders and local communities.

Ultimately, this process was designed to ensure that future adaptation and risk mitigation strategies are founded on robust scientific evidence, locally validated information, and a thorough understanding of the regional climate system, thereby strengthening the effectiveness and credibility of the measures to be developed in the following phases of the CLIMol Project.

Table 2-1 List of main stakeholders

Category	Designation	Contract
Water, energy, and transportation network utilities and infrastructure managers	AZIENDA SPECIALE MOLISE ACQUE	protocollo@pec.moliseacque.com
Water, energy, and transportation network utilities and infrastructure managers	GRIM	grimolise@pec.it
Water, energy, and transportation network utilities and infrastructure managers	ENEL GREEN POWER	enelgreenpoweritalia@pec.enel.it
Water, energy, and transportation network utilities and infrastructure managers	ANAS DIREZIONE REGIONALE MOLISE	anas.molise@postacert.stradeanas.it

Water, energy, and transportation network utilities and infrastructure managers	PROVINCIA DI ISERNIA - SETTORE AMBIENTE	protocollo@pec.provincia.isernia.it
Water, energy, and transportation network utilities and infrastructure managers	PROVINCIA DI ISERNIA - SETTORE VIABILITÀ	protocollo@pec.provincia.isernia.it
Water, energy, and transportation network utilities and infrastructure managers	PROVINCIA DI CAMPOBASSO - SETTORE AMBIENTE	provincia.campobasso@legalmail.it
Water, energy, and transportation network utilities and infrastructure managers	PROVINCIA DI CAMPOBASSO - SETTORE VIABILITÀ	provincia.campobasso@legalmail.it
Schools, Academic and researchers' institutions	UFFICIO SCOLASTICO REGIONALE	drmo@postacert.istruzione.it
Schools, Academic and researchers' institutions	UNIVERSITÀ DEGLI STUDI DEL MOLISE	amministrazione.cert@unimol.it
Schools, Academic and researchers' institutions	CIMA FOUNDATION	cimafoundation@pec.it
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Regional services with direct competence on agriculture, environment, territory and energy	SERVIZIO TUTELA E VALORIZZAZIONE DELLA MONTAGNA E DELLE FORESTE, BIODIVERSITA' AGRICOLA E GESTIONE FITO-SANITARIA	regionemolise@cert.regione.molise.it
Regional services with direct competence on agriculture, environment, territory and energy	SERVIZIO SISTEMI INFORMATIVI E TRANSIZIONE AL DIGITALE	regionemolise@cert.regione.molise.it
Regional services with direct competence on agriculture, environment, territory and energy	SERVIZIO PIANIFICAZIONE E GESTIONE TERRITORIALE E PAESAGGISTICA - TECNICO DELLE COSTRUZIONI	regionemolise@cert.regione.molise.it
Regional services with direct competence on agriculture, environment, territory and energy	SERVIZIO GEOLOGICO	regionemolise@cert.regione.molise.it
Regional services with direct competence on agriculture, environment, territory and energy	SERVIZIO INFRASTRUTTURE E LAVORI PUBBLICI	regionemolise@cert.regione.molise.it
Regional services with direct competence on agriculture, environment, territory and energy	SERVIZIO MOBILITA'	regionemolise@cert.regione.molise.it
Regional services with direct competence on agriculture, environment, territory and energy	SERVIZIO DIFESA DEL SUOLO, DEMANIO, OPERE IDRAULICHE E MARITTIME - IDRICO INTEGRATO	regionemolise@cert.regione.molise.it
Regional public agencies with direct competence on agriculture, environment and territory	ARPA MOLISE	arpamolise@legalmail.it [1]

Regional public agencies with direct competence on agriculture, environment and territory	ARSARP	arsarp@legalmail.it
Civil protection and emergency services	SERVIZIO DI PROTEZIONE CIVILE	regionemolise@cert.regione.molise.it
Civil protection and emergency services	SERVIZIO PER LA GESTIONE DELLE EMERGENZE REGIONALI 112	regionemolise@cert.regione.molise.it
Civil protection and emergency services	DIPARTIMENTO NAZIONALE DI PROTEZIONE CIVILE	protezionecivile@pec.governo.it
Civil protection and emergency services	PREFETTURA DI CAMPOBASSO	protocollo.prefcb@pec.interno.it
Civil protection and emergency services	PREFETTURA DI ISERNIA	protocollo.prefis@pec.interno.it
Civil protection and emergency services	VIGILI DEL FUOCO - COMANDO CAMPOBASSO	com.campobasso@cert.vigilfuoco.it
Civil protection and emergency services	VIGILI DEL FUOCO - COMANDO ISERNIA	com.isernia@cert.vigilfuoco.it
Civil protection and emergency services	VIGILI DEL FUOCO - DIREZIONE CAMPOBASSO	dir.molise@cert.vigilfuoco.it
Civil protection and emergency services	CARABINIERI FORESTALE - GRUPPO CAMPOBASSO	fcb43304@pec.carabinieri.it
Civil protection and emergency services	CARABINIERI FORESTALE - GRUPPO ISERNIA	fis43319@pec.carabinieri.it
Civil protection and emergency services	CARABINIERI - REPARTO BIODIVERSITÀ ISERNIA	fis43349@pec.carabinieri.it
Business companies	ARPES SRL	arpes@pec.it
Business companies	TIM SPA	gare.palcentro2@pec.telecomitalia.it
Business companies	BETA 80 GROUP SPA	beta80spa@legalmail.it
Business companies	FASTWEB + VODAFONE SPA	telefoniamobile9@vodafone.pec.it

On **15 September 2026**, a stakeholder workshop was held involving the groups previously identified. To maximise participation, the event was organised in a hybrid format, allowing both in-person and remote attendance.

The workshop provided an important opportunity for discussion on the climate emergency affecting the Molise Region, with a particular focus on the increasing risks associated with **intense rainfall events** and **wildfires**. During the event, the preliminary results of the **CLIMol Project**, implemented within the framework of the European **CLIMAAX (Horizon Europe)** initiative, were presented.

The project adopts a **multi-risk approach**, integrating regional and European meteorological data with territorial vulnerability assessments in order to identify the areas most exposed to climate-related hazards and support the development of effective future prevention and adaptation strategies.

Further details regarding the event are provided in the annex:

CLIMAAX-CLIMOL_Workshop_Report_20260915 (https://doi.org/10.5281/zenodo.23213400)

The document summarizes the results and findings of the territorial workshop dedicated to climate emergency issues in the Molise Region. The report is structured around the following main thematic areas:

- **Introduction and Context**: Presentation of the CLIMol Project and its multi-risk assessment approach for climate risk prevention and management within the Molise Region.
- **Participation and Key Performance Indicators (KPIs)**: Analysis of attendance figures (54 participants overall, including both in-person and remote attendees), involvement of 14 stakeholder categories, and verification that the communication and engagement targets established by the project were successfully exceeded.
- **Questionnaire Results**: Summary of participants' views and priorities regarding nature-based solutions, future investments in the agricultural and forestry sectors, and environmental education initiatives in schools.

The workshop also contributed to strengthening stakeholder engagement and fostering dialogue among institutions, technical experts, economic actors, and local communities, thereby laying the groundwork for the co-design of future climate adaptation and risk mitigation measures within the subsequent phases of the CLIMol Project.

2.2 Risk Exploration

The Molise Region, as highlighted in the Phase 1 Deliverable, is exposed to a wide range of environmental hazards due to its geographical location and physiographic characteristics. The predominantly hilly and mountainous landscape frequently favours the occurrence of intense precipitation events of synoptic origin, often resulting in severe snowfall episodes and exceptionally strong wind gusts. The region's morphology intercepts the warm and moist air masses coming from the sea, which subsequently rise, cool, condense, and release precipitation over the territory. In recent years, this process has intensified, primarily as a consequence of

increasing sea surface temperatures, which enhance the energy available to convective and storm systems [Cardillo et al., 2024; Cardillo et al., 2017; Cardillo et al., 2009].

Conversely, one of the key drivers of sea warming is the increasing frequency and intensity of **heatwaves**. Changes have been observed not only in their occurrence patterns but also in their duration and seasonal distribution [Cardillo et al., 2024; Cardillo et al., 2017; Cardillo et al., 2009]. These phenomena generate significant thermal anomalies that directly affect the condition of both live and dead vegetation fuels, which in turn strongly influence wildfire behaviour. As a result, wildfires are becoming increasingly difficult to control and are more frequently exceeding suppression capacities, both for ground-based and aerial firefighting resources.

The Region is also exposed to other environmental hazards, including **heavy snowfall, floods, and severe windstorms**, which may originate from the synoptic-scale meteorological conditions described above. However, it is considered that the hazards with the greatest impacts on both the population and the territory, including agricultural systems, agroforestry landscapes, buildings, and infrastructure, are **intense precipitation events** and **wildfires**.

For this reason, these two hazards have been selected as the primary focus of the CLIMol Project and constitute the main subject of the risk assessment and adaptation analyses presented in this report. Their growing frequency and intensity, combined with the intrinsic vulnerability of the regional territory, make them the most significant climate-related threats to the Molise Region in both the short and long term.

2.2.2 Screen risks (selection of main hazards)

As specified in the previous chapter, the hazards considered in this deliverable are the same as those analysed during the previous phase (**Phase 1**). Therefore, the present document continues the assessment of hazards and the associated risks related to **3-hour and 24-hour intense rainfall events** and **wildfires**, using the two methodologies described above.

Wildfires

With regard to wildfire analysis, the **Molise Region** has adopted its own **Wildfire Operational Plan**, as required by national legislation. This document must be updated periodically through the incorporation of new statistics, analyses, and relevant data, including those produced within the framework of the present study.

Intense Rainfall

As regards extreme precipitation, the available data are equally concerning. According to the **Regional Civil Protection System** (https://protezionecivile.molise.it/rischio-meteo-idrogeologico/) in recent years, a rapid intensification of extreme precipitation events has been observed, with a growing tendency for annual rainfall totals to be concentrated within a limited number of particularly severe events.

Historical analyses covering the period **1951-2007** show that extreme events, sometimes occurring in combination with other meteorological phenomena such as heavy snowfall or strong winds, have had devastating impacts on the population, infrastructure, and agricultural systems. Notable examples include the exceptional events of **2003** and **2023**. More recently, another significant event occurred in **April 2026**.

As expected, the statistical analysis produced a map depicting the estimated spatial distribution of the **average annual maximum 24-hour precipitation**. This mapping clearly highlights that the areas most affected by intense rainfall are concentrated along the **Apennine belt** of the region, where the interaction between **orography** and **meteorological processes** plays a key role in precipitation dynamics.

The results confirm the strong influence of the mountainous terrain on rainfall patterns, as the uplift of moist air masses enhances condensation and precipitation processes, leading to higher rainfall accumulations and a greater likelihood of extreme events in these areas. Consequently, the Apennine sector of the Molise Region represents one of the territories most exposed to hydro-meteorological hazards associated with intense precipitation.

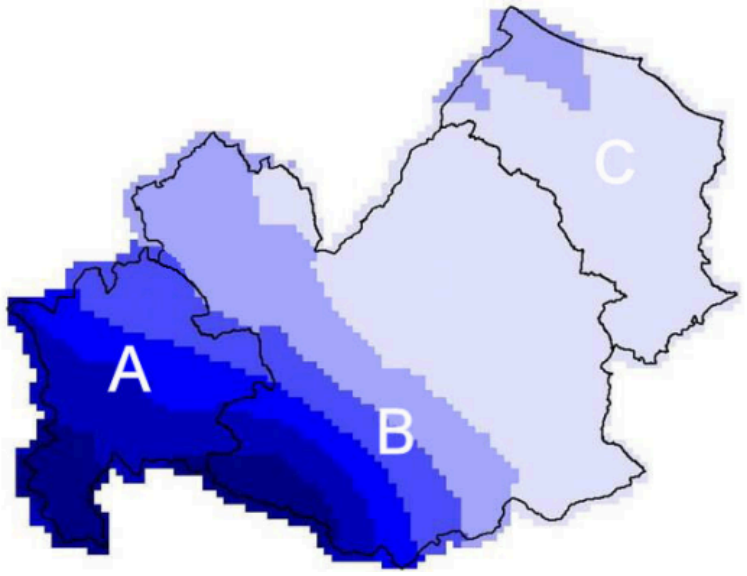


Figure 2-1 Qualitative Map of the Average Maximum 24-Hour Rainfall Accumulations

The purpose of the map is not to provide a quantitative estimate of rainfall across the different areas of the Molise Region, but rather to offer a qualitative representation of the areas most prone to this type of phenomenon.

Based on the analyses performed, it can be concluded that the hazards selected for the CLIMol Project continue to be among the most impactful climate-related threats affecting the region. Recent assessments further confirm the significant influence of both **intense precipitation events** and **wildfires** on the territory and its communities.

2.2.3 Choose Scenario

As in the previous phase, under the **first methodology** (application of the CLIMAAX algorithm), the selected scenario for the **Fire Weather Index (FWI)** was **RCP 2.6**, while for **extreme precipitation** the reference scenario was **RCP 8.5**, although additional analyses were also conducted using the **RCP 2.6** and **RCP 4.5** projections.

Under the **second methodology**, developed at the regional level, no emission scenarios were selected, as the analysis focused on current conditions. This approach provides a clear picture of how Molise is presently exposed to the risks under investigation.

Extreme Precipitation

The operational protocol adopted for intense rainfall follows the methodology applied to **Extreme Precipitation**.

In the first methodology implemented during Phase 2, annual rainfall maxima (for both 3-hour and 24-hour durations) were extracted through a downscaling process applied to the ERA5 dataset. Statistical distributions were then used to estimate expected maximum precipitation values and their corresponding return periods, differentiated by event duration and climate scenario. The analysis relied on EURO-CORDEX projections with a spatial resolution of 12 km, focusing on **frequency** and **magnitude** as the key indicators of hazard intensity. The reference dataset covers the historical period **1976-2005**, while future projections extend to **2041-2070**, integrating both Global Climate Models (GCMs) and Regional Climate Models (RCMs) under different Representative Concentration Pathways (RCPs).

In the second, regionally developed methodology, locally sourced data were interpolated to provide complete spatial coverage of the regional territory. Subsequently, vulnerability analyses of the built environment were performed, leading to the development of risk maps for intense rainfall events, considering both **3-hour** and **24-hour** storm scenarios.

Fire Weather Index (FWI)

For wildfire assessment, the selected workflow was based on the **Fire Weather Index (FWI)** methodology. This approach enables monitoring of the spatial and temporal evolution of the index and allows the analysis of seasonal variations in wildfire-related phenomena using data from the **Copernicus Climate Data Store**. The primary predictive scenario selected was **RCP 2.6**.

Empirical evidence collected by local experts, combined with the outputs of the FWI simulations, confirms that wildfires represent a particularly critical threat for the Molise Region. The associated risk affects not only ecosystem assets but also public safety, due to the progressive expansion of **Wildland-Urban Interface (WUI)** areas.

Unlike the first methodology, the regional approach did not perform an FWI analysis using local meteorological data. Instead, a broader assessment was carried out, taking into account the region's **topography**, the **composition and classification of available fuel types**, and the **vulnerability of both population and infrastructure**. This wider perspective allowed for a more comprehensive characterization of wildfire hazard and risk across the territory.

2.3 Regionalized Risk Analysis

For the analysis of **wildfire risk** and **extreme precipitation** in the Molise Region, higher-spatial-resolution datasets were used. As previously stated, these more detailed data do not originate directly from a regional dataset; rather, they were derived from the downscaling of the **ERA5 reanalysis dataset**, since locally available data are not sufficiently accurate in either spatial or temporal resolution.

A brief comparison between the models used during **Phase 1** and **Phase 2** is provided below:

- **Phase 1:** Dataset obtained from the **Copernicus Climate Data Store (CDS)**, based on six **EURO-CORDEX** models, with a temporal coverage of **1985-2004** and a spatial resolution of approximately **12.5 km**. The ensemble of models used reproduces historical conditions through simulations rather than direct observations.

- **Phase 2:** The source data originate from **ERA5** (Copernicus historical reanalysis data). A downscaling process was performed to a spatial resolution of approximately **2.2 km** (EUR-02 resolution), resulting in the creation of the **CHAPTER/RISICO dataset**. The temporal coverage is likewise **1985-2004**. Unlike the Phase 1 dataset, the source dataset is based on observational data.

It should therefore be emphasized that, within the first methodology applied during this second phase, the difference between Phases 1 and 2 of the **CLIMol Project** regarding the **FWI analysis** concerns exclusively the historical component, namely the baseline dataset used for hazard assessment. This is because future projections rely on the same climate projection models (**EURO-CORDEX**) in both Phase 1 and Phase 2.

In contrast, the results obtained for **extreme precipitation** showed more significant differences. The following chapters describe in detail the methodologies adopted and the results achieved.

2.3.1 Hazard #1 (Wildfire) - fine-tuning to local context. CLIMAAX algorithm approach

The data used to run the CLIMAAX algorithm for historical FWI analysis were derived from the **CHAPTER/RISICO dataset** (https://rdm.lab.lrz.de/records/0ppk7-znk14), which consists of an approximately **2.2 km resolution downscaling of ERA5** carried out using the **WRF (Weather Research and Forecasting) meteorological model**. This downscaling process provides more detailed information for the variables used to calculate the Fire Weather Index (FWI), namely **previous-day precipitation, wind speed, relative humidity, and air temperature**, covering the period **1981-2022** (the code used for this processing is available here).

The CHAPTER dataset was subsequently reprojected onto the **EURO-CORDEX grid** to ensure compatibility with the climate projection models. Unlike the historical simulations used in previous analyses, the historical period in this case relies on **locally observed data**, providing a more accurate baseline for hazard assessment.

Future projections, on the other hand, were based on **EURO-CORDEX climate models** available through the **Copernicus Climate Data Store (CDS)**, combined with **EFFIS vulnerability datasets** relating to vegetation, population distribution, and protected areas.

The analyses performed using the higher-spatial-resolution **CHAPTER/RISICO dataset** produced results that differed from those obtained during Phase 1 only about the **historical period**. As noted above, while the EURO-CORDEX models reconstruct historical FWI conditions through simulations based on atmospheric environmental variables, the dataset adopted in this phase relies on actual recorded observations.

Therefore, future simulations yield essentially the same results as those obtained in Phase 1, since they are based on the same predictive climate models. For this reason, an additional approach was adopted to investigate wildfire risk. This approach follows the methodology used in the preparation of the **Molise Regional Wildfire Operational Plan**, involving a different territorial analysis aimed at providing a complementary assessment of wildfire hazard and risk.

The methodology adopted and the results obtained through this alternative approach are described in the following chapters.

2.3.1.1 Hazard assessment

The wildfire hazard analysis is based on the processing of historical observed data, as specified in the previous chapter. Hazard is defined as the probability that an event will occur in a given location and is therefore independent of the factors that determine the *severity* of the event. For this reason, an analysis of the historical FWI was carried out following the methodology described previously.

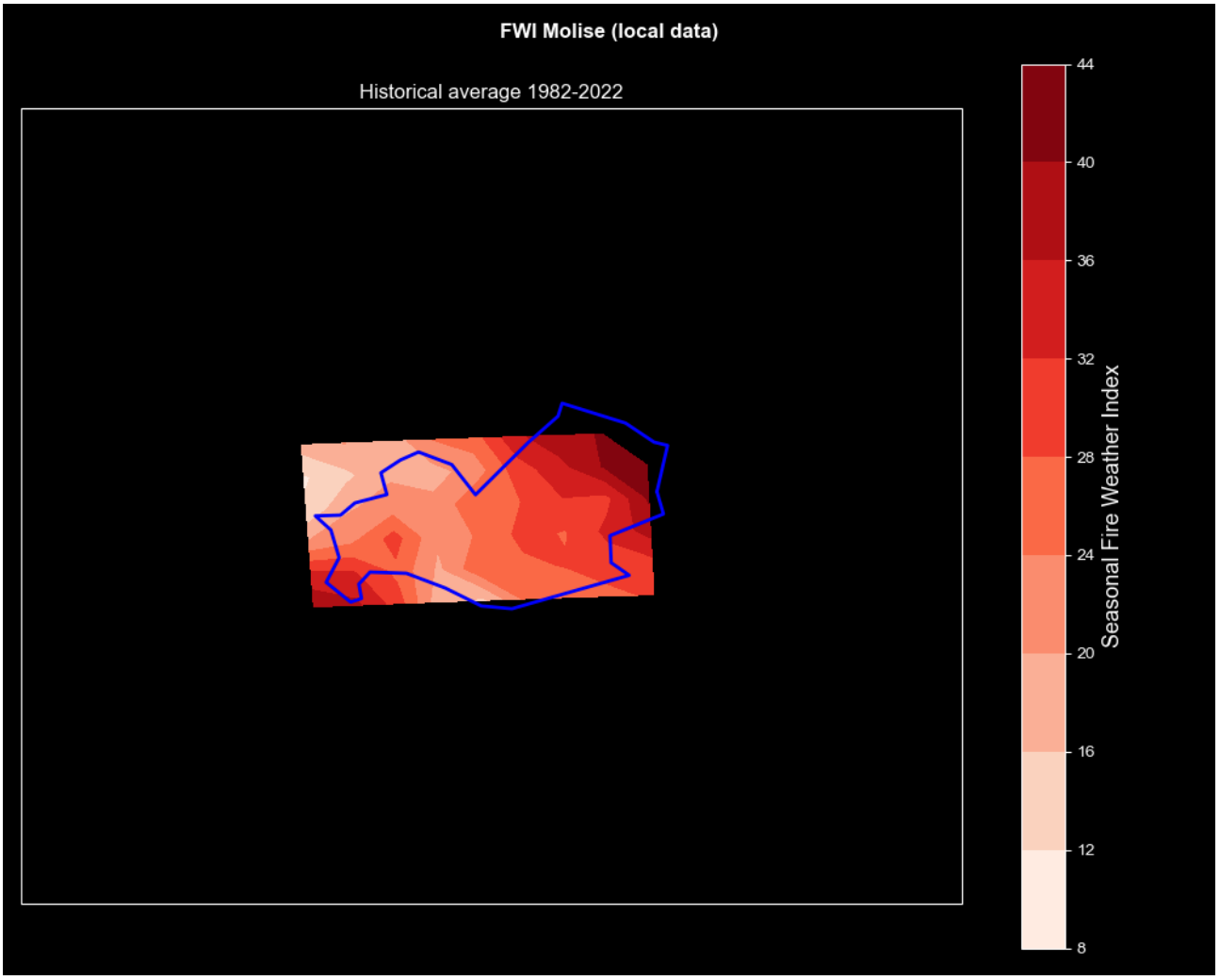


Figure 2-2 Historical average FWI derived from the analysis of the CHAPTER/RISICO dataset. The figure shows that, historically, the highest FWI values are concentrated in the coastal areas and along the Apennine belt of the Region.

The seasonal FWI index represents the average of the daily values recorded during the critical wildfire season, conventionally defined as the period between June and September. This parameter is calculated by dividing the sum of the daily index values by the duration of the season. Within the CLIMol Project, two specific five-year periods were analysed: 2046-2050 and 2051-2055. With regard to emission pathways, the study focused on the RCP2.6 scenario, while the RCP4.5 and RCP8.5 scenarios were considered as secondary variants. To ensure greater statistical robustness, the multi-model ensemble mean was adopted. Regarding the severity of the estimates, the system allows the selection of “best-case”, “worst-case”, or “medium” scenarios; for the present analysis, the latter was chosen.

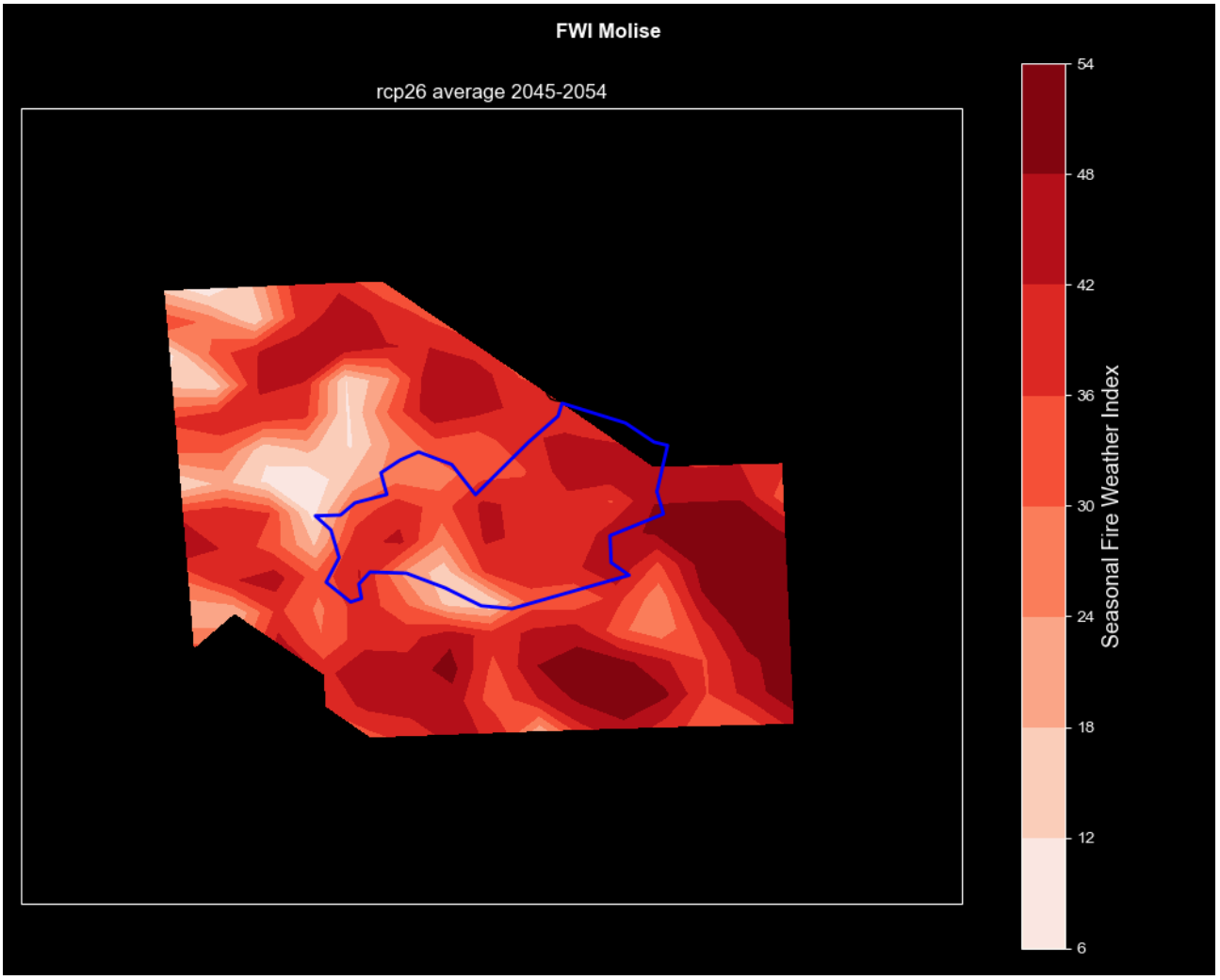


Figure 2-3 Seasonal average FWI based on the RCP2.6 projection, corresponding to the "medium-case" scenario.

Historical and projected maps make it possible to assess how climate change may affect the duration of wildfire-prone periods. Through the use of the "best-case", "medium-case", and "worst-case" scenarios, it is possible to identify the range of potential variations. The extremes of this range are obtained by incorporating the standard deviation (representing variability among models and between years) into the baseline value. Although the scenarios may appear substantially different due to the differing FWI estimates produced by the climate models, this spread does not compromise the accuracy of the analysis. On the contrary, it represents the range of possible future conditions in the Molise Region, encompassing both the most optimistic and the most extreme projections.

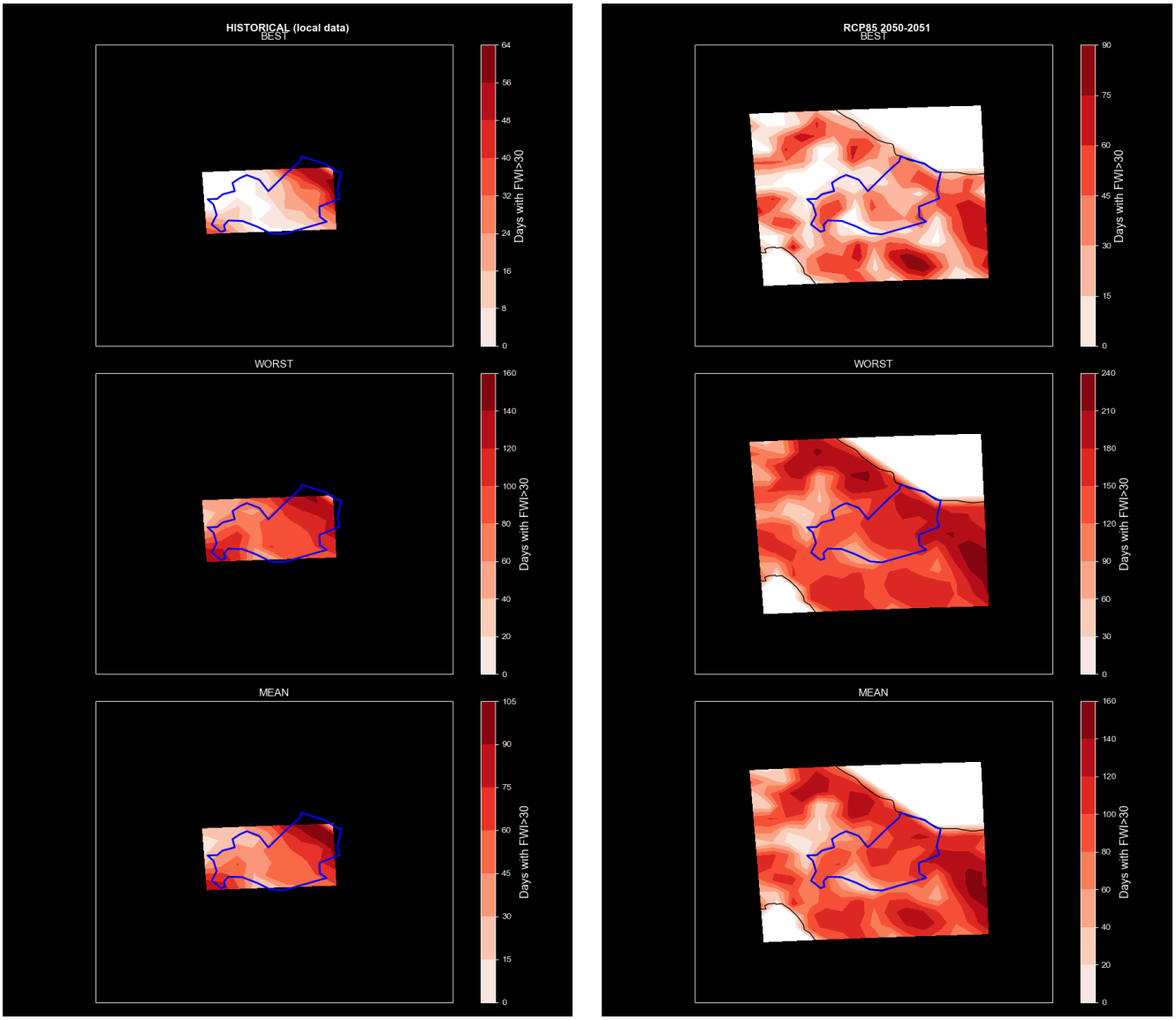


Figure 2-4 1 and 2: On the left, the historical simulation of the number of days with FWI greater than 30 under the "worst-case", "best-case" and "medium-case" scenarios. On the right, the future projection of the number of days with FWI > 30 under the same three projection scenarios.

The two maps shown above represent the historical projection (left) and the future projection (right) according to the three scenarios discussed previously. As mentioned earlier, while the historical projections differ from those obtained in Phase 1 of the project, due to the use of observed data collected within the study area, the future projections remain unchanged.

2.3.1.2 Risk assessment

The risk assessment, being based on future projections derived from the EURO-CORDEX models, remains unchanged with respect to the analysis carried out during Phase 1 of the project, as previously described.

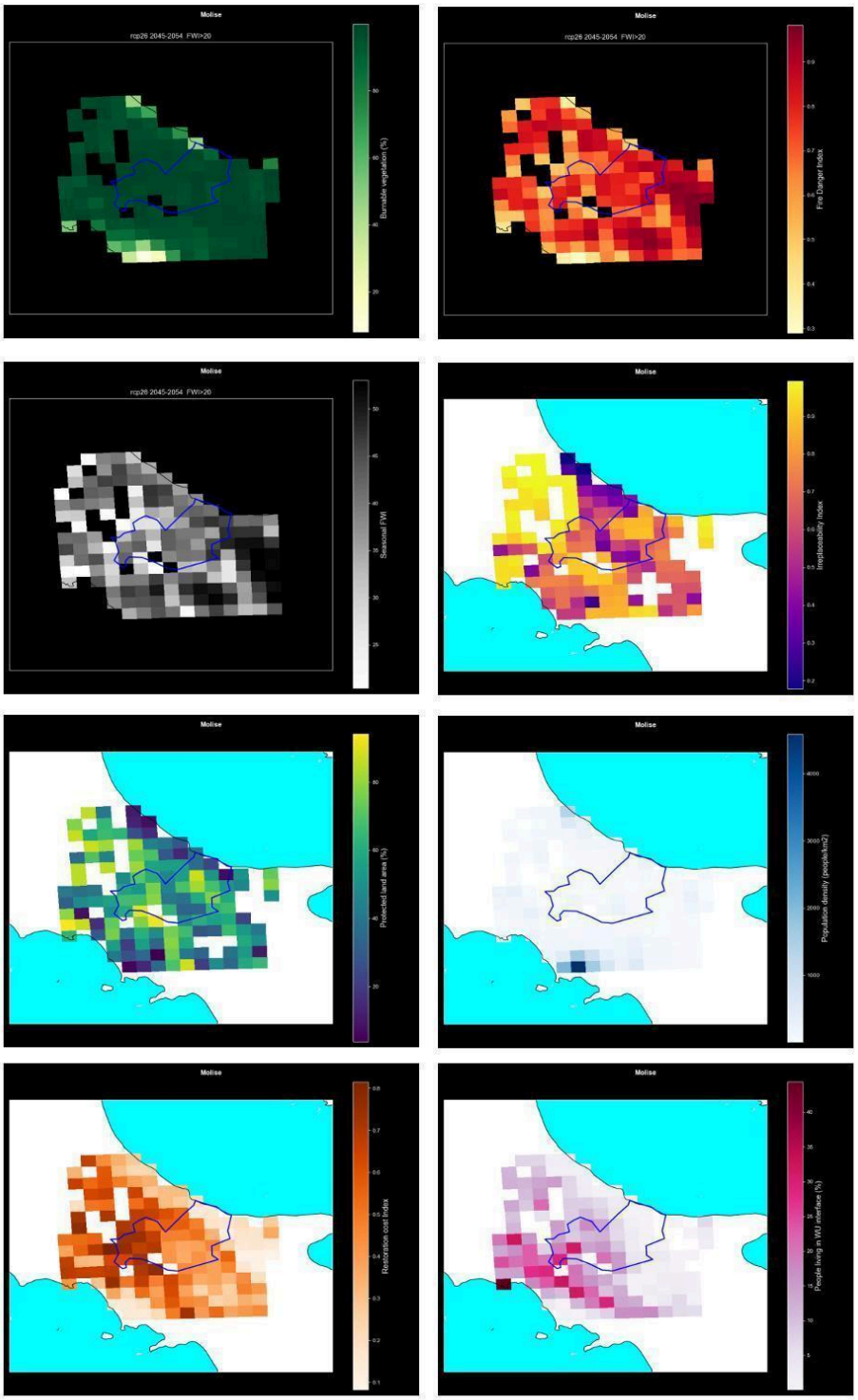


Figure 2-5 On the left from the top: burneable vegetation, seasonal FWI, protected areas, restoration cost. On the right from the top: danger index, irreplaceability index, population density, wildland-urban interface.

2.3.2 Hazard #2 (Heavy rainfall) - fine-tuning to local context. CLIMAAX algorithm approach

For the analysis of hazards related to short-duration intense rainfall events (up to 3 hours) and prolonged heavy frontal rainfall events (from 3 to 24 hours), both of which can potentially generate localized or widespread flooding, a dual dataset approach was adopted, using both locally sourced regional data collected from automatic meteorological stations and the CHAPTER/RISICO dataset, following the methodologies described in the previous chapter.

The need for this comparison arises from the previously mentioned issues related to the spatial distribution of meteorological stations and the length of their observation records. In order to obtain results with both spatial and statistical significance, it was therefore decided to apply the algorithm provided in the CLIMAAX Handbook using both datasets.

This chapter presents the results obtained, and the comparison is carried out for both hazard and risk assessments across the entire regional territory.

For future projections, EURO-CORDEX models (Copernicus Climate Data Store) were used, with a spatial resolution of 12 km and projections covering the period 2041-2070.

The outputs related to the hazard assessment of intense precipitation refer to the cities of Campobasso, Isernia, and Termoli. The graphs below show the future projection of expected precipitation (left) and the probability distributions of maximum precipitation series based on the Generalized Extreme Value (GEV) distribution (right), respectively for each city.

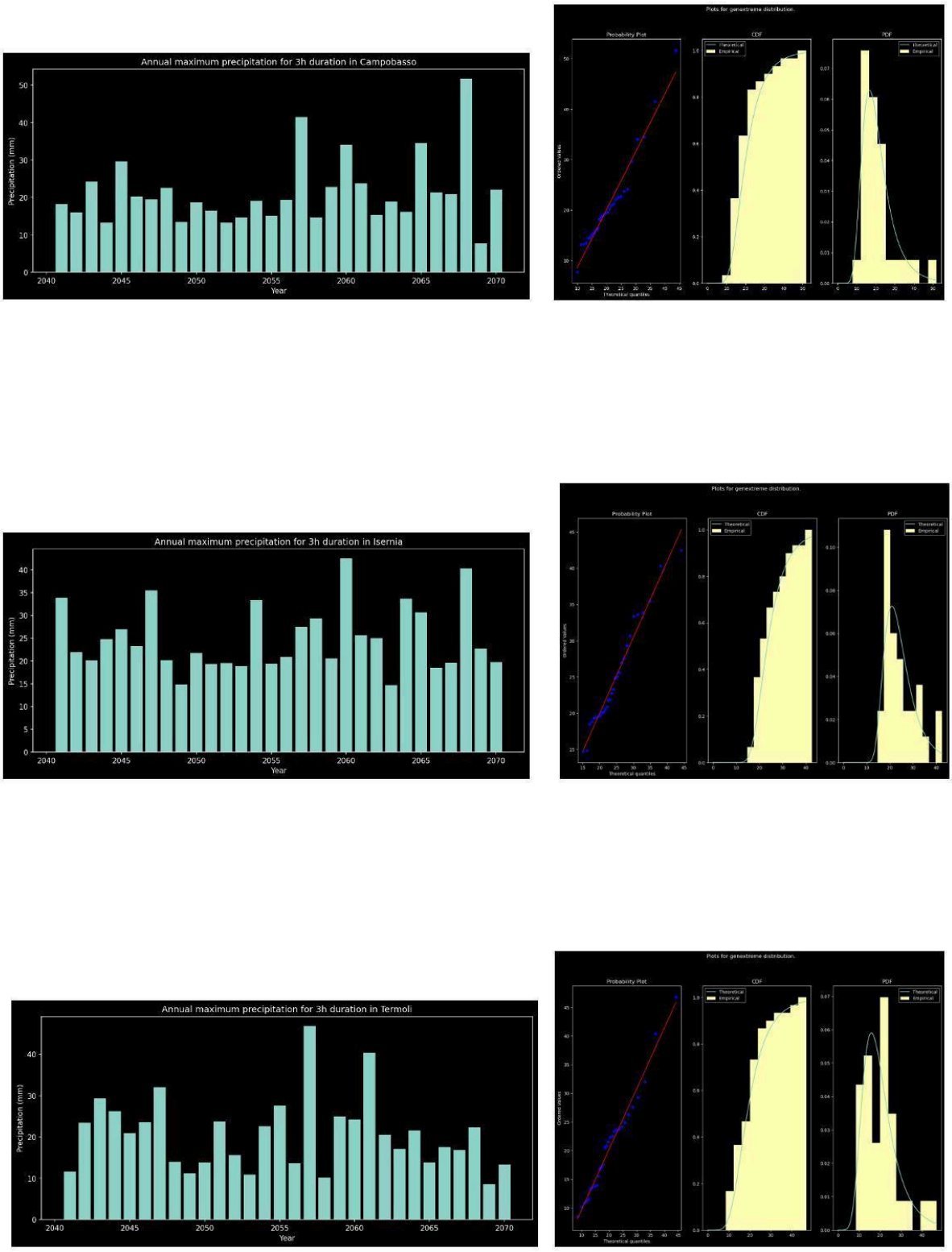


Figure 2-6 ***Left:*** *projection of annual maximum 3-hour precipitation (2041-2070) for the cities of* ***Campobasso***, ***Isernia***, *and* ***Termoli***, *respectively (from top to bottom).* ***Right:*** *the corresponding* ***GEV distributions****. The* ***CHAPTER/RISICO*** *dataset was used for this analysis.*

In addition, graphs were produced showing the expected 3-hour precipitation events for the 2041-2070 period, considering different return periods (1, 5, 10, 50, and 100 years) and the three projection scenarios ("best-case", "worst-case", and "mean-case"), using the CHAPTER/RISICO dataset.

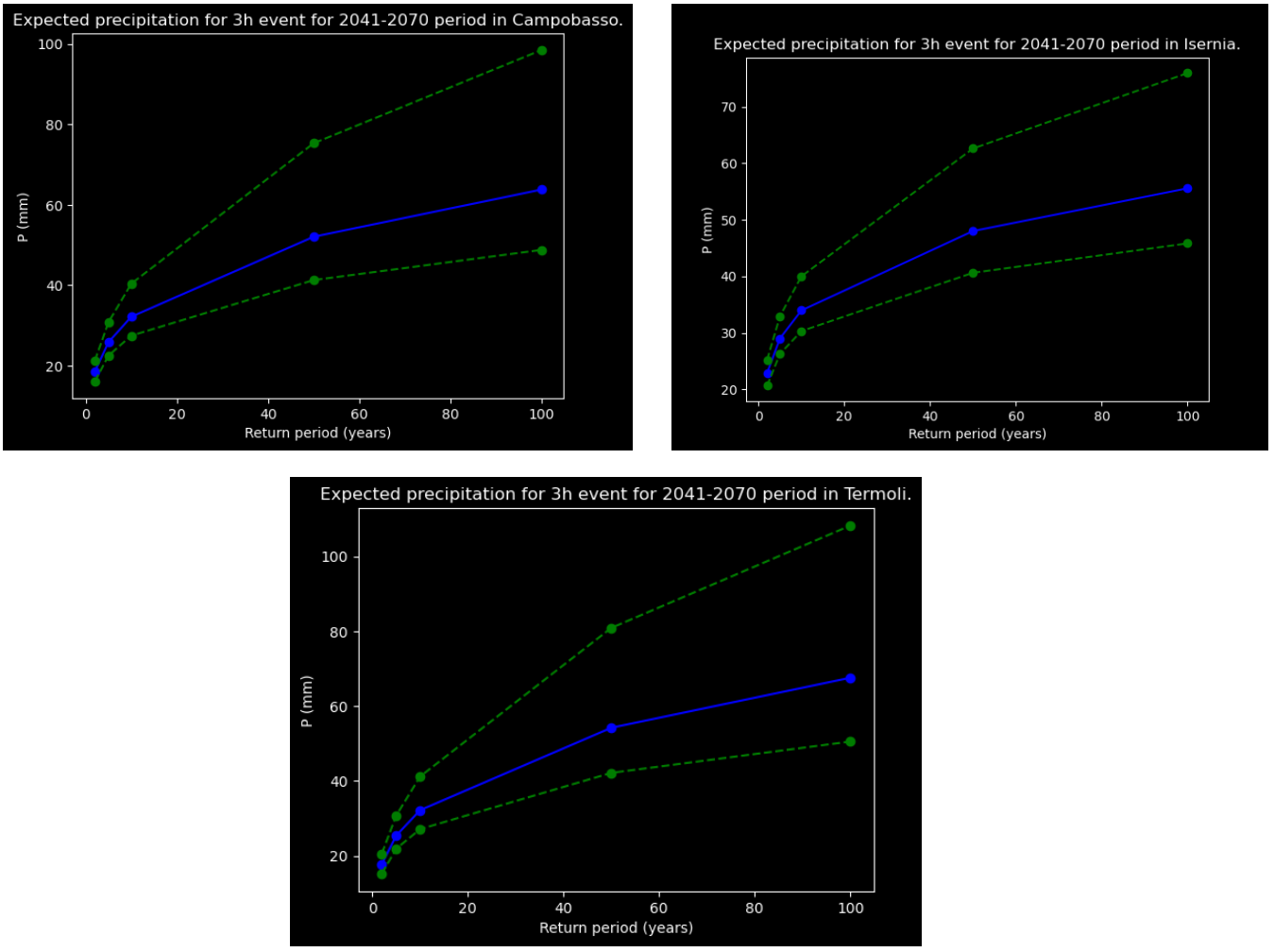


Figure 2-7 Expected precipitation for 3-hour events during the period 2041-2070 for the city of Campobasso (top left), Isernia (top right), and Termoli (bottom), considering return periods of 2, 5, 10, 50, and 100 years, respectively.

The results related to the **hazard assessment of intense precipitation** are presented. In this case, a comparison is made between the results obtained using the two different datasets.

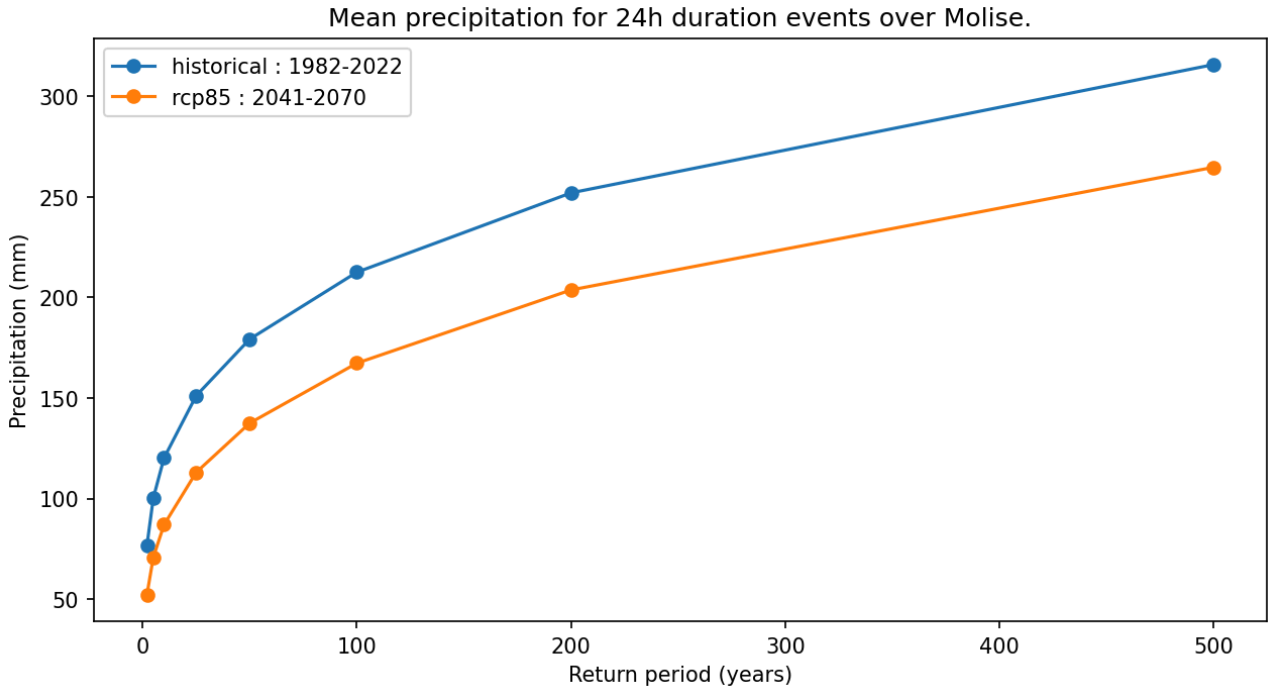


Figure 2-8 Average maximum 24-hour precipitation for events with different return periods (2, 5, 10, 50, 100, and 500 years) under the future "worst-case" scenario (RCP8.5) and the historical period. The figure was produced using the CHAPTER/RISICO dataset.

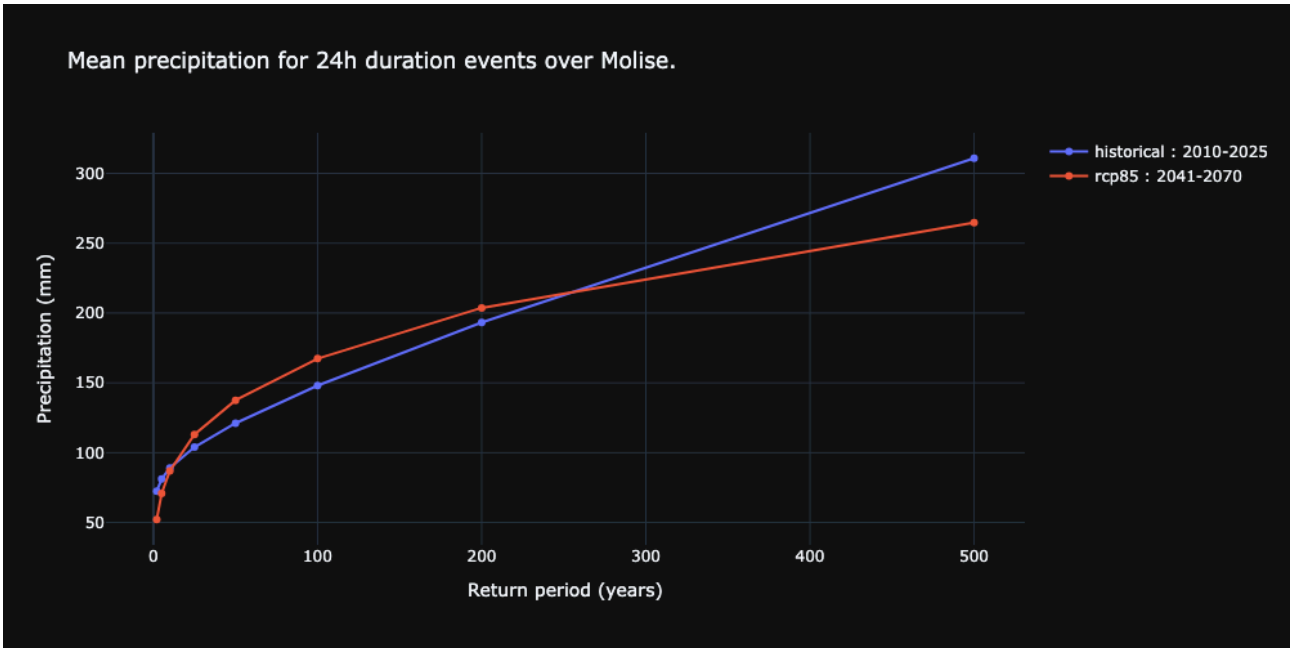


Figure 2-9 Average maximum 24-hour precipitation for events with different return periods (2, 5, 10, 50, 100, and 500 years) under the future "worst-case" scenario (RCP8.5) and the historical period. The figure was produced using the Regional Monitoring Network dataset.

The comparison between the two graphs reveals a substantial and significant difference. The **CHAPTER/RISICO dataset** provides a more optimistic outlook regarding future precipitation trends for different return periods. For all the time spans and durations analysed, the future projections indicate that precipitation totals should never exceed the values historically recorded. This would suggest a general and uniform weakening of extreme precipitation events.

This appears to contrast with the projected temperature signal, as a further increase in average annual and seasonal temperatures would imply greater energy and latent heat available within the land-sea-troposphere system, resulting in a higher probability of more intense events.

Conversely, the scenario obtained using the **Regional Monitoring Network dataset** is more complex. It shows a trend substantially opposite to that described above: for all the time spans and durations examined, precipitation is projected to exceed historically recorded values for return periods ranging from 10 to 250 years. Outside this range, historical precipitation values remain higher, in millimetres, than future values.

Both models have technical aspects that require improvement and must be taken into consideration. Although the **CHAPTER/RISICO dataset** has extensive spatial and temporal coverage, it remains a projection based on a dataset of European origin. This inevitably entails a degree of statistical uncertainty. On the other hand, the model based on the **Regional Monitoring Network** was developed for a geographically limited area, making the data highly reliable for regional climate analysis. However, its spatial and temporal coverage is not yet sufficient to provide statistically significant projections.

The graphs below show the projected future variation in 24-hour precipitation with a 10-year return period under the **RCP2.6, RCP4.5, and RCP8.5 scenarios**.

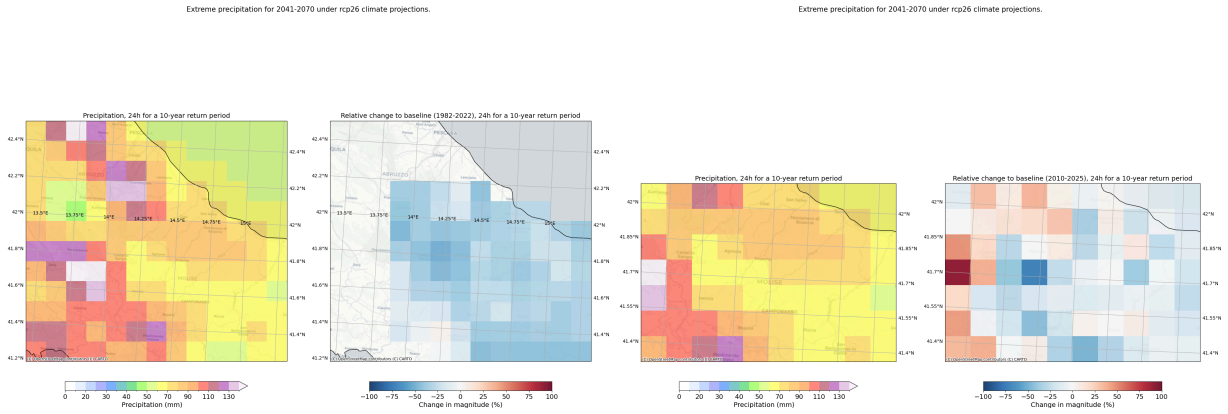


*Figure 2-10 Projections of **24-hour precipitation** for the period **2041-2070** under the **RCP 2.6 scenario**. The image on the left was produced using the **CHAPTER/RISICO dataset**, while the image on the right was generated using the **Regional Monitoring Network dataset**. The inset maps show, for both cases, the **absolute change** (left) and the **relative change** (right) in projected precipitation.*

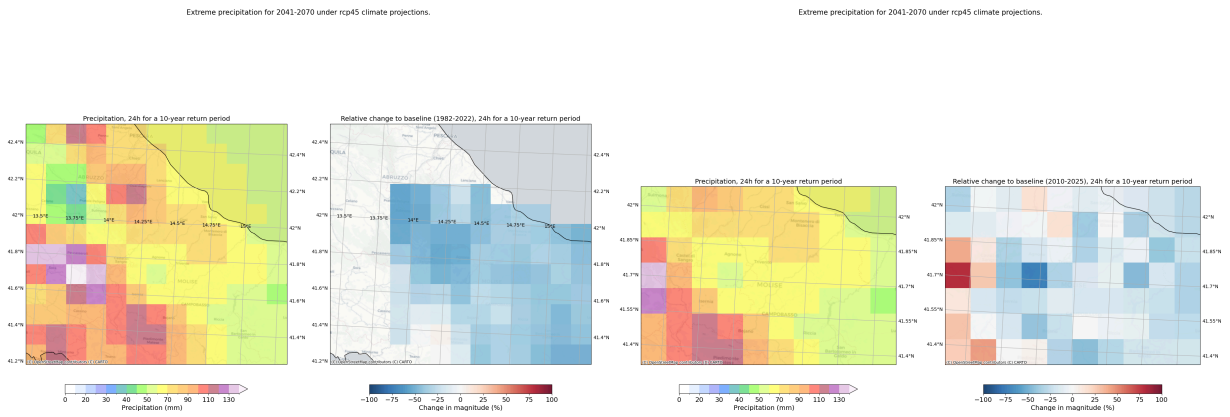


Figure 2-11 Projections for 2041-2070 of 24-hour precipitation under the RCP4.5 scenario. The image on the left was produced using the CHAPTER/RISICO dataset, while the image on the right was produced using the Regional Monitoring Network dataset. The inset maps show, for both cases, the absolute level of change (left) and the relative level of change (right).

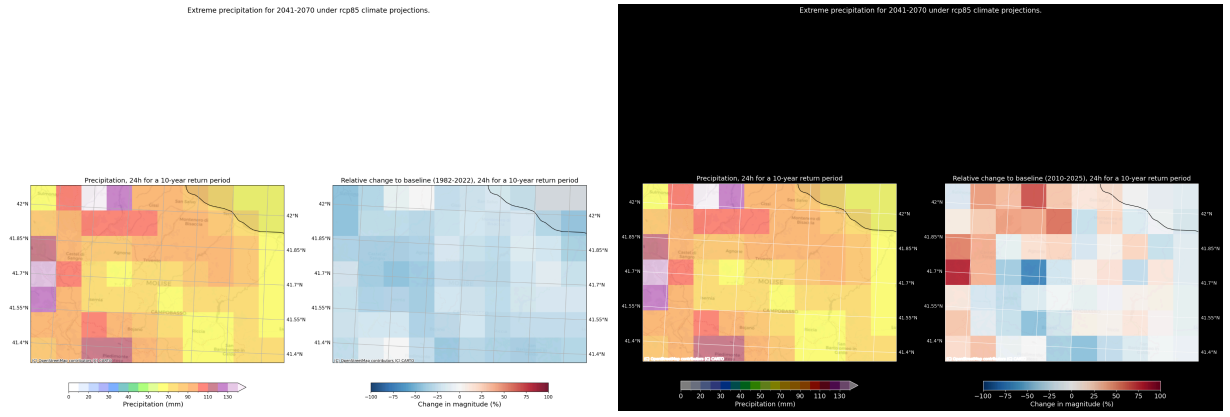


*Figure 2-12 Projections of **24-hour precipitation** for the period **2041-2070** under the **RCP 8.5 scenario**. The image on the left was produced using the **CHAPTER/RISICO dataset**, while the image on the right was generated using the **Regional Monitoring Network dataset**. The inset maps show, for both cases, the **absolute change** (left) and the **relative change** (right) in projected precipitation.*

Also in this case, the CHAPTER/RISICO model appears to be highly optimistic with regard to potential future precipitation trends. The analysis does not reveal a significant trend across the regional territory, whereas the Regional Monitoring Network model shows a more irregularly distributed signal, with increases in extreme precipitation primarily concentrated in the north-western areas of the Region.

2.3.2.1 Risk assessment

During this second phase, risk maps related to intense precipitation events were also produced for the Molise Region.

The results obtained through the application of the two different models, namely the **CHAPTER/RISICO dataset** and the **Regional Monitoring Network dataset**, are presented below.

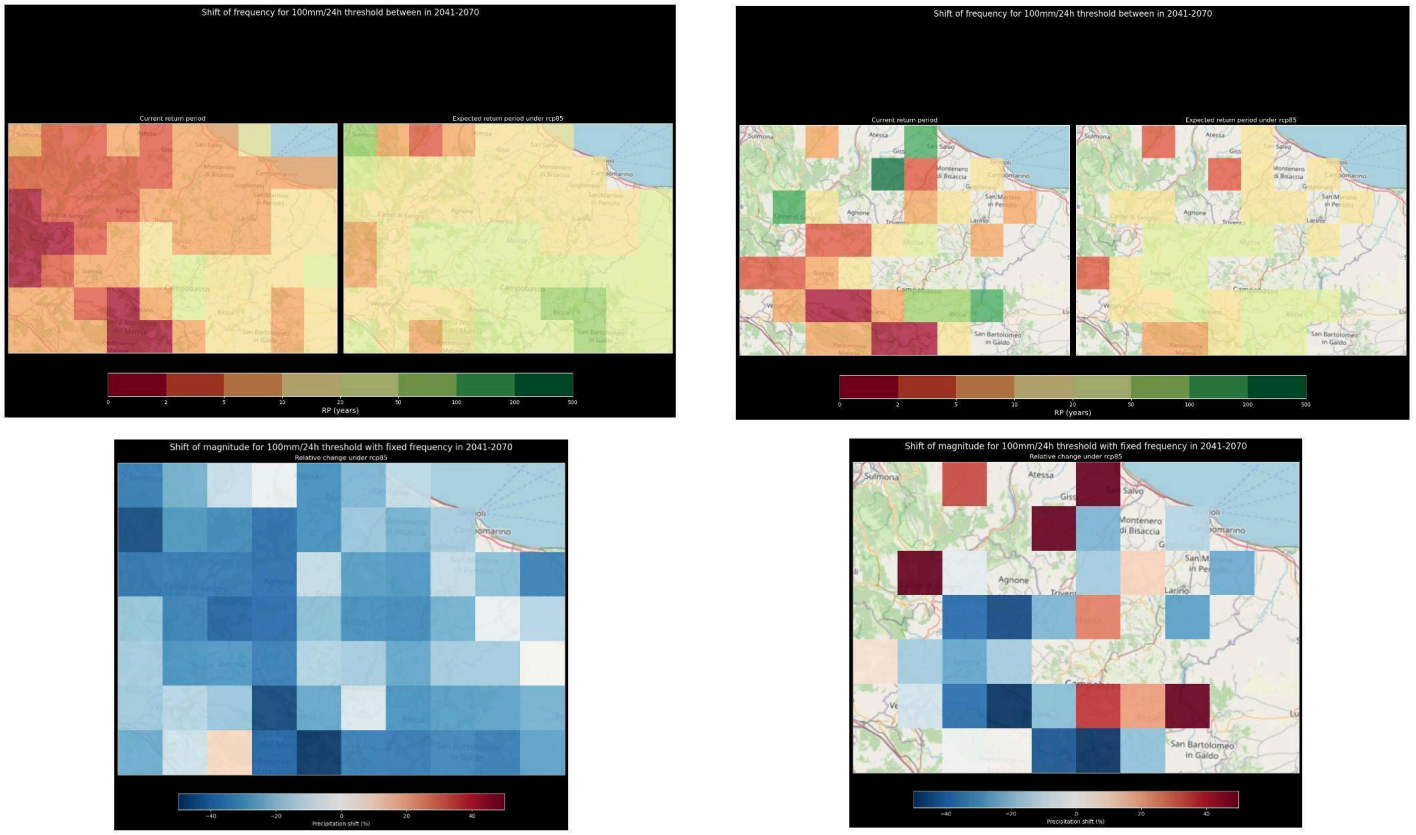


Figure 2-13 ***Left:*** *change in the frequency and magnitude of precipitation events exceeding the* ***100 mm/24h threshold*** *in the 2041–2070 projection, using the CHAPTER/RISICO dataset.* ***Right:*** *the same maps produced using the Regional Monitoring Network dataset.*

The two sets of results are substantially different. An initial analysis immediately highlights the issue of the spatial coverage of the two datasets: the CHAPTER/RISICO dataset covers the entire Region, as it is derived from the downscaling of ERA5, whereas the local dataset covers the Region only partially, since the meteorological stations do not provide uniform spatial or temporal coverage.

Another major difference between the two models concerns the future projections. As already highlighted in the previous analysis, the CHAPTER/RISICO dataset provides highly optimistic projections for the 100 mm/24h precipitation threshold. The entire Region could experience a decrease in the frequency of precipitation events exceeding this threshold, suggesting less intense rainfall events and, at the same time, longer return periods.

Conversely, the Regional Monitoring Network dataset indicates an increase in accumulated precipitation and shorter return periods for events exceeding the same threshold, although only in

specific areas of the territory. This climate signal would be difficult to apply operationally when defining measures to mitigate the associated risk, particularly with regard to the allocation of financial resources, which might not be used in a sufficiently targeted manner.

2.3.3 Additional assessments based on local models and data. Regional approach

As explained in the previous chapters, in addition to the methodology proposed by CLIMAAX, parallel analyses were carried out for both risk categories using specific methodologies developed at the regional level in Molise. Following, as far as possible, the same chapter structure adopted for Method 1, this section presents the characteristics of these regional methodologies and the results obtained through their application.

2.3.3.1 Hazard assessment

2.3.3.2 Heavy rainfall

In parallel with the process described above, a second approach was pursued, made necessary by the difficulty in interpreting the data obtained through the execution of the algorithm provided by CLIMAAX. The methodology used and the data obtained are presented below.

Starting from the proposed “mathematical” definition of risk, according to the Italian National Civil Protection Department and ISPRA, as the product of expected rainfall, slope, and vulnerability:

R = Precipitation × Slope × Vulnerability

which can also be expressed as:

R = Hazard × Vulnerability

Hazard Calculation

For the calculation of hazard, and therefore for the creation of the hazard map, two factors were taken into account: the average historical rainfall for 3-hour and 24-hour events and the average slope of the territory:

- **Slope:** this information was extracted from the Region’s 20-metre DTM, available for download from the National Geoportal, using the GDAL Slope processing tool in QGIS. This process generates a raster file (.tiff) from the original DTM, in which each pixel is assigned a slope value calculated from the elevation difference with adjacent pixels.
- **3-hour and 24-hour events:** accumulated precipitation values for 3-hour and 24-hour events were extracted from data recorded by the Molise Region’s meteorological stations from 2007 to August 2026. Data prior to 2007 were not considered because they were not homogeneous or continuous according to WMO standards and were therefore unsuitable, as well as difficult to interpret, for the subsequent statistical analyses.

To reduce the problem of limited spatial resolution, since the meteorological stations do not form a dense and continuous network across the regional territory, interpolations were performed between neighbouring stations in order to estimate precipitation values where no recorded data

were available. This resulted in four types of raster files: the average and maximum rainfall values for 3-hour and 24-hour events.

The interpolation was performed using the georeferenced coordinates of known meteorological station locations in Molise and their corresponding 3-hour and 24-hour rainfall values. A grid with pixels measuring **44.4 × 44.4 metres**, covering the entire territory of Molise, was then created. The **Inverse Distance Weighting (IDW)** method was applied to the grid points, producing a spatially continuous thematic map whose accumulated values remain strictly within the minimum and maximum values actually measured on the ground.

The two types of maps were standardised to ensure that the calculations could be performed correctly. They were projected into the **EPSG 32633 – WGS 84 / UTM Zone 33N** coordinate reference system, with a spatial resolution of 20 metres, using the **GDAL Warp (Reproject)** processing tool in QGIS.

Finally, the hazard raster file (.tiff) was created using the raster calculator and the following expression:

Hazard = (Rainfall × 0.7) + (Slope × 0.3)

An experimental weight of **70%** was assigned to precipitation values, while **30%** was assigned to slope. This weighting was adopted because accumulated rainfall is considered to have a greater influence on intense rainfall hazard than slope. However, slope still plays a fundamental role, since increasing slope leads to higher surface runoff velocity and, consequently, greater erosive power.

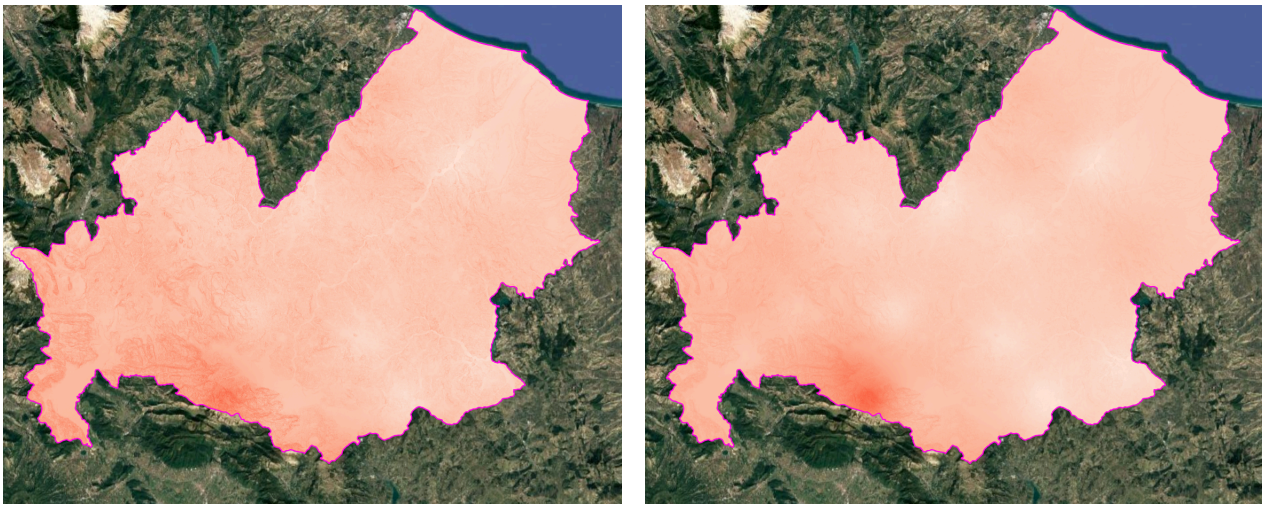


Figure 2-14 Hazard of intense rainfall events with a duration of 3 hours (left) and 24 hours (right). The colour scale ranges from white (minimum hazard) to red (maximum hazard).

2.3.3.3 Wildfire

In parallel with the analysis described above, additional hazard maps were produced and aggregated at the municipal level.

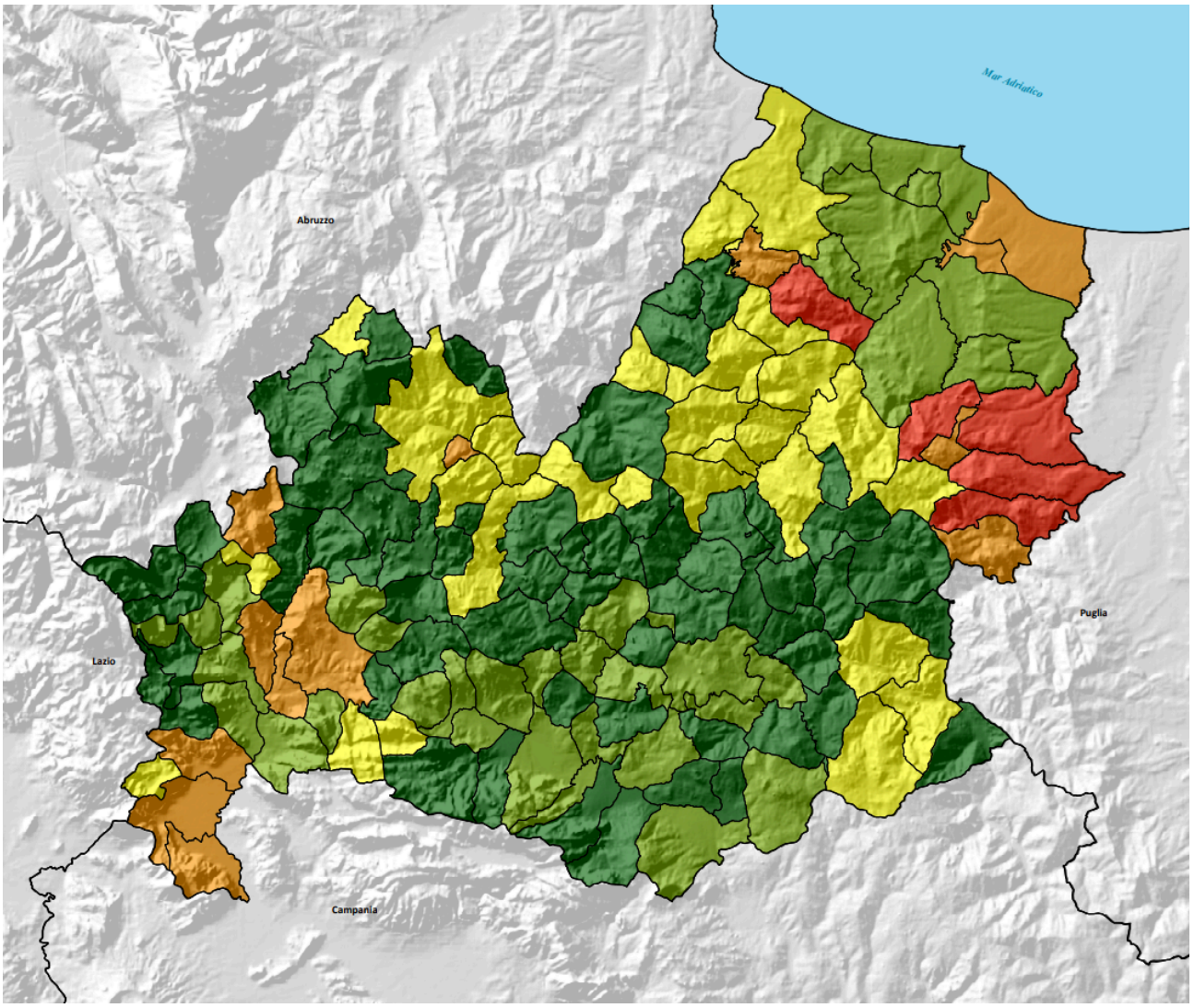


Figure 2-15 Wildfire hazard map of the Molise Region, aggregated by municipality.

The map shown above uses a colour scale corresponding to different levels of wildfire hazard, ranging from dark green, which indicates low hazard, to red, which indicates high hazard.

The analysis begins with the extraction of historical wildfire records over a 24-year period (1992–2015). For each municipality in Molise, the total number of events and the total annual area affected by fire were considered.

Based on the historical data, six statistical and quantitative indicators were calculated for each municipality:

- Average annual burned area;
- Median annual burned area;
- Maximum area affected by fire in a single year, representing an estimate of the highest attainable hazard level;
- Average annual wildfire incidence per 10 km²;
- Number of years in which large wildfires (>10 hectares) occurred per 10 km²;
- Percentage of years with wildfires larger than 10 hectares per 10 km².

Since the indicators considered had different units of measurement and scales, the variables were first standardised by calculating their mean and standard deviation, thus making them comparable and allowing them to be processed simultaneously.

A multivariate statistical **Cluster Analysis** technique was then applied to the standardised variables. This process grouped municipalities with similar statistical profiles, identifying five homogeneous hazard classes across the Region. Each class is quantitatively defined by its centroid, namely the mean value of the variables within the group, and described as follows:

1. **Class 1:** Sporadic wildfires affecting limited areas and having a minimal incidence across the territory.
2. **Class 2:** Small wildfires with low spreading potential, but recurring over time.
3. **Class 3:** Moderately frequent wildfires, with spreading potential and recurring over time.
4. **Class 4:** Frequent wildfires, affecting medium-to-large areas and having medium-to-high spreading potential.
5. **Class 5:** Wildfires affecting large areas, with high spreading potential, recurring over time, and having the highest incidence.

The results of the Cluster Analysis were imported into GIS software, specifically ArcMap and QGIS. Each municipal polygon was assigned its corresponding hazard class, ranging from 1 to 5, thus generating the final map at the municipal scale.

A similar analysis was carried out in greater depth to establish a supra-municipal territorial classification of the Region according to wildfire hazard. **Basic Areas** were defined as territorial and geographical reference units for the organisation of wildfire prevention and suppression services. To ensure environmental, socio-economic, and management homogeneity, these areas correspond to homogeneous territorial zones characterised by similar climatic, vegetation, and topographic conditions:

1. Low-Hill and Coastal Belt
2. Mid-Hill Belt
3. Southern Apennine Belt
4. Eastern Hill Belt
5. Northern Apennine Belt

The analysis followed the same procedure described above up to the Cluster Analysis stage. A territorial synthesis was then performed: for each Basic Area, the hazard class was assigned by weighting the hazard classes of the municipalities located within it according to their respective surface areas.

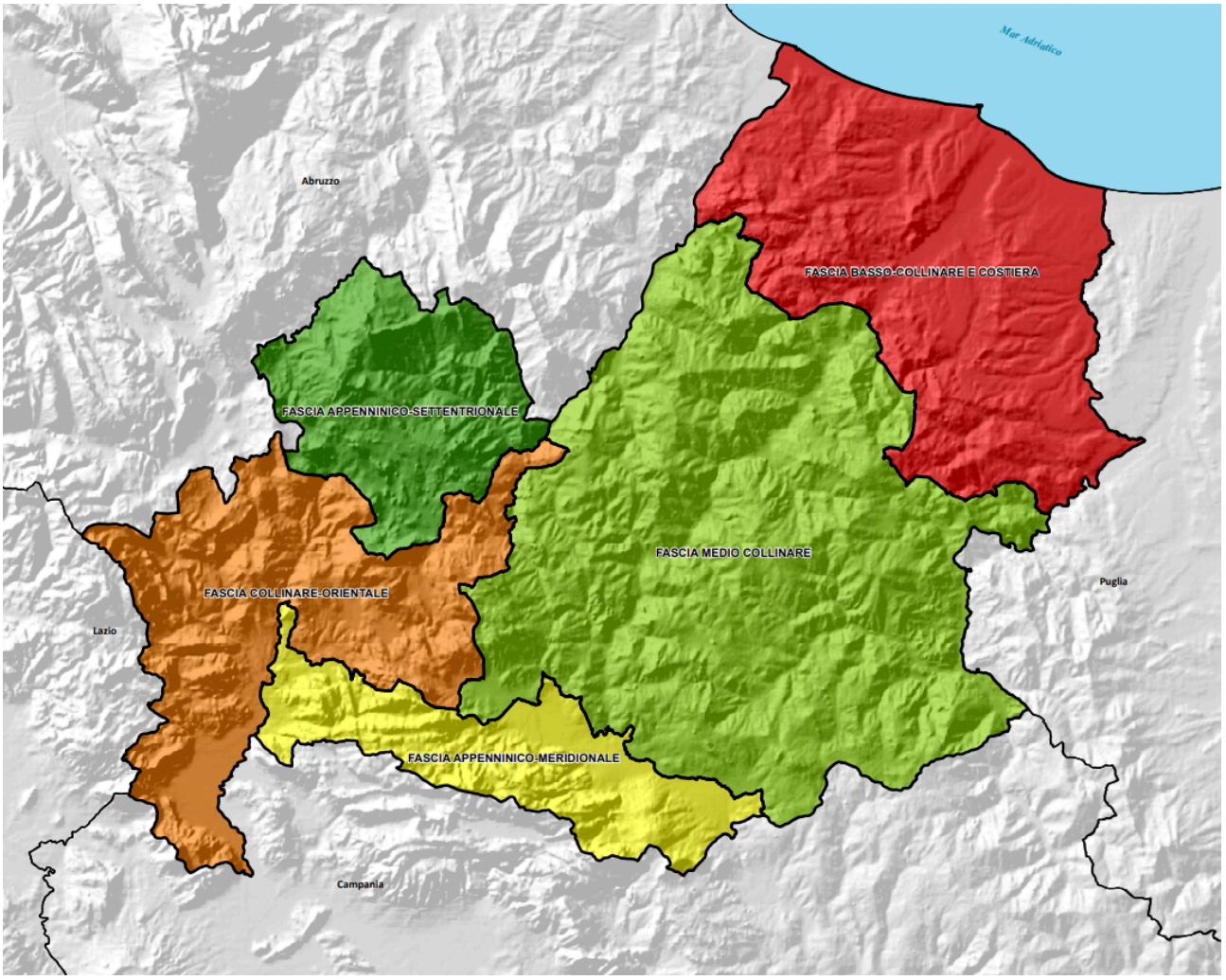
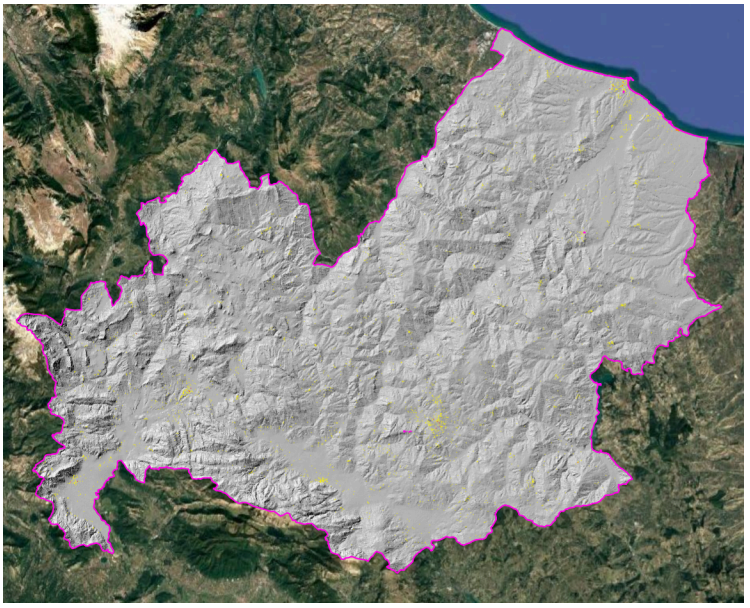


Figure 2-16 Wildfire Hazard Map of the Molise Region, Classified by Basic Areas

2.3.3.4 Risk assessment

2.3.3.5 Heavy rainfall

Once the hazard has been calculated, this information layer must be combined with vulnerability.



- **Vulnerability:** vulnerability is defined as the condition of being exposed to and suffering damage as a result of an external or internal event (see previous chapters). Therefore, infrastructure that may contain people with varying levels of susceptibility to harm was considered vulnerable. Based on this definition, all buildings in the Molise Region were extracted from OpenStreetMap in shapefile format. The buildings were reclassified according to a "risk weight" value, as follows:
    - Hospitals and other healthcare facilities: **5**
    - Schools, educational institutions, and similar facilities: **4**
    - Accommodation facilities (campsites, hotels, and similar structures): **3**
    - All other buildings: **2**

A corresponding raster file (.tiff) was generated from this dataset, assigning a value of **1** to "NoData" cells, namely pixels where no building is present. This was done because the future risk map must take the type of building into account, while maintaining a certain minimum level of risk even in areas where no buildings are present.

Infine questo strato informativo è stato incrociato con il pericolo degli eventi di 3h e 24h per ottenere così le carte del rischio, utilizzando la seguente formula:

Rischio = Pericolo x Vulnerabilità

In questo caso non sono stati assegnati alcuni pesi, seguendo le direttive del Dipartimenti di Protezione Civile Nazionale e dell'ISPRA.

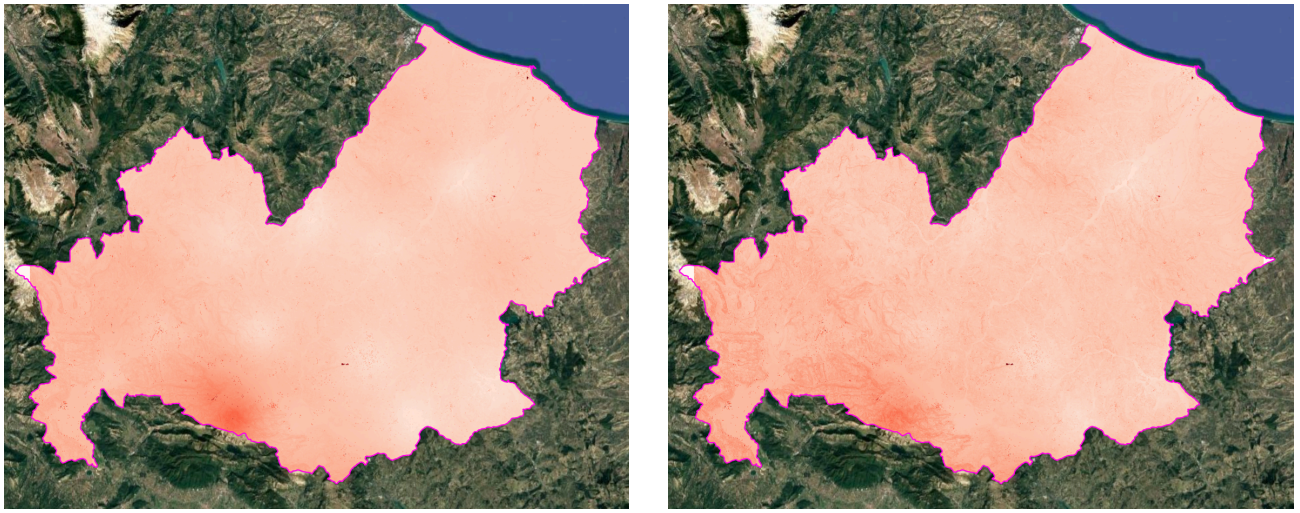


Figure 2-17 Risk maps for 24-hour (left) and 3-hour (right) intense precipitation events.

2.3.3.6 Wildfire

Following the analysis carried out to produce hazard maps at both Municipal and Basic Area levels, a corresponding risk map was also developed. However, in this case, it was necessary to distinguish the risk according to the time of year, resulting in separate assessments for winter risk and summer risk.

This distinction was required due to the significant variations in the factors contributing to wildfire risk across the two seasons, including changes in meteorological conditions, vegetation characteristics, fuel moisture content, and overall environmental susceptibility, as discussed in the following sections.

Consequently, seasonal risk mapping provides a more accurate representation of wildfire dynamics and supports the identification of targeted prevention and mitigation measures tailored to the specific conditions prevailing during different periods of the year.

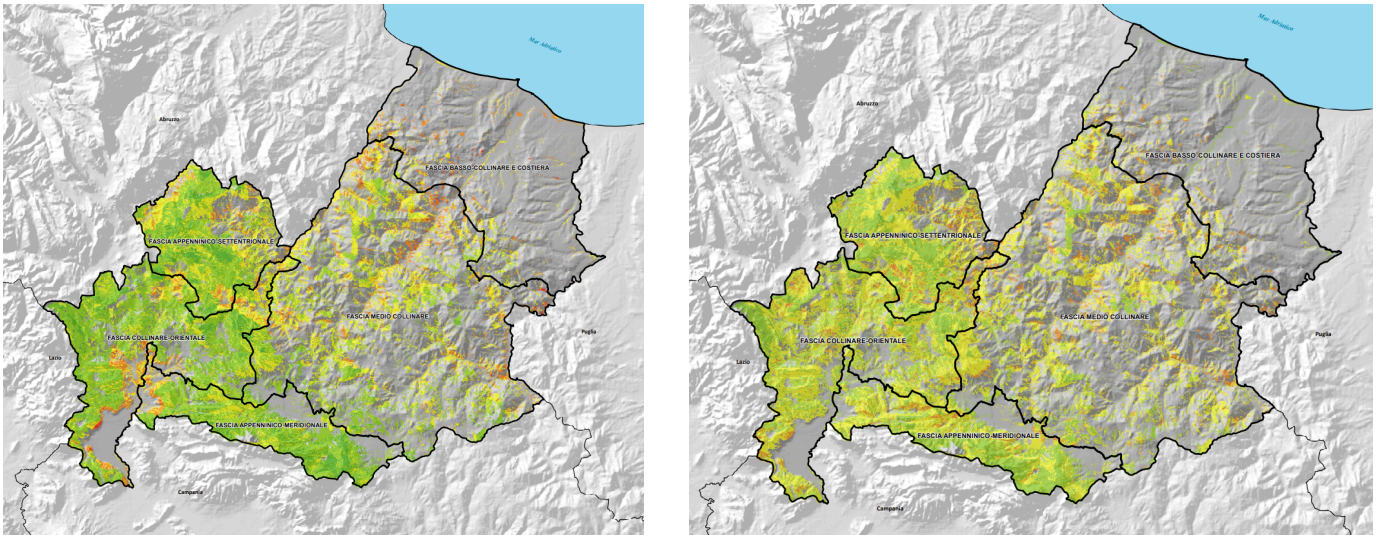


Figure 2-18 Wildfire risk map for the summer period (left) and the winter period (right).

The production of the **"Summer Risk Map"** is the result of an additive and weighted mathematical-cartographic model, originally developed for the United States and subsequently adapted to the Italian context. Unlike hazard assessment, which evaluates the historical frequency of events, wildfire risk is defined as a long-term static factor expressing the propensity of different types of vegetation cover to be affected by fire based on environmental and weather-climatic factors. Since predisposing factors vary significantly between summer and winter, models specifically calibrated for the different seasons were developed.

For the calculation of risk during the summer quarter, the algorithm combines four territorial variables, each assigned a specific percentage weight according to its influence on the spread of summer wildfires:

1. **Summer phytoclimate/bioclimate (Weight: 40%):** this represents the most heavily weighted factor in the summer model, quantifying the water and heat stress affecting vegetation.

2. **Land cover and land use/fuel models (Weight: 30%):** this expresses the quantity, structure, and flammability of vegetation.

3. **Terrain aspect (Weight: 15%):** this assesses the impact of solar radiation on the dryness of dead fuel.

4. **Terrain slope (Weight: 15%):** this measures the effect of slope inclination on the uphill spread rate of flames.

Each individual rasterised information layer, represented as a pixel grid, was indexed and classified using a risk score ranging from 0 to 100:

- **Summer bioclimate:** the risk level was assigned according to the bioclimatic subregion. Supratemperate and humid areas were assigned the minimum risk score of 10, while dry-to-subhumid meso-Mediterranean and thermo-Mediterranean areas were assigned the maximum risk score of 100.

- **Fuel models:** these were derived from the Map of Forest and Pre-Forest Types of Molise and converted to the Behave/Rothermel standard, together with field surveys of necromass conducted using the LIS methodology. Each fuel model was indexed according to its propensity to burn during the summer season.

- **Terrain aspect:** this was extracted from the Digital Terrain Model (DTM). South-facing slopes were assigned the maximum risk score of 100 due to high solar radiation and low relative humidity; flat terrain = 65; east- and west-facing slopes = 45; north-facing slopes = 0.

- **Slope:** this was derived from the DTM and divided into five slope classes: 0–8° = 5; 9–10° = 10; 11–15° = 20; 16–22° = 60; <22° = 100.

Once the four raster information layers had been indexed, the risk index was calculated in QGIS using the raster calculator.

The algorithm performs a pixel-by-pixel weighted linear combination according to the following expression:

Summer Risk Index = (0.40 × Phytoclimate) + (0.30 × Fuel) + (0.15 × Aspect) + (0.15 × Slope)

The continuous output generated by the algorithm was divided into five colour-coded summer risk classes, calculating the regional area falling within each class:

1. **Low Risk (Dark Green):** 18,699.20 ha
2. **Medium-Low Risk (Light Green):** 90,517.76 ha, representing the predominant class
3. **Medium Risk (Yellow):** 64,779.36 ha
4. **Medium-High Risk (Orange):** 18,183.36 ha
5. **High Risk (Red):** 772.64 ha

The final map shows that the highest summer risk levels, corresponding to the Medium-High and High classes, are concentrated in areas where thermophilic vegetation, southern exposures, and

steep slopes coincide. In particular, the most critical areas are found along the valley floors of the Trigno River, the Middle and Upper Biferno, western Lower Molise, the Lower Molise section of the Volturno, and the Upper Fortore.

The production of the **"Winter Risk Map"**, like the summer map, is based on the application of an additive and weighted static risk assessment model.

However, since the spread of winter wildfires is influenced by different predisposing factors from those affecting summer wildfires, such as the presence of dry grasslands, necromass, and the effects of winds at hilly and mountainous elevations, the calculation algorithm includes additional variables and a different distribution of weights.

Unlike the summer model, which uses four variables, the winter risk calculation integrates five information layers, introducing elevation as an additional factor:

1. **Land cover and land use/fuel models (Weight: 30.67%):** this factor remains highly relevant in defining the load and structure of vegetation.
2. **Winter phytoclimate/bioclimate (Weight: 29.33%):** its relative weight is lower than in summer, when it accounts for 40%, but it quantifies winter weather and climatic stress.
3. **Elevation (Weight: 20%):** this variable is not included in the summer model, where its weight is 0%, but is introduced in winter to assess the greater exposure of hilly and mountainous areas.
4. **Terrain aspect (Weight: 11.33%):** this measures the influence of solar radiation and prevailing winds.
5. **Terrain slope (Weight: 8.67%):** this assesses the ease with which fire spreads uphill.

The five rasterised information layers were indexed using risk scores ranging from 0 to 100 according to winter wildfire behaviour:

- **Elevation:** the model assigns the maximum risk value to the intermediate hilly and mountainous elevation range:
    - 0–100 m above sea level: risk score 10
    - 100–1,000 m above sea level: risk score 100, representing maximum winter vulnerability
    - 1,000–1,500 m above sea level: risk score 50
    - 1,500–2,200 m above sea level: risk score 10
    - 2,200 m above sea level: risk score 0
- **Winter bioclimate:** this was reclassified to reflect the dryness and temperature conditions of the cold season, assigning risk values such as 0, 20, or 40 to the different bioclimatic units.

- **Winter fuel models:** vegetation types were reconfigured by indexing their susceptibility to ignition during winter, when grasslands, shrublands, and the litter of deciduous broadleaved trees show high flammability.

The five raster layers were combined in a GIS environment using the raster calculator, according to the following expression:

Winter Risk Index = (0.3067 × Fuel) + (0.2933 × Winter Bioclimate) + (0.2000 × Elevation) + (0.1133 × Aspect) + (0.0867 × Slope)

The continuous risk index values were grouped into five equal-interval risk classes, converting the pixel count into the corresponding area in hectares:

1. **Low Risk (Dark Green):** 339.68 ha, representing a sharp decrease compared with the summer value of 18,699.20 ha
2. **Medium-Low Risk (Light Green):** 67,042.56 ha
3. **Medium Risk (Yellow):** 108,056.80 ha, representing the predominant class during winter
4. **Medium-High Risk (Orange):** 17,445.60 ha
5. **High Risk (Red):** 67.68 ha

Compared with the summer season, the Winter Risk Map shows a clear shift in critical conditions towards the interior of the Region. The Medium Risk class becomes predominant, almost doubling in extent to more than 108,000 ha, and is mainly concentrated in the intermediate hilly and mountainous areas of inland Molise, between 100 and 1,000 m above sea level.

An analysis of vulnerability to wildfires was also carried out. According to the CLIMAAX framework, vulnerability is defined as “the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC, 2022, p. 5). It also includes “all relevant factors of an environmental, physical, technical, social, cultural, economic, institutional, or political nature that contribute to susceptibility and/or the lack of capacity to prepare, prevent, respond, cope, or adapt”. In this analysis, only sensitivity and susceptibility to harm arising from environmental and social factors were considered, without taking response capacity into account. The reasons for this choice are explained below.

To produce the vulnerability map, an information layer containing all buildings in the Molise Region was implemented within a GIS environment. The buildings were classified according to their type and, consequently, their level of susceptibility to harm. Campsites, all accommodation facilities such as B&Bs, hotels, and guesthouses, and healthcare facilities such as public hospitals and similar structures were extracted.

The following weights were assigned to the different types of structures within the building shapefile:

- **Hospitals and healthcare facilities:** 3
- **Campsites and other accommodation facilities:** 2
- **All remaining buildings:** 1
- **All other areas:** 0

The dataset was then rasterised using the assigned weight as the rasterisation field.

As stated previously, the resilience or adaptive capacity of the different structures was not considered in this analysis, since national legislation requires each structure to have an internal safety plan governing all actions to be undertaken in the event of both external and internal risks. However, these actions may vary from case to case, and their inclusion would therefore have resulted in an extremely complex information-layer structure.



Figure 2-19 Wildfire Vulnerability Map

The vulnerability classification assigned to each building follows a colour scale ranging from **transparent** (*No Data*, i.e. no building present), to **orange** (generic buildings), **red** (campsites and other accommodation facilities), and **purple** (hospitals and similar healthcare facilities).

2.4 Key Risk Assessment Findings

As stated in the CLIMAAX Handbook, the assessment of the key risks addressed by this project is based on the analysis of three fundamental aspects: severity, urgency, and the resilience capacity of the community in its broadest sense.

Severity refers to the impact that a given phenomenon has on a territory, including both its natural and ecosystem components and its anthropogenic component. It therefore provides an indicator of the potential economic damage to the environment.

Urgency refers to the temporal dimension of a hazard and therefore provides a quantitative measure of the change currently taking place, in this case climate change.

Resilience capacity, finally, refers to all those elements belonging to a community that enable it to maintain its existing state despite the occurrence of an external disturbance.

2.4.1 Mode of engagement for participation

As explained in the previous chapters, the stakeholder engagement model will be implemented at the beginning of Phase 3 of the CLIMol Project. The feedback collected to date has been reported in Phase 1 of the project.

2.4.2 Gather output from Risk Analysis step

Wildfires

For wildfire risk, the output selected for the overall risk assessment is the **summer wildfire risk map**. This dataset is considered more representative because, during the summer months, population exposure (and therefore vulnerability) to wildfires increases due to higher tourist influxes, while the probability of wildfire occurrence also rises.

This approach is considered more suitable for analysing the associated **severity**, **urgency**, and **resilience capacity**, and consequently for identifying the most appropriate future mitigation measures.

Intense Precipitation

For intense precipitation, the risk assessment outputs selected for subsequent analyses are the **3-hour and 24-hour rainfall risk maps**.

These results are considered more reliable than those obtained through Method 1 because they were specifically developed using local data and tailored to local conditions, providing greater accuracy and a closer representation of the territorial reality of the Molise Region.

2.4.3 Assess Severity

Severity represents the actual impact that a risk has on a community in its broadest sense. Within the CLIMol Project, the aspects most susceptible to the severity of the risks analysed are those related to the social dimension, namely how a community perceives and reacts to a specific risk.

Wildfire risk has historically had a significant impact on the population, since the period of highest risk (summer) coincides with the period of greatest population presence, while the areas most susceptible to wildfire are also those most heavily populated during the same season. To date, however, relatively few losses have been recorded in terms of damaged infrastructure. The decision to conduct an in-depth analysis within this project also derives from the cascading effects

that wildfires can have on the territory. By temporarily removing vegetation cover, wildfires expose the soil to erosion caused by atmospheric agents such as intense rainfall and wind. Over the long term, this results in a loss of soil fertility, leading to greater ecological and economic impacts. Therefore, when the severity of a wildfire is particularly high, immediate restoration actions are required.

The situation is somewhat different with regard to **intense precipitation risk**. The severity of this phenomenon is more widespread both spatially, as it affects larger portions of the territory, and temporally, since heavy precipitation events can occur throughout the year. The most recent severe event occurred in **April 2026**, when a very intense low-pressure system developed over the Ionian area of Italy, causing the inflow of cold and moist air over the regional territory. The result was a severe storm event, including snowfall over the Apennine areas, which triggered numerous and widespread landslides, some of considerable magnitude. These events led to the isolation of at least 100 people and disrupted major road transport corridors in central Italy.

For these reasons, the following values were assigned in the **Key Risk Dashboard Template**.

SEVERITY		
	Actual	To Be
Intense Precipitation	4	4
Wildfires	3	4

3 - Substantial: High frequency and/or substantial impacts for the region or community, with potentially intolerable consequences (for example, considering the effects that a wildfire could have on a tourist accommodation facility such as a campsite), and possible systemic effects. The functioning of communities, ecosystems, assets and infrastructure, the economy, and the life and well-being of citizens may be threatened (for example, impacts on the agri-food sector and tourism).
4 - Critical: High frequency and/or severe impacts for the region or community, with potentially intolerable consequences (see the example of the exceptional precipitation event of April 2026). Potential systemic effects may occur, including cascading impacts and secondary risks (as explained above, wildfires remove vegetation cover, promoting soil fertility loss and causing damage to subsequent crops). This may result in critical disruption to communities, ecosystems, assets and infrastructure, severe economic impacts, or life-threatening conditions for citizens.

2.4.4 Assess Urgency

Urgency introduces the time dimension into risk assessment, acting as an early warning signal for the impacts of the climate crisis. This factor defines the level of timeliness required to implement the necessary mitigation and adaptation measures.

Both hazards investigated in this study are expected to intensify in the future, both in terms of the frequency of occurrence (including the recurrence of critical wildfire years) and their magnitude, as discussed in the previous chapters. The worsening of these parameters determines the priority of interventions, although accurately determining the timing and extent of future impacts remains

challenging, since the studies conducted are based on projection simulations rather than meteorological forecasts.

Given the nature of the phenomena under consideration, a gradual evolution is not expected. Instead, they are likely to manifest as abrupt and rapid **sudden-onset events**, which, although partially predictable, are capable of producing long-lasting effects. Consequently, it is reasonable to expect longer and more recurrent periods of forest drought, alongside extreme precipitation events occurring with greater frequency, thereby prolonging the damage inflicted on the territory over time.

It should also be emphasized that, even under current conditions, the climate hazards considered are already significant and have the potential to generate severe impacts on both the population and the local economy.

URGENCY	
Intense Precipitation	3
Wildfires	3

3 - More Action Needed: Climate hazards and related processes are already being observed, or are projected to undergo significant changes. These changes are expected to persist over time or occur during critical periods. Should an increasing trend in hazard intensity or frequency be confirmed, the region or community may have limited capacity to respond rapidly. Adaptation to the associated climate risks is therefore likely to require a medium- to long-term effort, potentially spanning several years up to a decade.

2.4.5 Understand Resilience Capacity

Resilience capacity provides an indication of how effectively a population can return to a state of normality following an extreme climate event. This aspect depends on a combination of economic resources, human capital, natural assets, physical infrastructure, and social capacities.

The **Molise Region** benefits from several resilience mechanisms that are already established. First and foremost, it has a comprehensive legislative framework for Civil Protection, which addresses a wide range of hazards, including those examined in the present project. The Region has also adopted both a **Wildfire Operational Plan** and a **Multi-Risk Warning System for the Molise Region**, which analyze various risk factors and establish operational protocols. The former focuses on wildfire prevention and management, while the latter addresses a range of environmental hazards, including intense rainfall events to which Molise is exposed. Together, these regulatory and planning instruments provide a solid foundation upon which additional resilience measures can be developed.

The Region can also rely on significant human resources. In particular, alongside the **Italian National Fire and Rescue Service**, which is responsible for emergency response to environmental hazards, the **Civil Protection Volunteer Corps** plays a crucial role. Through its equipment, vehicles, expertise, warning bulletins, emergency facilities and infrastructure, and operational support services, it provides valuable assistance to affected communities during emergencies.

Unfortunately, other aspects of resilience remain comparatively weak. Economic and financial capacity, in particular, represents a critical challenge for several reasons. The regional economy is largely based on small-scale industry, micro-enterprises, agriculture, livestock farming, and traditional crafts, while much of the available funding is allocated to economic development and other priority sectors. This situation also reflects a broader perspective on the region's human capacities. Although technical expertise and scientific knowledge are advancing, public awareness and understanding of environmental risks appear to have lagged behind. Environmental hazards are still approached primarily from an emergency-response perspective rather than through prevention and long-term risk reduction strategies.

It should be recognized that the natural capacity of ecosystems to recover and regenerate is increasingly challenged by the growing intensity and frequency of extreme events. As such events occur more often, the resilience of natural systems may gradually diminish, reducing their ability to maintain essential ecological functions and services.

This highlights the importance of strengthening a preventive and adaptive approach, combining scientific knowledge, territorial planning, community engagement, and ecosystem-based strategies to enhance the long-term resilience of the Molise Region.

RESILIENCE	
Intense Precipitation	2
Wildfires	3

2 – Medium: Medium resilience capacity, with some Climate Risk Management (CRM) measures already in place.

3 – Substantial: Substantial and widespread resilience capacity, with specific Climate Risk Management (CRM) measures in place, although there is still room for improvement.

2.4.6 Decide on Risk Priority

For the **risk prioritization assessment**, the **CLIMAAX Key Risk Dashboard Template** was used. The analysis indicates that, after evaluating **current and future severity, urgency, and resilience**, the most significant risk faced by the **Molise Region** is associated with **intense rainfall events**.

This priority ranking was assigned because two factors clearly differentiated intense rainfall from the other hazards considered: **current severity** and **resilience capacity**.

With regard to severity, the impact of intense rainfall is considered greater because these events often affect much larger portions of the territory, thereby exposing a greater number of people and assets. Furthermore, their consequences are typically more disruptive, as heavy rainfall is frequently associated with landslides, flooding, and localized hydrogeological instability, all of which can significantly undermine the safety and functioning of communities.

Regarding resilience, although warning bulletins, operational procedures, and emergency protocols are in place, the regional community currently has fewer resources and response instruments available to cope with extreme rainfall events than it does for wildfire emergencies. Consequently, the capacity to prevent, manage, and recover from the impacts of intense precipitation remains comparatively lower, contributing to the higher overall risk assessment.

These findings highlight the need to strengthen both structural and non-structural measures aimed at reducing vulnerability to extreme rainfall, while enhancing preparedness, response capabilities, and long-term adaptation strategies throughout the region.

Risk Workflow	Severity		Urgency	Capacity	Risk Priority
	C	F		Resilience/ CRM	
River flooding					
Coastal flooding					
Heavy rainfall	4	4	3	2	Very high
Heatwaves					
Drought					
Fire	3	4	3	3	High
Snow					
Wind					

Severity	Urgency	Resilience Capacity	Risk Ranking
Critical	Immediate action needed	High	Very high
Substantial	More action needed	Substantial	High
Moderate	Watching brief	Medium	Moderate
Limited	No action needed	Low	Low

Figure 2-20 Table of Risk Priority Assessment for the Hazards Affecting the Molise Region.

To further support the hypothesis that intense and heavy rainfall represents the highest-priority risk, an additional risk analysis was carried out. The ultimate objective was to interpret the two risk assessments as a single integrated result, in order to obtain a holistic understanding of the actual risk conditions affecting the Molise Region.

In this analysis, the **intense rainfall risk** (3-hour and 24-hour events) and the **wildfire risk** were combined by summing the respective risk layers. For the wildfire dataset, *No Data* values were assigned a value of **0**. This approach was adopted to identify the macro-areas most exposed to these hazards.

The maps produced through this procedure are referred to as **cumulative risk maps**.

The cumulative risk was calculated using the following expression:

Cumulative Risk = 3-hour and/or 24-hour intense/heavy rainfall risk + wildfire risk.

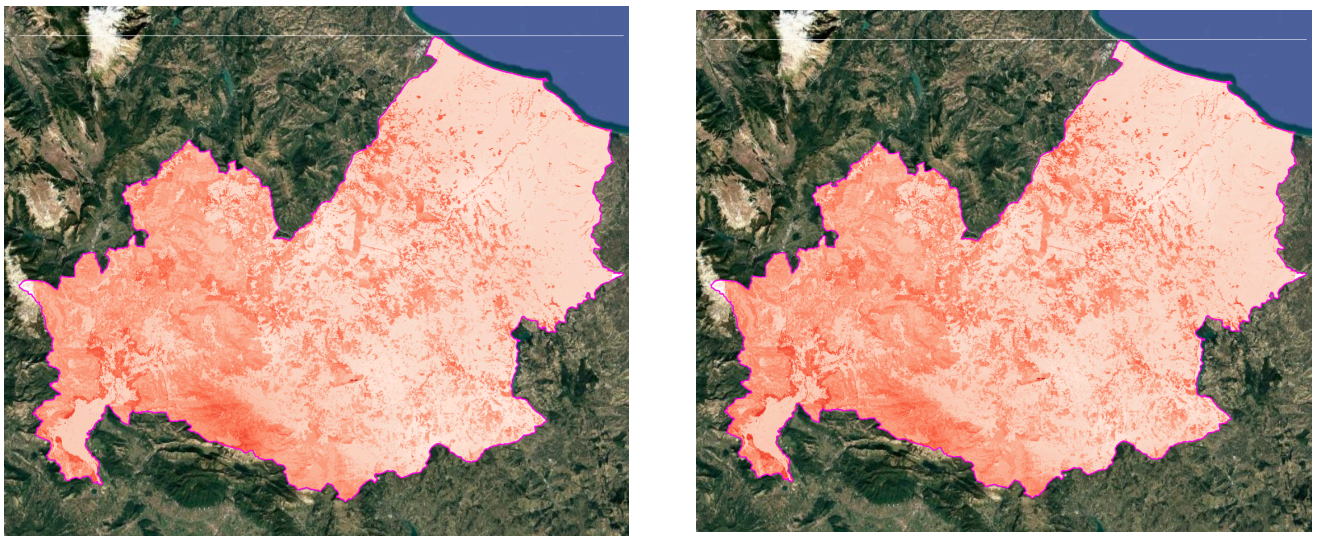


Figure 2-21 ***Left:*** *cumulative risk map combining wildfire risk and* ***3-hour intense precipitation risk****.* ***Right:*** *cumulative risk map combining wildfire risk and* ***24-hour intense precipitation risk****.*

Areas with the highest combined exposure to the two hazards are represented by **bright red** colours, while areas with the lowest cumulative risk are shown in **white**. Both maps indicate that the most exposed areas are concentrated in **western Molise**, the **Matese Massif**, and the **coastal zone**. In the latter area, large zones of high cumulative risk are not evident at regional scale; however, a more detailed analysis reveals small but significant areas characterized by high risk, mainly located near **tourist accommodation facilities**.

Both cumulative risk maps were reclassified on a scale ranging from **0 to 12**. To identify as clearly as possible the macro-areas most exposed to these hazards, the centroids of pixels whose cumulative risk values fall within the upper third of the scale were exported in vector format. Specifically, for the 0–12 classification scale, the centroids of all pixels with values **greater than 8** were extracted and generated.

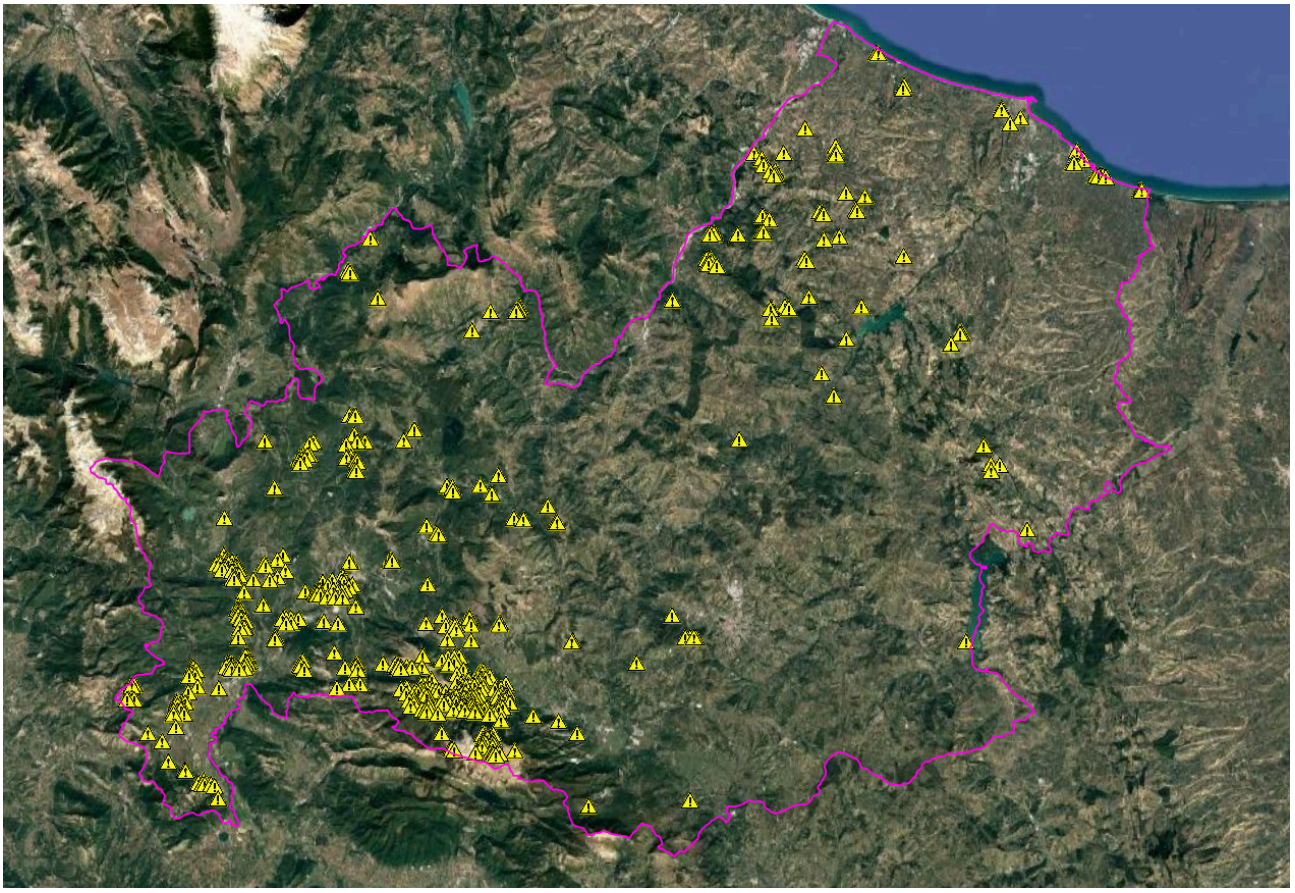


Figure 2-22 ***Above:*** *cumulative risk map combining wildfire risk and* ***3-hour intense precipitation risk****;* ***on the right:*** *the corresponding map obtained using* ***24-hour intense precipitation risk****.*

The map clearly shows a subdivision of the Region into two main areas: the **south-western sector** and the **central-northern (coastal) sector**. When compared with the hazard maps presented in the previous chapters for **3-hour and 24-hour intense precipitation** and **summer wildfire hazard**, it becomes evident that the spatial pattern observed in the cumulative risk map is fully consistent with the findings of the previous analyses.

In particular, the high-risk areas located in the south-western part of the Region are primarily attributable to their greater exposure to **intense precipitation events**, whereas the central and northern areas are more strongly affected by **wildfire risk**.

This final analysis was necessary to identify where and how specific risk mitigation measures should be implemented. Only the municipalities located within the **Eastern Hilly Belt** appear to be significantly exposed to both hazards simultaneously.

2.5 Monitoring and Evaluation

Phase 2 of the CLIMol Project has made it possible to clarify a number of key aspects.

1. **Regional Monitoring Network Dataset:** At present, the Molise Regional meteorological dataset requires interpolation procedures in order to be effectively used for environmental analyses and to generate statistically meaningful results.

The accuracy of such interpolations increases with the density of the meteorological station network on which they are based, as routinely carried out by meteorological services. Consequently, the need emerges to strengthen the existing monitoring network through the installation of additional meteorological stations strategically distributed across the territory.

2. **Use of the CLIMAAX Algorithm:** The application of the CLIMAAX algorithm proved essential in highlighting the critical issues discussed above, particularly the need to adopt local data, methods, and analytical frameworks in order to obtain estimates that more accurately reflect regional conditions.

3. **Prioritisation:** Thanks to the methodology provided in the CLIMAAX Handbook, it was possible to clearly identify the environmental risks requiring the highest level of attention in the short term. The assessment of **severity**, **urgency**, and **resilience capacity** enabled the definition of a clear framework for understanding the priority level associated with the risks analysed.

From a technical perspective, excellent collaboration was established with a wide range of stakeholders and specialised experts. The acquisition of the necessary datasets, the execution of the algorithms, and the interpretation of the results were made possible through the effective cooperation among the various actors involved.

Particularly important were the information and outreach activities carried out for the local population. These initiatives represented valuable opportunities for education, awareness-raising, and capacity building, helping communities better understand the environmental challenges that the Molise Region is currently facing and is expected to face in the coming years.

2.6 Climatological and statistical characterisation of meteorological data from the Regional Civil Protection meteorological observation network

The study of the main thermo-meteorological parameters, and extreme precipitation in particular, is currently based both on historical time series of data measured *in situ* by a network of rain gauges and on reanalysis datasets, such as ERA5 data produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). These datasets use a wide variety of inputs, including ground-based measuring stations, weather balloons, measurements from polar-orbiting and geostationary meteorological satellites, aircraft observations, and other sources. The data are then processed according to the laws of thermodynamics using an advanced numerical weather prediction model, such as the Integrated Forecasting System (IFS). The dataset currently used for applied studies such as the present one can be defined as very high resolution, focused on land variables and distributed over a regular grid of approximately 9 km, or 0.25° × 0.25°.
It is therefore evident that the outputs of the statistical analyses derived from the two different scientific approaches may show significant numerical discrepancies.

These differences arise from the following factors:

1. **Grid smoothing:** A ground-based rain gauge measures the rainfall occurring at a specific location, whereas the simulation model calculates the average accumulated precipitation by distributing it across a square grid cell approximately 9 km wide. From a statistical climatological perspective, this results in the simulation model generally underestimating precipitation outliers.
2. **Convective precipitation:** Convective precipitation in the broad sense is not accurately detected or simulated by the ERA5 mathematical model, since clouds with strong vertical development, which cause the most intense showers and cloudbursts, generally cover an area much smaller than the computational grid. The model must therefore use

mathematical approximations that are not always able to reproduce the actual point intensity of precipitation events at ground level.

3. **Orographic effect:** In mountainous areas, precipitation in the broad sense strongly depends on local morphological and morphometric characteristics, which can only be described through linear and radial measurements. Furthermore, even a very fine grid tends to underestimate the maximum elevation of mountain ranges, thereby also underestimating the effect of forced orographic uplift and, consequently, albeit indirectly, the accumulated precipitation generated by atmospheric disturbances.

The downscaling approach used significantly reduces these effects associated with atmospheric thermodynamics and the morphology of the territory, but it does not completely eliminate the differences. The issue associated with the discrepancy between the two sets of output measurements therefore remains evident.

Within the physical territory of Molise, the considerable orographic and geographical complexity makes both *in situ* measurements and, indirectly, the modelling of intense rainfall phenomena a scientific issue that remains extremely complex. More specifically, since the duration of the precipitation events examined in this study varies considerably, ranging from short-duration 3-hour events to orographic-synoptic events lasting between 6 and 24 hours, many factors contribute to the numerical differences between the two types of climate analysis used in the project.
A common issue affecting both types of analysis concerns air masses originating from the first and second quadrants, over the Adriatic Sea, or from the third and fourth quadrants, over the Tyrrhenian and Mediterranean Seas, which suddenly encounter the mountain barriers of the Matese and Meta massifs. Precipitation is alternately more abundant and concentrated on the windward slopes, namely the Adriatic side in the first case and the Tyrrhenian side in the second.

A study conducted by Fazzini et al. shows that, within the Molise territory, precipitation totals with an orographic component account for more than 70% of the annual totals.
Convective precipitation mainly occurs during the warm half of the year, between May and October, and its spatial distribution is strongly influenced by morphology, including the local overheating of inland basins. In this case as well, mathematical models tend to underestimate the associated localised and intense precipitation phenomena.
That said, it should be noted that the modern monitoring network covering the physical territory of the Molise Region and a significant part of its surrounding areas, including the Campanian Sannio, the middle Volturno Valley, and Daunia, began operating in 1998, although in a highly irregular manner due to the gradual replacement of the former manual monitoring network managed by the now-discontinued National Technical Services.

As a result of this interruption, most of the existing thermo-pluviometric historical series extending to the end of the twentieth century were permanently discontinued. Even by applying the most advanced techniques for homogenising historical time series, it is not possible to reconstruct series that can be considered homogeneous, particularly with regard to intense precipitation data. Indeed, as previously highlighted and widely recognised in the technical and scientific fields, such events have an extremely unpredictable spatial distribution, with substantial differences in accumulated precipitation even over very short distances.

A detailed examination of the temporal coverage of the historical series shows that only 6 of the 52 currently operational monitoring stations have approximately 30 years of data, beginning in 1998. Twenty-seven stations provide data covering approximately the last 20 years, beginning in 2007. Although these records do not comply with WMO Standard No. 1203, they are considered generally adequate for advanced statistical analysis aimed at spatially identifying areas with homogeneous climatic behaviour.

Given the considerable effort required to retrieve, validate, and assess the quality of the data mentioned above, it should be noted that these important statistical analyses are still ongoing. The results will be presented in the **Phase 3 Deliverable** of the project.

To quantify the average climate signal, a preliminary analysis was therefore conducted on the available historical records, covering approximately 20 years, a period which is nevertheless sufficient to attempt to characterise the climate at the regional scale. This preliminary analysis, based on annual maximum values for the time spans examined in the study and their overall trends, revealed a statistical distribution that will necessarily need to be scientifically validated through a dedicated Cluster Analysis.

The preliminary results suggest that the regional territory can be divided into four homogeneous precipitation areas:

- **A – Coastal and lower hilly belt**
- **B – Middle and upper sub-Apennine hilly belt**
- **C – Matese Massif area**, probably also including the Meta Massif area
- **D – Western Upper Molise and Volturno River Basin area**

This territorial subdivision differs slightly from that identified in the previously mentioned regional-scale study, which was based on older but considerably more numerous datasets and on monthly precipitation parameters. The results of that study were subsequently incorporated into the 2013 regional document entitled **"Hydrogeological and Pluviometric Study"**. That study identified five homogeneous areas, distinguishing the Upper Molise area from the Volturno River Basin area.
In this respect, the most significant issue is that there is not a single homogeneous historical series covering more than 20 years across the entire upper and middle basin area.

Through a subsequent back-analysis, four monitoring stations representative of the 20-year climate signal were selected from among those with the longest historical records:

- **Area A:** Termoli
- **Area B:** Campobasso
- **Area C:** Roccamandolfi
- **Area D:** Pietrabbondante
-

The graphical results of the trend analysis, including the corresponding trends, are presented in **Tables** and **Figures** below.

Table 2-2 Area A – Termoli – 75 m . – Table 1

Termoli	3h	6h	12h	24h
05/09/2001	29,6	42,4	62,6	64,4
29/08/2002	81,4	95,4	112,8	112,8
15/10/2003	55,8	70	88,6	89,2
14/11/2004	37,6	55,4	72,6	86,4
20/09/2005	35,2	42,4	54,6	63,8
27/08/2006	35	40,8	59,2	59,4
07/10/2007	26,4	30,8	36	43,2
15/11/2008	25,2	26,4	37,6	47,8

23/10/2009	48,4	62,2	65	87,4
10/09/2010	31	37	49,4	56,2
20/09/2011	83,6	92,2	98	107
13/09/2012	21,2	30	39,6	48,2
01/12/2013	25,2	40,2	69	91,2
04/10/2014	53,2	74	82,4	85,6
26/11/2015	24,8	38,8	59,2	88,8
15/07/2016	37,4	59,8	64,4	66,8
25/07/2017	22,4	36,4	57,8	85,2
26/08/2018	34	39,8	42,8	61
10/07/2019	41,4	45,8	46,6	46,6
20/11/2020	19,8	33,2	50,2	80,6
28/08/2021	29,8	30,4	39,6	48,8
25/09/2022	21,2	31,8	46,6	55,8
20/01/2023	33	46	57,2	68,4
09/09/2024	25,2	25,2	30	34,4
16/10/2025	40,6	47,8	78,4	91,2
average	**36,7**	**47,0**	**60,0**	**70,8**
Max	**83,6**	**95,4**	**112,8**	**112,8**

Table 2-3 Area B – Campobasso – 751 m. – Table 2

Campobasso	3h	6h	12h	24h
13/11/2001	17,2	25,4	29,2	38,6
03/10/2002	12,7	12,7	12,7	12,7
18/06/2003	27,4	34,2	36,4	53
05/02/2004	20,1	20,1	40,2	40,2
03/10/2005	33,4	41,8	48	48,6
02/06/2006	18	22,2	39,8	47,6
10/06/2007	17,6	17,6	20	25,4
04/11/2008	37,4	45,2	45,4	45,4
27/06/2009	17,8	20	23,8	33,6
03/08/2010	27	36,2	47,8	59,6
15/08/2011	38,4	40	42,8	56,2
14/09/2012	19,2	30,2	32,2	53,6
29/09/2013	52,4	58,4	68,4	74,4

12/04/2014	41,4	46,6	46,8	49
14/10/2015	36,2	47	54,8	67,6
06/06/2016	28	32,6	33,6	46,2
02/09/2017	27,8	30,2	33,6	51,8
05/05/2018	31,4	32,4	38,4	48,4
24/08/2019	33,8	35,8	44,8	55,2
04/07/2020	32,8	35,8	48	56
08/12/2021	26,8	36,4	48	58,4
25/09/2022	26,6	44,4	66,6	70
07/06/2023	34,2	34,4	35,8	35,8
20/08/2024	34,4	37,6	37,6	37,8
23/04/2025	22,2	22,2	26,8	37
average	**28,6**	**33,6**	**40,1**	**48,1**
Max	**52,4**	**58,4**	**68,4**	**74,4**

Table 2-4 Area C – Roccamandolfi – 851 m. – Table 3

Roccamandolfi	3h	6h	12h	24h
28/07/2001	43,4	45,4	51,8	67,4
22/09/2002	48,6	71,2	85,2	90,6
03/06/2003	59	78,6	97,6	108,8
14/11/2004	53,2	70	91	161
27/11/2005	30,6	53	93,8	127,4
15/09/2006	33,4	46,8	60	60
31/10/2007	35,4	45,6	57	77
05/12/2008	40	58,8	80,6	108,6
21/09/2009	42	60,2	93,6	96
08/01/2010	43,4	77,6	111,4	127
16/02/2011	43	64,6	101	118,8
24/07/2012	38,6	43,2	64,8	103
26/12/2013	51,6	83,6	119,8	135,2
09/02/2014	40,2	50,2	65,4	69,8
14/10/2015	71	87,4	94	116
05/03/2016	36,6	49	63	92,4
15/12/2017	62	91	127	147,2
28/10/2018	63,8	108,6	143,8	187

05/11/2019	66,2	101,8	140	152,8
27/09/2020	62,4	91,2	110,8	112
03/11/2021	59,4	74	126,2	166,2
09/08/2022	73,6	77	117,4	130,8
17/01/2023	52,6	81,8	114,4	147,6
28/08/2024	38,8	52,8	66,8	101
10/09/2025	79,6	84,6	103,6	130
average	**50,7**	**69,9**	**95,2**	**117,3**
Max	**79,6**	**108,6**	**143,8**	**187**

Table 2-5 Area D – Pietrabbondante – 955 m. – Table 4

Pietrabbondante	3h	6h	12h	24h
27/08/2001	40	40	41,8	42,4
13/05/2002	32	38,6	38,8	55,8
20/10/2003	47,2	57,2	67	68,2
08/08/2004	43	43	48	48
16/11/2005	43	71,8	74,6	75,2
29/07/2006	55,8	57,8	57,8	57,8
31/10/2007	28,8	36,4	37,4	38,4
03/06/2008	32,2	34	45,4	68
21/06/2009	39,6	42,6	58,8	88,8
10/11/2010	33,8	43,8	46	68,8
30/06/2011	47	47,2	47,2	47,2
26/08/2012	34,4	34,6	34,6	49,6
20/08/2013	42,8	43,8	46,6	69
22/07/2014	35	42,6	50,2	67,2
14/10/2015	25,8	32,4	41,4	56
30/06/2016	57,8	68,6	68,6	81,2
10/09/2017	52,8	53,2	65,6	74,6
07/09/2018	36	44,4	62,2	76,6
19/12/2019	24,8	31,4	46,8	64,2
15/08/2020	39,4	39,4	56,4	71,4
24/08/2021	38,4	38,6	45,2	71,2
26/08/2022	36,6	36,6	36,6	41,2
28/03/2023	20,4	23,4	34,5	38

23/12/2024	15,8	17,8	21,6	22,4
25/04/2025	35,4	38,2	40,8	63,2
average	**37,5**	**42,3**	**48,6**	**60,2**
Max	**57,8**	**71,8**	**74,6**	**88,8**

Seeking to identify a **relationship between extreme meteorological parameters and elevation**, the analysis shows that no statistically significant relationship exists, as correlation coefficients are close to zero for all the time intervals examined. Instead, the influence of the orographic barrier effect exerted by the **Matese Massif**, repeatedly highlighted throughout this study, becomes evident once again.

However, as shown in the tables above, the **coastal area** exhibits absolute meteorological values for short-duration events, driven by **deep convection**, that are in some cases even higher than those typical of the Matese area.

This finding confirms that, given the increasingly well-documented warming of the Mediterranean Sea surface, the **land-sea-troposphere system** now contains enormous amounts of latent heat available throughout the entire warm season, no longer limited to the July-September period alone. Under conditions of instability in the lower and middle troposphere, this energy can trigger short-lived but particularly intense meteorological phenomena.

The impacts of such events at ground level are increasingly reflected in conditions of **high hydrogeological risk**, including urban flooding in lowland areas, flash floods along secondary river networks, and slope instability processes in the clay-rich terrains of the lower and middle hilly sectors of the region.

The downscaling approach used significantly reduces these effects associated with atmospheric thermodynamics and the morphology of the territory, but it does not completely eliminate the differences. The issue associated with the discrepancy between the two sets of output measurements therefore remains evident.

Within the physical territory of Molise, the considerable orographic and geographical complexity makes both *in situ* measurements and, indirectly, the modelling of intense rainfall phenomena a scientific issue that remains extremely complex. More specifically, since the duration of the precipitation events examined in this study varies considerably, ranging from short-duration 3-hour events to orographic-synoptic events lasting between 6 and 24 hours, many factors contribute to the numerical differences between the two types of climate analysis used in the project.

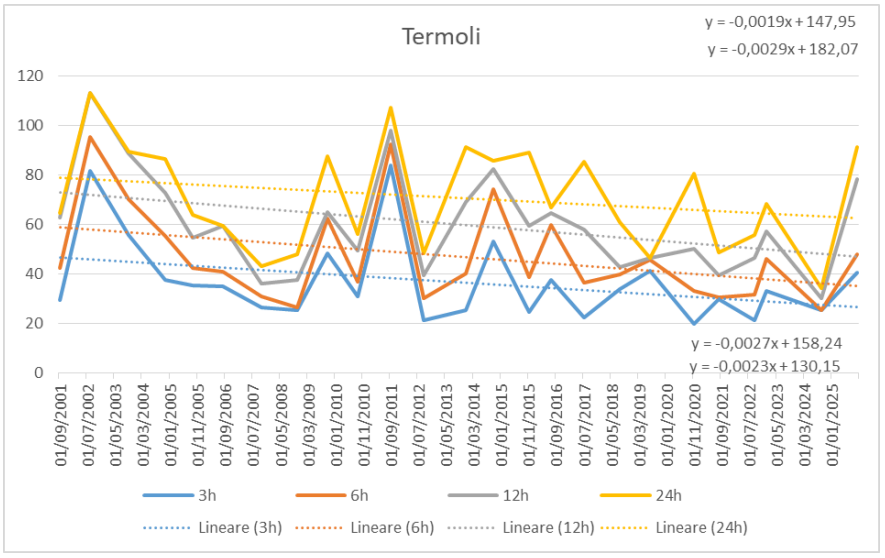
A common issue affecting both types of analysis concerns air masses originating from the **Adriatic Sea** (first and second quadrants) or from the **Tyrrhenian and Mediterranean Seas** (third

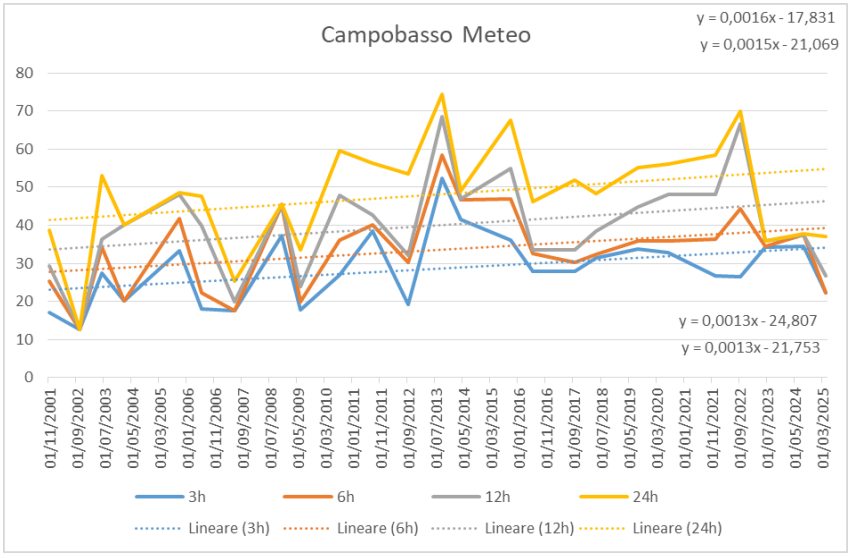
and fourth quadrants), which abruptly encounter the mountain barriers of the **Matese** and **Meta** massifs. Precipitation tends to be more abundant and concentrated on the windward slopes, namely the Adriatic slopes in the first case and the Tyrrhenian slopes in the second.

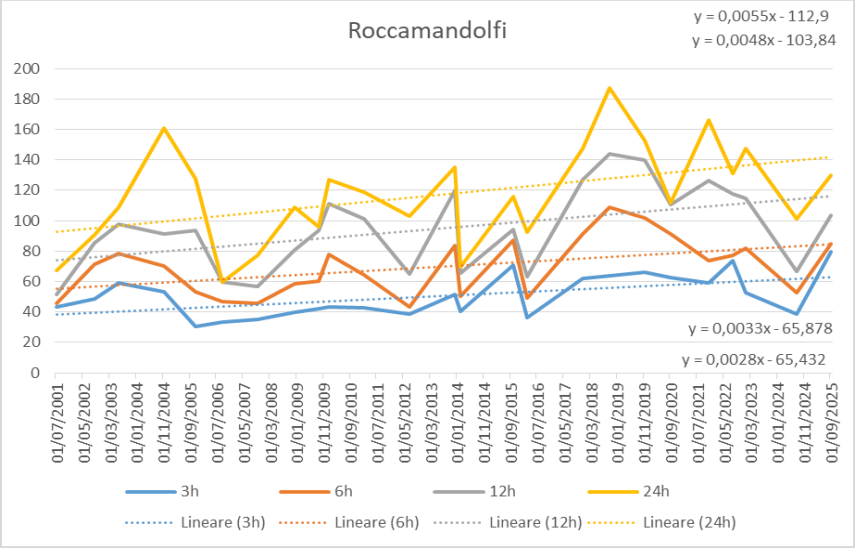
A study by **Fazzini et al.** shows that, within the Molise territory, precipitation with an orographic component accounts for more than **70% of annual totals**.

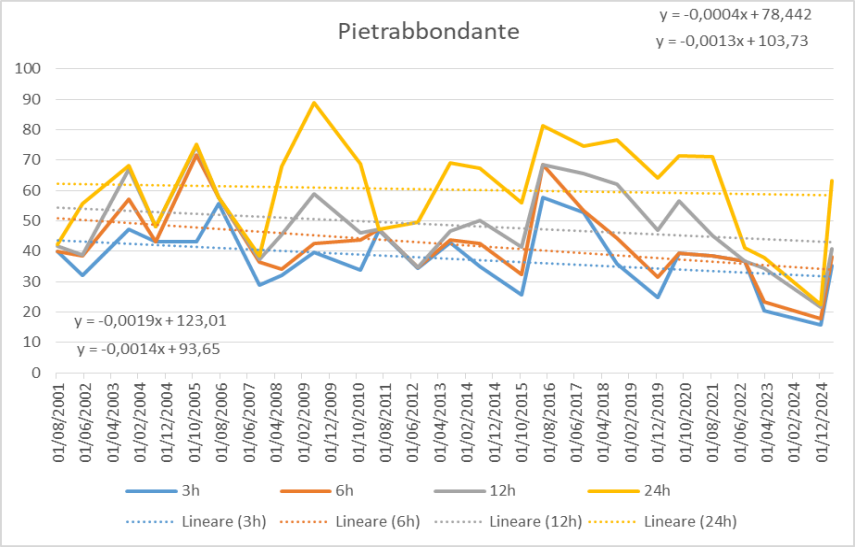
Convective precipitation predominantly characterises the warm semester, between **May and October**, and its spatial distribution is strongly influenced by local morphology, including the overheating of inland basins. In this case as well, mathematical models tend to underestimate the associated localised and intense precipitation phenomena.

Figure 2-23 1-4 –Recent climatological trends of annual maximum precipitation for time spans ranging from 3 to 24 hours, highlighting the interpolated linear trend functions and their corresponding equations.









The analysis of the outputs relating to the recent precipitation signal reveals a non-homogeneous pattern. In the Sannio–Matese area, although the statistics are not significant, the trend appears to show a slight overall increase for all the time spans analysed, whereas a slightly negative trend is observed in the coastal sector, Upper Molise, and the upper Volturno River basin.

This does not mean that absolute intense and heavy precipitation is increasing in the first area and decreasing in the second. Rather, a more detailed analysis of the graphs shows that recent precipitation outliers have occurred more frequently over the last few decades in the first area and during the first decade of the current century in the second area.

This evidence suggests that extreme events may be driven not so much by the evident warming that also characterises the study area, but rather by mesoscale and local-scale factors capable of influencing the quantitative behaviour of short-duration convective phenomena in the broad sense, as opposed to advective phenomena in the broad sense.

The previously mentioned analysis of all available historical series covering the last twenty years may either confirm or disprove this preliminary signal.

In conclusion, the initial results of the statistical analysis of the available data highlight several limitations of the current meteorological and climate monitoring network, which is excellently managed by the Molise Regional Civil Protection Service:

- **Lack of a significant number of homogeneous and continuous historical series** on which to perform statistical analyses and compare the results with those obtained from ERA5 model processing. In approximately twenty years, the current network, even without further densification, may be considered adequate for characterising the climatology of the physical territory of Molise.

With regard to the current spatial and altitudinal distribution of the operational network, the following measures are recommended:

- **Implementation of dedicated sensors**, which are essential in the mountainous area of the Meta Massif, where there are currently no monitoring stations above 500 metres above sea level.
- **Densification of the monitoring network in the Frentani Mountains**, particularly along secondary watershed ridges, where topography plays a key role in the distribution of summer orographic-convective phenomena and advective events during the cold season. In particular, stations are needed in the area between Agnone, Castiglione Messer Marino, Schiavi d'Abruzzo, and Torrebruna, near the border with the Province of Chieti.
- **Completion of the monitoring network in the coastal and lower hilly area bordering the Province of Foggia**, particularly in the Larino–Campomarino–Ururi–San Martino in Pensilis area, which has experienced high-magnitude flash floods in recent years. The same issue also affects the southern Sannio area and the Daunia area in the strict sense, along the borders with the Provinces of Foggia and Benevento.
- **Densification of the snow monitoring network above 1,200 metres above sea level**, particularly in relation to the possible occurrence of flash floods in the smaller catchments located below the Region's main mountain ranges, as well as high-magnitude floods in the middle and lower valley sections of the main river basins. Such events may occur when abundant snowfall is followed by the advection of Mediterranean air, with liquid precipitation reaching high elevations and causing rapid snowmelt.

This type of meteorological development at the regional scale of the Mediterranean basin is occurring with increasing frequency during spring and, to a lesser extent, in late autumn, not only along the Apennine range but also in the Pre-Alpine areas.

2.7 Work plan Phase 3

Phase 3, the final phase of the CLIMol Project, aims to implement practical measures across the territory to mitigate the risks identified and analysed during the first two phases of the project.

Intense Precipitation

From the precipitation perspective, the analyses highlighted that the current spatial distribution of meteorological stations is not sufficient to provide homogeneous territorial coverage, making data analysis more challenging. For this reason, one of the objectives of Phase 3 will be to assess the spatial distribution of the monitoring network and to further investigate the data analyses presented in Section 2.6.

Wildfires

With regard to wildfire risk, the study has emphasized that territorial mitigation measures must be supported by an adequate organizational structure consisting of qualified personnel, technical expertise, technologies, and operational procedures.

In this context, it is desirable that Phase 3 of the CLIMol Project initiates the process for updating the **Regional Wildfire Operational Plan**, which is the document through which each Italian Region regulates and organizes its wildfire prevention and suppression system. This document is essential not only for defining operational protocols, analyses, and training programmes, but also for planning future activities, including wildfire prevention works such as improvements to the road network, enhancement of strategic infrastructure, and other preparedness measures.

The expansion and improvement of the meteorological monitoring network would also provide significant benefits for wildfire forecasting activities. Continuous monitoring of **humidity, temperature, wind, and precipitation** supplies highly accurate information on the indices and components used to calculate the **Fire Weather Index (FWI)**, thereby improving the assessment and prediction of wildfire danger conditions.

3 Conclusions Phase 2- Climate risk assessment

Several conclusions can be drawn from the CLIMol Project. These are presented below according to the specific risk category analysed.

Wildfires

The Molise Region is vulnerable to wildfires due to the presence of sensitive elements such as ecosystems, urban settlements, and economic activities. The analysis of this environmental hazard has made it possible to focus more clearly on issues related to **forecasting**, particularly the lack of a sufficiently robust local dataset, and **territorial planning**, highlighting how many tourism and accommodation facilities are especially exposed to wildfire risk.

Intense Precipitation

Although the results obtained from the different analyses are not entirely consistent, it remains evident that the Region's vulnerability and exposure to intense precipitation events are significant. An example is the precipitation event of **April 2026**, partly characterised by snowfall, which affected Molise and temporarily disrupted major transport connections to southern Italy.

Another important outcome of the analysis is the need to improve the **Regional Monitoring Network dataset** through the installation of additional meteorological stations, ensuring a more homogeneous and comprehensive spatial coverage of the territory. Such an enhancement would significantly improve the quality of climate analyses, hazard assessments, and future risk projections.

4 Progress evaluation

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
At least [2] workflows successfully applied on Deliverable 1	**goal achieved**
A minimum of [2] communication actions taken to share results with stakeholders (specific project sections also on www.regione.molise.it and www.protezionecivile.molise.it)	**goal achieved**
A minimum of [3] publications and dissemination actions (also using official social media pages (@pcmolise) while creating the hashtag #CLIMol for better spreading information)	**goal achieved**
[2] press conference	**objective partially achieved (1 press conference held, second to be held)**
A minimum of [2] articles in regional media mentioning the project	**goal achieved**
A minimum of [2] fully updated hazard maps of the applicant territory included in Deliverables 2	**goal achieved**
A minimum of [2] updated exposure maps of the applicant territory included in Deliverables 2	**goal achieved**
A minimum of [2] updated risk maps of the applicant territory included in Deliverables 2	**goal achieved**
A minimum of [7] different categories of stakeholders involved in the activities of the project	**goal achieved**

Table 4-2 Overview milestones

Milestones	*Progress*
CLIMAAX 1st workshop participation in Barcelona	**goal achieved**
Stakeholders mapping	**goal achieved**
Workflow 1 application	**goal achieved**
Workflow 2 application	**goal achieved**
Data collection	**goal achieved**
Risks scenario(s) refinement and improvement	**Objective partially achieved (the inhomogeneity of the local network data does not allow the complete application of the CLIMAAX workflows, but we are very satisfied as it was an opportunity to enhance and analyse the data of our local network and hypothesize spatial distribution solutions for**

Milestones	*Progress*
	the new network to be proposed in the Phase 3 deliverable, at the end of the project)
Evaluate impacts on RM plans	**goal achieved. Regional stakeholders have shared the project results and, above all, the proposed intervention priorities—foremost among them being data sharing to gain insight into what is happening across the territory. We are committed to achieving this shared goal as soon as possible, specifically to ensure universal access to recorded data, as we believe that data-driven insight is the foundation of knowledge. In any case, we will strive to improve outcomes in this area during Phase 3, which is already underway.**
Stakeholders participation meetings	**goal achieved**
Stakeholders mitigation proposals integration	**Ongoing activities**
CLIMAAX 2nd workshop participation in Bruxelles	**Activities to do**

5 Supporting documentation

- Dissemination

Document/Site	Note	Link
Protezione Civile Molise	Section of the Molise Civil Protection's official website dedicated to disseminating the project results.	https://protezionecivile.molise.it/climaax_climol/
Dissemination of the Phase I report	Italian Version	https://protezionecivile.molise.it/wp-content/uploads/2026/10/CLIMAAX_M6_Deliverable_template_FSTP_final_rev02.pdf
Dissemination of the Phase I report	English Version	https://protezionecivile.molise.it/wp-content/uploads/2026/10/CLIMAAX_M6_Deliverable_template_FSTP_final_rev02_en.pdf
Dissemination geographic data of CLIMAAX-CLIMOL project	Civil Protection Geocatalog with accredited access to the entire catalog (approximately 200 agencies)	https://resilience.arpes.it/login
Heavy Raifall Analyses based on CLIMAAX toolbox algorithms and local sensor network		https://protezionecivile.molise.it/climaax_climol/

molise_heavyrain_risk_shift_magnitude_rcp85_100mm24h_2041-2070 2_CAE.png	Change in Heavy Rainfall Magnitude (RCP8.5, 2041–2070) Maps the projected shift in precipitation intensity for 24-hour rainfall events exceeding 100 mm under the high-emissions RCP8.5 scenario.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_risk_shift_frequency_rcp85_100mm24h_2041-2070 2_CAE.png	Change in Extreme Event Frequency (RCP8.5, 2041–2070) Displays the expected change in frequency for 24-hour extreme rainfall events (≥100 mm) under the RCP8.5 scenario.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_pr_annualMax_3h_2041-2070_Termoli_CAE.png	3-Hour Annual Maximum Rainfall Hazard – Termoli (2041–2070) Projections of maximum annual 3-hour precipitation hazard for the municipality of Termoli.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_pr_annualMax_3h_2041-2070_Isernia_CAE.png	3-Hour Annual Maximum Rainfall Hazard – Isernia (2041–2070) Projections of maximum annual 3-hour precipitation hazard for the municipality of Isernia.	https://protezionecivile.molise.it/climaax_climol/

molise_heavyrain_hazard_pr_annualMax_3h_2041-2070_Campobasso_CAE.png	3-Hour Annual Maximum Rainfall Hazard – Campobasso (2041–2070) Projections of maximum annual 3-hour precipitation hazard for the municipality of Campobasso.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_mean_prec_rcp85_24h_2010-2025_2041-2070_CAE.png	Mean 24-Hour Precipitation Hazard Comparison (RCP8.5) Comparative hazard assessment of mean 24-hour precipitation between the baseline (2010–2025) and future projections (2041–2070).	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_espo_rcp85_24h_10y_return_period_2041_2070_CAE.png	10-Year Return Period Exposure – RCP8.5 (2041–2070)Exposure analysis for a 24-hour rainfall event with a 10-year return period under the high-emissions RCP8.5 scenario.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_espo_rcp45_24h_10y_return_period_2041_2070_CAE.png	10-Year Return Period Exposure – RCP4.5 (2041–2070)Exposure analysis for a 24-hour rainfall event with a 10-year return period under the moderate RCP4.5 scenario.	https://protezionecivile.molise.it/climaax_climol/

molise_heavyrain_espo_rcp26_24h_10y_return_period_2041_2070_CAE.png	10-Year Return Period Exposure – RCP2.6 (2041–2070) Exposure analysis for a 24-hour rainfall event with a 10-year return period under the low-emissions RCP2.6 scenario.	https://protezionecivile.molise.it/climaax_climol/
Heavy Rainfall Analyses based on CLIMAAX toolbox algorithms and CHAPTER_RISICO data		
molise_heavyrain_risk_shift_magnitude_rcp85_100mm24h_2041-2070 2_CHAPTER_RISICO.png	Change in Heavy Rainfall Magnitude (RCP8.5, 2041–2070) Shift in precipitation intensity for 24-hour rainfall events exceeding 100 mm under the high-emissions RCP8.5 scenario.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_risk_shift_frequency_rcp85_100mm24h_2041-2070_CHAPTER_RISICO.png	Change in Extreme Event Frequency (RCP8.5, 2041–2070) Shift in frequency of 24-hour extreme rainfall events (≥100 mm) under the RCP8.5 scenario.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_pr_annualMax_3h_2041-2070_Termoli_CHAPTER_RISICO.png	3-Hour Annual Maximum Precipitation Hazard – Termoli (2041–2070) Projections of annual maximum 3-hour rainfall hazard for the municipality of Termoli.	https://protezionecivile.molise.it/climaax_climol/

molise_heavyrain_hazard_pr_annualMax_3h_2041-2070_Isernia_CHAPTER_RISICO.png	3-Hour Annual Maximum Precipitation Hazard – Isernia (2041–2070) Projections of annual maximum 3-hour rainfall hazard for the municipality of Isernia.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_pr_annualMax_3h_2041-2070_Campobasso_CHAPTER_RISICO.png	3-Hour Annual Maximum Precipitation Hazard – Campobasso (2041–2070) Projections of annual maximum 3-hour rainfall hazard for the municipality of Campobasso.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_mean_prec_rcp85_24h_1982-2022_2041-2070_CHAPTER_RISICO.png	Mean 24-Hour Precipitation Hazard Comparison (RCP8.5) Comparison of mean 24-hour precipitation hazard between the historical baseline (1982–2022) and future projections (2041–2070).	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_GEV_termoli_CHAPTER_RISICO.png	Generalized Extreme Value (GEV) Distribution – Termoli GEV statistical model fit for extreme precipitation hazard analysis in Termoli.	https://protezionecivile.molise.it/climaax_climol/

molise_heavyrain_hazard_GEV_isernia_CHAPTER_RISICO.png	Generalized Extreme Value (GEV) Distribution – Isernia GEV statistical model fit for extreme precipitation hazard analysis in Isernia.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_GEV_campobasso_CHAPTER_RISICO.png	Generalized Extreme Value (GEV) Distribution – Campobasso GEV statistical model fit for extreme precipitation hazard analysis in Campobasso.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_expected_prec_3h_2041-2070_Termoli_CHAPTER_RISICO.png	Expected 3-Hour Rainfall Hazard – Termoli (2041–2070) Expected 3-hour precipitation hazard projections for the municipality of Termoli.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_expected_prec_3h_2041-2070_Isernia_CHAPTER_RISICO.png	Expected 3-Hour Rainfall Hazard – Isernia (2041–2070) Expected 3-hour precipitation hazard projections for the municipality of Isernia.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_hazard_expected_prec_3h_2041-2070_Campobasso_CHAPTER_RISICO.png	Expected 3-Hour Rainfall Hazard – Campobasso (2041–2070) Expected 3-hour precipitation hazard projections for the municipality of Campobasso.	https://protezionecivile.molise.it/climaax_climol/

molise_heavyrain_espo_rcp85_24h_10y_return_period_2041_2070_CHAPTER_RISICO.png	10-Year Return Period Exposure – RCP8.5 (2041–2070) Exposure analysis for a 24-hour rainfall event with a 10-year return period under the high-emissions RCP8.5 scenario.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_espo_rcp45_24h_10y_return_period_2041_2070_CHAPTER_RISICO.png	10-Year Return Period Exposure – RCP4.5 (2041–2070) Exposure analysis for a 24-hour rainfall event with a 10-year return period under the moderate RCP4.5 scenario.	https://protezionecivile.molise.it/climaax_climol/
molise_heavyrain_espo_rcp26_24h_10y_return_period_2041_2070_CHAPTER_RISICO.png	10-Year Return Period Exposure – RCP2.6 (2041–2070) Exposure analysis for a 24-hour rainfall event with a 10-year return period under the low-emissions RCP2.6 scenario.	https://protezionecivile.molise.it/climaax_climol/
Fire Analyses based on CLIMAAX toolbox algorithms		
molise_wildfire_vulnerability_Wui_rcp26_2045_2054.png	Wildfire Vulnerability: Wildland-Urban Interface (RCP2.6, 2045–2054) Assesses wildfire vulnerability focusing on the Wildland-Urban Interface (WUI) area under the low-emissions RCP2.6 scenario.	https://protezionecivile.molise.it/climaax_climol/

molise_wildfire_vulnerability_RestCost_rcp26_2045_2054.png	Wildfire Vulnerability: Restoration Costs (RCP2.6, 2045–2054) Evaluates vulnerability based on potential ecosystem restoration costs following a wildfire under RCP2.6.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_vulnerability_ProtArea_rcp26_2045_2054.png	Wildfire Vulnerability: Protected Areas (RCP2.6, 2045–2054) Maps wildfire vulnerability specifically within protected nature reserves and ecological zones under RCP2.6.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_vulnerability_PopDens_rcp26_2045_2054.png	Wildfire Vulnerability: Population Density (RCP2.6, 2045–2054) Analyses wildfire vulnerability in terms of human exposure and population density distribution under RCP2.6.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_vulnerability_Irrep_rcp26_2045_2054.png	Wildfire Vulnerability: Ecological Irreplaceability (RCP2.6, 2045–2054) Measures vulnerability based on irreplaceability of ecological species and habitats at risk under RCP2.6.	https://protezionecivile.molise.it/climaax_climol/

molise_wildfire_vulnerability_FWI_rcp26_2045_2054.png	Wildfire Vulnerability: Fire Weather Index (RCP2.6, 2045–2054) Vulnerability assessment derived from projected meteorological fire risk factors (FWI) under RCP2.6.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_vulnerability_BurnVeg_rcp26_2045_2054.png	Wildfire Vulnerability: Burnable Vegetation (RCP2.6, 2045–2054) Evaluates vegetation susceptibility and fuel availability for wildfire propagation under RCP2.6.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_risk_FWI_risk.png	Overall Wildfire Risk (FWI-Based) Integrated wildfire risk assessment based on Fire Weather Index (FWI) mapping.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_risk_FWI_rcp26_average_2045_2054.png	Projected Wildfire Risk (RCP2.6, 2045–2054) Average projected wildfire risk based on FWI under the low-emissions RCP2.6 scenario.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_risk_FWI_historical_average_1982_2022.png	Historical Wildfire Risk (1982–2022) Baseline assessment showing the 40-year historical average wildfire risk derived from FWI data.	https://protezionecivile.molise.it/climaax_climol/

molise_wildfire_hazard_FWI_historic_rcp85.png .png	Historical vs. RCP8.5 Wildfire Hazard Comparison Comparative hazard assessment between historical baseline conditions and high-emissions RCP8.5 projections.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_hazard_FWI_hazard.png	Wildfire Hazard Map (FWI-Based) General hazard map illustrating overall meteorological conditions favorable to fire occurrence.	https://protezionecivile.molise.it/climaax_climol/
molise_wildfire_hazard_FWI_furure_rcp85_2050_2051.png	Future wildfire hazard map for the Molise region (Italy) under the RCP 8.5 emissions scenario, showing the projected Fire Weather Index (FWI) for the 2050–2051 period	https://protezionecivile.molise.it/climaax_climol/
HeavyRainfall based Molise Region Civil Protection methodology		
molise_heavyrain_vulnerability_vulnerable_buildings.tif	Heavy Rain Vulnerability: Buildings Spatial layer mapping the structural vulnerability of buildings exposed to heavy rainfall events in Molise.	https://resilience.arpes.it/login
molise_heavyrain_risk_mean_24h_precipitation .tif	Heavy Rain Risk: 24-Hour Mean Precipitation Integrated risk map for heavy rainfall impacts evaluated over a 24-hour duration.	https://resilience.arpes.it/login

molise_heavyrain_risk_mean_3h_precipitation.tif	Heavy Rain Risk: 3-Hour Mean Precipitation Integrated risk map for sub-daily heavy rainfall impacts evaluated over a 3-hour duration.	https://resilience.arpes.it/login
molise_heavyrain_hazard_24h.tif	Heavy Rain Hazard: 24-Hour Event Raster hazard layer representing precipitation intensity and potential hazard for 24-hour storm events.	https://resilience.arpes.it/login
molise_heavyrain_hazard_3h.tif	Heavy Rain Hazard: 3-Hour Event Raster hazard layer representing short-duration extreme precipitation intensity for 3-hour storm events.	https://resilience.arpes.it/login
molise_heavyrain_basic_data_mean_24h_precipitation.tif	Baseline Data: 24-Hour Mean Precipitation Base input dataset representing mean 24-hour precipitation levels used for hazard and risk modeling.	https://resilience.arpes.it/login
molise_heavyrain_basic_data_mean_3h_precipitation.tif	Baseline Data: 3-Hour Mean Precipitation Base input dataset representing sub-daily mean 3-hour precipitation levels used for modeling.	https://resilience.arpes.it/login
Fire based on Molise Region Civil Protection methodology		

molise_wildfire_vulnerability_wildfire.tif	Wildfire Vulnerability Layer Raster dataset mapping overall territorial vulnerability to wildfire impacts across Molise.	https://resilience.arpes.it/login
molise_wildfire_risk_winter_wildfire_risk.tif	Winter Wildfire Risk Map Raster layer evaluating seasonal wildfire risk conditions during winter months.	https://resilience.arpes.it/login
molise_wildfire_risk_summer_wildfire_risk.tif	Summer Wildfire Risk Map Raster layer assessing peak seasonal wildfire risk conditions during summer months.	https://resilience.arpes.it/login
molise_wildfire_hazard_hazard_municipalities.shp	Wildfire Hazard by Municipality Vector dataset providing aggregated wildfire hazard levels at the municipal administrative level (Comuni).	https://resilience.arpes.it/login
molise_wildfire_hazard_hazard_basic_areas.shp	Wildfire Hazard by Basic Territorial Units Vector dataset presenting wildfire hazard assessment segmented by local sub-municipal units (Aree di Base).	https://resilience.arpes.it/login
Multi risk based on Molise Region Civil Protection methodology		

molise_cumu_risk_upper_third.shp	Highest Cumulative Risk Zones (Upper Tertile) Vector dataset identifying territorial areas falling within the highest third (top 33%) of combined cumulative multi-risk.	https://resilience.arpes.it/login
molise_cumu_risk__hr24h_inc.tif	Cumulative Risk: 24-Hour Heavy Rain & Wildfire Raster layer combining multi-hazard risk for 24-hour heavy rainfall events and wildfire hazard (incendi).	https://resilience.arpes.it/login
molise_cumu_risk__hr3h_inc.tif	Cumulative Risk: 3-Hour Heavy Rain & Wildfire Raster layer combining multi-hazard risk for short-duration 3-hour heavy rainfall events and wildfire hazard (incendi).	https://resilience.arpes.it/login

- Main report
- Workflow:
  - Wildfire: FWI
  - Heavy rainfalls

6 References

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