Deliverable Phase 1 – Climate risk assessment

Climate Risk and Vulnerability Assessment of the Region of Murcia (REGMURCIA CLIMAAX)

Spain, Region of Murcia

HORIZON-MISS-2021-CLIMA-02-01 - Development of climate change risk assessments in European regions and communities based on a transparent and harmonised Climate Risk Assessment approach

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Document Information

Deliverable Title	Phase 1 – Climate risk assessment
Brief Description	Deliverable 1 presents the baseline Climate Risk and Vulnerability Assessment for the Region of Murcia (REGMURCIA CLIMAAX). Applying the harmonised CLIMAAX methodology, it screens the region's main climate hazards—droughts, heatwaves, and river-coastal flooding—. The report highlights priority risk "hot-spots", provides an initial appraisal of severity, urgency and adaptive capacity, and sets out the work plan that will guide higher-resolution analyses and stakeholder-led adaptation design in Phases 2-3. These results supply the first evidence base for regional decision-makers to integrate science-based adaptation measures into policy, advance sector-specific action plans, and strengthen Region of Murcia's Climate Change Mitigation and Adaptation Strategy.
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Abbreviations and acronyms

Abbreviation / acronym	Description
AEMET	Agencia Estatal de Meteorología
CARM	Autonomous Community of the Region of Murcia
CC	Climate Change
CEDEX	Center for Hydrographic Studies
CES	Economic and Social Council of the Region of Murcia
CHS	Segura Hydrographic Confederation
CLC	Corine Land cover
CRA	Climate Risk Assessment
CREM	Regional Statistics Centre of Murcia
DEM	Digital Elevation Model
EEA	European Environment Agency
ERMACC	Estrategia Regional de Mitigación y Adaptación al Cambio Climático de la Región de Murcia
GVA	Gross Value Added
IMIDA	Murcian Institute of Agricultural and Environmental Research and Development
INE	Spanish National Statistics Institute
MITECO	Ministry for the Ecological Transition and the Demographic Challenge
PNACC	National Climate Change Adaptation Plan
RP	Return Period
SLR	Sea Level Rise
SNCZI	National Flood Hazard Mapping System
SSP	Shared Socioeconomic Pathways
UMU	University of Murcia

Executive summary

This deliverable presents the results of Phase 1 of the REGMURCIA CLIMAAX project, which supports the Region of Murcia in implementing a Climate Risk and Vulnerability Assessment (CRA) based on the CLIMAAX Common Methodology. The region, located in southeastern Spain, faces increasing climate-related pressures, including droughts, extreme heat, and river and coastal flooding. This deliverable addresses the need to better understand these risks and establish a solid, regionally tailored analytical and institutional foundation for adaptation planning. The document is intended for regional decision-makers, technical experts, and stakeholders involved in climate adaptation, territorial planning, water resource management, emergency services, and related domains. It offers a structured diagnosis of climate risks based on harmonised European indicators, complemented by an initial assessment of consistency with high-resolution local data and preliminary stakeholder input.

Phase 1 activities were organised in line with the CLIMAAX framework and included: (1) the definition of objectives and scope of the assessment; (2) the application of three risk analysis workflows targeting priority hazards: droughts, river/coastal floods and heatwaves; (3) the collection and integration of regional and European datasets to analyse exposure and vulnerability patterns: (4) the initial engagement of stakeholders through a Risk-Ownership Committee and exploratory expert interviews; (5) the preliminary evaluation of key risks based on severity, urgency, and adaptive capacity; and (6) the establishment of a monitoring framework and forward-looking work plan for Phases 2 and 3.

The results highlight several key findings. The Region of Murcia is highly exposed to multiple and intensifying climate hazards, with differentiated spatial patterns. Agricultural areas, particularly crops such as olives and almonds, are especially vulnerable to agricultural drought. Yield losses are in most of cases over a mean value of 30%, reaching up to 60% in some areas in the RCP 8.5 by the end of the century, signaling a major risk for regional agricultural resilience. Coastal and low-lying urban areas, particularly along the East Coast of the region, are exposed to increasing flood risks. Projected flooded areas grow significantly with return periods and over time: in 2050, under RP250, flooded area estimates reach 156.6 hm² with NASADEM and 399.8 hm² with MERIT DEM. Corresponding economic losses also rise sharply, with river flood damages increasing from €7.6 billion (RP10) to over €11.1 billion (RP500). Urban flood risk is concentrated in the metropolitan area, with up to 141,517 people potentially exposed and more than 54,000 displaced under RP500 scenarios. Also, heatwaves emerge as a particularly severe and rapidly escalating hazard. The number of annual events is projected to increase from ~3 to over 50 by the end of the century under RCP 8.5 (an order-of-magnitude rise). Interior and southern areas show the largest increases, with elderly populations in these zones facing very high to extreme risk levels by 2100. Despite good availability of spatial datasets describing exposure and hazard distribution, the analysis reveals notable gaps in vulnerability data—especially for social and demographic indicators. Some global and European datasets also lack the spatial resolution required for operational decision-making at local or municipal levels. Finally, the initial stakeholder engagement confirms a solid baseline of institutional expertise, but also highlights the need for stronger vertical coordination between regional and local administrations, as well as broader inclusion of key sectors such as healthcare, critical infrastructure, and civil society. Early feedback has proven essential for validating the assessment outputs and ensuring alignment with regional planning priorities.

In terms of project performance, all key deliverables, milestones, and indicators scheduled for Phase 1 have been met. The Climate Risk and Vulnerability Assessment has been completed and documented in this report. A stakeholder engagement structure has been initiated and a dedicated webpage has been created. The outcomes contribute to the overall CLIMAAX project by demonstrating how the Common Methodology can be adapted to regional contexts, and by identifying data, policy, and institutional needs to be addressed in subsequent phases.

In conclusion, this deliverable provides an analytical foundation for climate adaptation planning in the Region of Murcia. It defines the region’s main hazards and vulnerabilities, identifies key data and governance gaps, and proposes a clear roadmap for the refinement of the assessment and the design of actionable adaptation measures in the upcoming phases of REGMURCIA CLIMAAX. It positions the Region to take informed and coordinated steps toward climate resilience, aligned with the European Climate Law and the objectives of the CLIMAAX project.

1 Introduction

1.1 Background

The Region of Murcia, located in the southeast of the Iberian Peninsula, is a Mediterranean region characterized by strong geographical contrasts, including coastal areas, inland basins, and mountain ranges. It covers an area of approximately 11,300 km² and has a population of around 1.5 million inhabitants. The region's economy relies heavily on agriculture, agri-food industry, tourism, and increasingly on renewable energy and logistics, which makes it particularly sensitive to climate-related impacts on water availability, coastal integrity, and infrastructure resilience.

Murcia is one of the most arid regions in Europe, with a semi-arid Mediterranean climate marked by high interannual variability in precipitation and frequent episodes of drought. However, the most critical natural risks affecting the region are hydrometeorological hazards, particularly flash floods, prolonged droughts, and heatwaves. These hazards have increased in frequency and intensity in recent decades due to climate change and growing urban pressure on flood-prone areas.

The region's topography, land use patterns, and urban development, often in hazard-prone areas, amplify the exposure and vulnerability of the population and economic activities. Furthermore, the combination of climate hazards with social vulnerability, such as aging populations in rural municipalities or unregulated urban expansion, increases the systemic risk.

At the sectoral level, the CARM economy presents the classic distribution of a developed and tertiary economy. However, the peculiarities of its economic structure, together with its geographic endowment, make the CARM economy and society especially vulnerable to climate risks, especially river and coastal flooding, heatwaves, and droughts. Four key economic subsectors are crucial in this regard: agriculture, tourism, trade, and transport.

According to the Gross Value Added (GVA) by sector of economic activity (Figure 1-1), of the €36,814,662 GVA in the CARM in 2023, 69% comes from the services sector. Compared to the national average of 75%, this reflects a lower tertiary sector in the CARM compared to the national average. This gap is due to the greater weight of regional agriculture and industry. In the case of agriculture, the regional figures are almost double the national figure (4.6% of regional GVA, compared to 2.7% nationally).

However, it is necessary to examine the underlying differences to understand the specificity of the regional economy. Thus, of the total GVA of the industrial sector in the CARM, 24% corresponds to the food industry, a sector directly linked to activities related to the agricultural model. Similarly, of the more than 1.2 million motor vehicles in the CARM in 2023, more than 12% were trucks and vans. These figures are much higher than the national average and highlight another highly specialized regional sector, indirectly related to agriculture: the transportation of agricultural products and goods. The composition of regional exports demonstrates this fact. Thus, in 2024, the CARM exported agricultural goods worth over €3.75 billion. These values represent 25.5% of the more than €14.2 billion exported. Similarly, in second place, with 21.3% (€3.036 billion) of the value of exports, are goods from the food industry. Thus, almost €7 billion of regional exports annually come directly or indirectly from agriculture. This reflects the economic and social importance of a sector highly vulnerable to climate change (CREM, 2025).

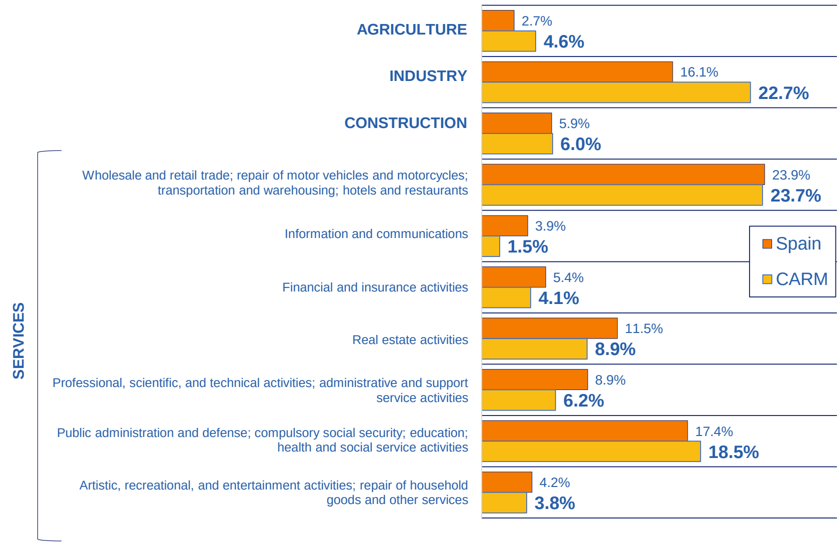


Figure 1-1 GVA by sector of economic activity in the CARM and Spain in 2023. Figure source: CREM, 2025.

The social and territorial relevance of agriculture is also reflected in other facts. More than 11% of employment and 14% of total unemployment in the CARM correspond to the agricultural sector. Values much higher than the percentage weight of the sectoral GVA, showing lower average incomes and a greater impact of unemployment in agriculture than in the rest of the sectors (Figure 1-2).

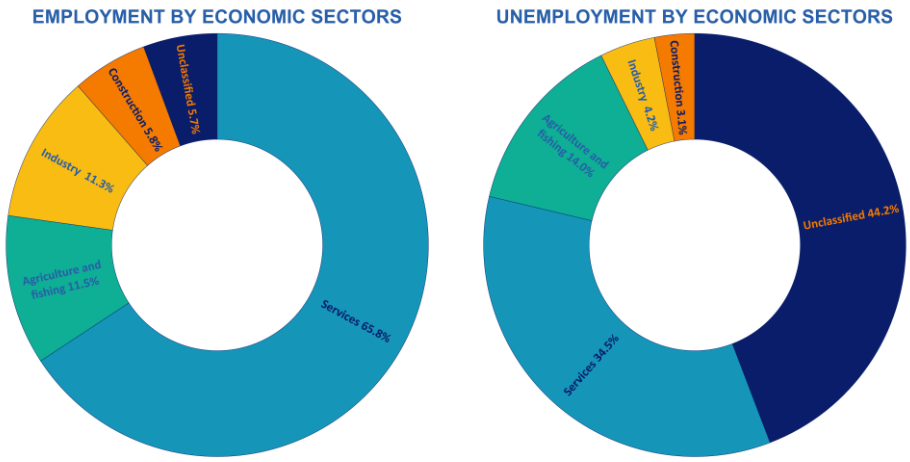


Figure 1-2 Employment and unemployment by economic sector in the CARM in the first quarter of 2025. Figure source: CREM, 2025.

On the other hand, the territorial, landscape, and environmental importance of agriculture is overwhelming. More than 31% of the CARM's surface area corresponds to cropland. Of this area, 45.8% corresponds to irrigated agriculture and the remaining 54.2% is dryland.

This duality also extends to crop types, with significant asymmetries in terms of production (in tons) and cultivated area (Figure 1-3). While almost two-thirds of the cultivated area corresponds to woody crops (almonds being particularly prominent, accounting for 26% of the cultivated area), production of this type of crop falls to 44% (almonds represent only 0.7% of production). Other significant cultivated areas correspond to olive groves, vineyards, cereals, citrus fruits, and vegetables. However, this does not correspond to production. While vegetables account for only 18% of the cultivated area, they represent almost half of the total production. This confirms the economic engine of agriculture for the regional economy. Something similar occurs with citrus fruit, with production exceeding its spatial representation. Quite the opposite of what occurs with cereals, olive groves, and other types of production. These values reflect an asymmetrical agricultural system, with highly productive fruit and vegetable agriculture versus traditional, dryland agriculture, which has a significant spatial footprint but little direct economic impact.

Other key sectors with high vulnerability include transportation and the road network, directly affected by river and coastal flooding. Key sectors in the CARM include oil refining and the energy supply industry (11.3% of the regional GVA in 2023) and a value of refined oil exports exceeding €2.24 billion in 2024. These values depend on the Cartagena-Escombreras petrochemical hub, located on the regional coast, with the resulting vulnerability to coastal flooding.

Regional tourism deserves special mention, with an estimated contribution of more than 10.3% of regional GDP in 2024, still two percentage points below the Spanish average. The tourism sector is primarily driven by domestic tourists, 60% of whom stay in a secondary residence, mostly in coastal areas, during the summer (CES, 2025). This situation of high seasonality in the months of higher temperatures and in coastal areas poses a challenge for adaptation to CC.

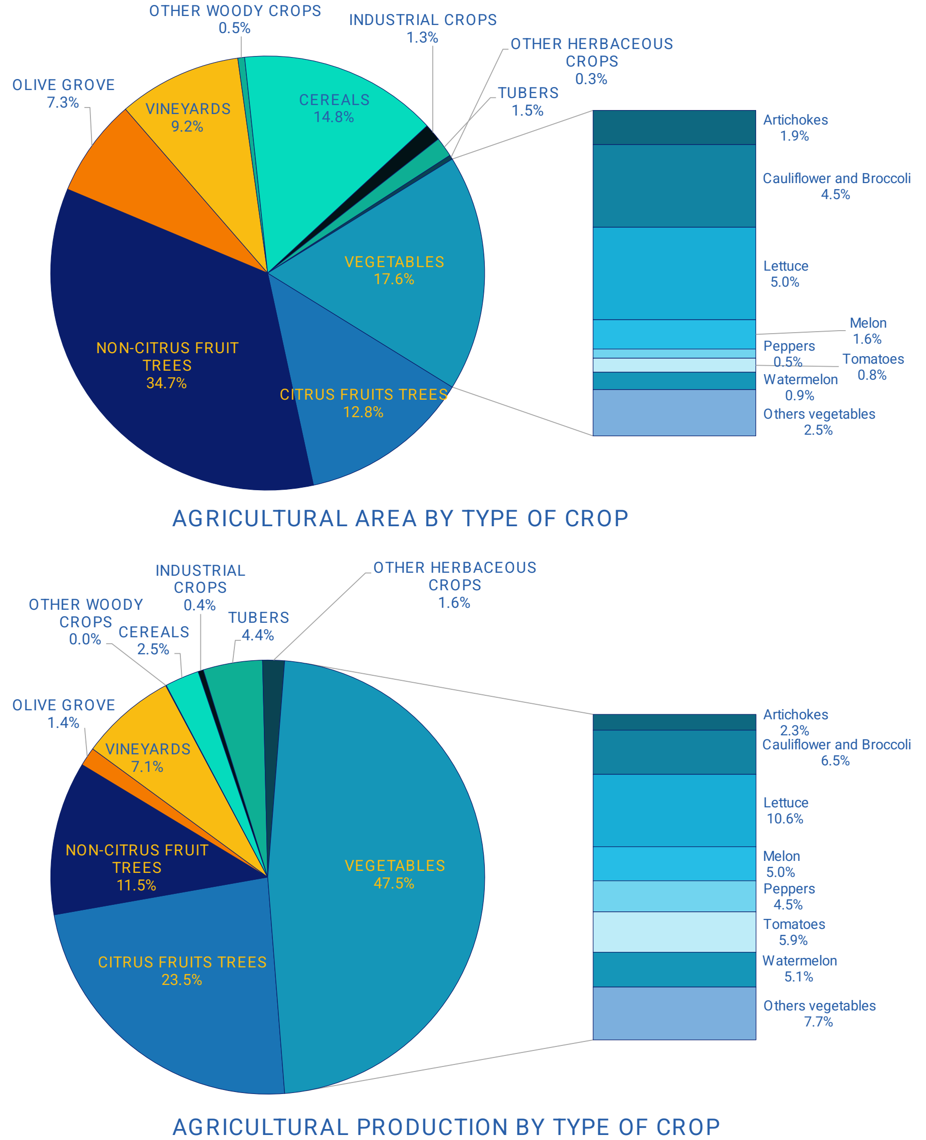


Figure 1-3 Agricultural surface (top) and production (bottom) in the CARM according to crop type (Average 2019-2023). Figure source: CREM, 2025.

1.2 Main objectives of the project

REGMURCIA CLIMAAX will deliver a fully CLIMAAX-compliant Climate Risk Assessment for the Region of Murcia, ensuring scientific rigour, transparency and comparability with other European territories. The objectives that follow set out how the project will (1) quantify priority hazards; (2) pinpoint risk “hot-spots”; (3) prioritise action through participatory assessment; and (4) build the technical and governance capacity required for just and effective climate adaptation. These objectives can be summarised as:

- Conduct an Integrated Climate Risk Assessment (CRA) fully compliant with the five stages of the CLIMAAX Framework—Scoping, Risk Exploration, Risk Analysis, Key Risk Assessment, and Monitoring & Evaluation—for CARM.
- Quantify current and future risks for priority climate hazards in CARM. In this regard, the priority workflows implemented are droughts and river & coastal floods. Some information about heatwaves is also included.
- Locate spatial "hotspots" and sectoral vulnerabilities (irrigated fruit and vegetable farms, critical infrastructure, urban heat islands, tourism assets, and protected natural areas) to support evidence-based decision-making.
- Prioritize risk management through a participatory Key Risk Assessment, applying the severity, urgency, and adaptive capacity criteria defined in the CLIMAAX Handbook and linking the results to the Regional Strategy for Mitigation and Adaptation to Climate Change of the Region of Murcia (ERMACC).
- Strengthen technical capacities and collaborative governance through practical training in CLIMAAX workflows, fostering the autonomy of the CARM for future CRA updates.
- Prepare phases 2 and 3 (adaptation and investment design) by establishing metrics, baselines, and stakeholder commitments that allow for the development of measures and the implementation of resilience mechanisms.
- Strengthen collaboration between public authorities, academia, and civil society, ensuring participatory governance and building lasting technical capacity.

The project is expected to deliver the following key benefits, adding clear value to both the CARM and the wider CLIMAAX community:

- Harmonized methodology and European comparability: The application of the standard protocol allows the results obtained in the CARM to be directly compared with those of more than 50 CLIMAAX regions, fostering mutual learning and benchmarking.
- Access to open and validated workflows: Python and R notebooks, along with curated data sets for droughts, floods, extreme heat, etc., shorten analysis times and ensure methodological traceability.
- Strengthened credibility and greater political adoption: Alignment with a framework endorsed by the European Commission increases the legitimacy of the diagnosis among legislators, funders, and civil society, facilitating the translation of science into concrete policies.
- Resource efficiency and scalability: Modular workflows avoid duplication, optimize time, and are easily updated with new scenarios (e.g., CMIP7) or census data. Continuous training and just resilience: The Handbook's training modules promote a lifelong learning cycle, enabling CARM institutions to iterate the CRA and incorporating emerging hazards (composite climate events, saltwater intrusion).

With these objectives and benefits, REGMURCIA CLIMAAX is positioned as an essential catalyst for accelerating adaptation and resilience to climate change in one of the Mediterranean regions most affected by water stress and pressure on coastal ecosystems.

1.3 Project team

The team implementing REGMURCIA CLIMAAX combines the regulatory authority of the CARM with the scientific and technical excellence of the University of Murcia (UMU).

The CARM, through the Regional Secretary of Energy, Sustainability and Climate Action, assumes overall coordination, provides administrative data, and ensures the integration of results into the ERMACC, its legal framework, and other territorial management plans. UMU is responsible for the full application of the CLIMAAX methodology, the refinement of the assessment using high-resolution climate databases and GIS, advanced modeling of droughts, floods, and heatwaves, as well as the facilitation of technical meetings and the participatory process of the Key Risk Assessment.

The UMU team is made up of experts in Geography and Earth Physics with more than 200 JCR-Q1 publications and regularly collaborates with internationally renowned centers such as NCAR, ETH Zurich, and Yale University. It leverages proprietary tools (CLIMAX, SINQLAIR, COST, 4DROP) and a 1,008-CPU, 1 PB HPC cluster, ensuring rapid calculations and scientific traceability. This partnership ensures a robust climate risk assessment aligned with European standards and backed by the institutional capacity necessary to update and transform it into concrete adaptation measures.

1.4 Outline of the document's structure

This deliverable is organised into several sections that follow the logic of the CLIMAAX framework and reflect the structure and outcomes of the Climate Risk and Vulnerability Assessment conducted for the Region of Murcia during Phase 1 of the REGMURCIA CLIMAAX project.

Section 1 introduces the overall context and motivation of the project. It outlines the socioeconomic and climatic characteristics of the Region of Murcia (section 1.1), explains the main objectives and expected benefits of the assessment (section 1.2), presents the project team and institutional structure (section 1.3), and closes with this summary of the document's organisation (section 1.4).

The following Section 2 constitutes the core of the deliverable, detailing the Climate Risk Assessment carried out in accordance with the CLIMAAX methodology. It is divided into six main subsections, each corresponding to a specific step in the CLIMAAX CRA methodology.

- Section 2.1 – Scoping defines the objectives of the CRA and situates the assessment within the broader policy, socioeconomic, and governance context of the Region of Murcia. It also describes the stakeholder landscape and outlines the participatory process implemented to ensure risk ownership and engagement across sectors.
- Section 2.2 – Risk Exploration initiates the technical analysis with a screening of relevant climate hazards in the region of Murcia. It focuses on the selection of key hazards (heatwaves, droughts, and floods, both river and coastal) and explains the rationale behind the chosen workflows. It also addresses the choice of climate scenarios and explores the availability and limitations of input data.
- Section 2.3 – Risk Analysis presents the preliminary results derived from the application of the selected CLIMAAX workflows. It is divided into three subsections, each describing a specific analytical workflow: Workflow #1 (droughts); Workflow #2 (coastal and river flooding; and Workflow #3 (heatwaves).

- Section 2.4 – Preliminary Key Risk Assessment Findings synthesises the core outcomes of the risk analysis. It evaluates the severity, urgency, and adaptive capacity associated with each of the identified hazards and offers an initial prioritisation of risks for the Region of Murcia.
- Section 2.5 – Preliminary Monitoring and Evaluation proposes a preliminary structure for monitoring progress and evaluating the effectiveness of adaptation actions during future project phases.
- Section 2.6 – Work Plan outlines the next steps in the REGMURCIA CLIMAAX project. It sets the foundation for Phases 2 and 3, focusing on refinement using local data and the participatory co-design of sector-specific adaptation measures.

Section 3 provides a concise synthesis of the conclusions drawn from Phase 1. It summarises the key findings of the assessment and offers strategic reflections on how the results can inform future adaptation planning and decision-making processes in the region. Section 4 presents a self-assessment of the progress made during this initial phase of implementation. It evaluates how the project has contributed to the objectives defined at inception and assesses the readiness of the region to transition to the next phases of refinement and adaptation planning. Section 5 compiles relevant supporting documentation, including methodological appendices, regulatory references, and complementary materials used throughout the assessment process. This section also includes additional resources consulted during the implementation of the CLIMAAX workflows. Last, Section 6 lists the scientific and technical references cited throughout the deliverable. This includes peer-reviewed literature, national and regional policy documents, statistical databases, and outputs from European initiatives, ensuring full transparency and traceability of the methodology and results.

Due to the complexity of the REGMURCIA CLIMAAX project—covering the entire 11,316 km² territory of the Region of Murcia and applying three complete workflows (agricultural droughts, river and coastal floods, and heatwaves)—the length of this Deliverable exceeds the recommended limit. This extended scope is considered necessary to ensure methodological consistency, scientific robustness, and comprehensive coverage of all priority hazards.

2 Climate risk assessment – phase 1

Phase 1 applies the CLIMAAX common methodology to screen priority hazards, assemble the best-available evidence, and produce a first set of harmonised hazard–exposure–vulnerability layers for the whole of CARM. The effort targets the region's core risk nexus—drought, river/coastal flooding and heatwaves—given their historic and projected impacts on agriculture, settlements, tourism and critical infrastructure.

This phase also stress-tests the toolbox against regional data: where global layers are too coarse or outdated, higher-resolution national/regional datasets are substituted or queued for Phase-2 refinement. The result is a decision-oriented baseline that highlights hotspots, quantifies uncertainty and identifies the additional data/models needed for robust planning.

2.1 Scoping

The scoping links regional objectives (protect the agri-food sector, coastal economy and lifeline infrastructure, etc.) with governance levers (planning law, water and civil-protection mandates) and with the external programmes that can finance action.

It also sets practical boundaries: priority workflows, time horizons and datasets; stakeholder roles via a two-tier participation architecture; and explicit data/model gaps to be addressed in Phase-2. This ensures the assessment remains implementable while charting a clear path to higher resolution and confidence.

2.1.1 Objectives

The CRA for the Region of Murcia (CARM) aims to deliver a policy-ready, multi-hazard diagnosis—centred on agricultural droughts, river and coastal floods, and heatwaves—that quantifies hazard, exposure and vulnerability at actionable scales and translates findings into guidance for land-use, water and civil-protection decisions. The assessment is explicitly designed to feed high-level instruments (e.g., Spatial Plan/PORM, municipal general plans, climate-resilience bylaws) and to support investment programming (ERDF, LIFE, CAP eco-schemes, NextGen EU, private green finance). This regional scope and institutional anchorage ensure direct uptake by the administration with statutory powers over planning, water and emergency management.

Purpose and expected outcomes are threefold. First, to characterise how intensifying hazards intersect with CARM's economic base—irrigated market gardening and agri-food, coastal tourism, logistics and energy—thereby quantifying risks to GDP, jobs and ecosystem services. Second, to generate harmonised risk layers and curves that regulators can insert into territorial and sectoral plans. Third, to co-produce framework strategies and technical guidelines with risk owners and stakeholders through a two-tier engagement model (Risk-Ownership Committee and Consultation Panel).

Phase-1 outputs are constrained by (i) resolution mismatches between global CLIMAAX defaults and high-resolution regional datasets, (ii) incomplete vulnerability evidence for specific groups, and (iii) limited downscaled climate projections for key variables. The CRA therefore prioritises integrating authoritative national/regional layers (SNCZI, cadastre/SIGPAC, SIOSE-AR, MAPA/ESYRCE) and flags further needs for Phase-2.

2.1.2 Context

CARM´s economy is heavily specialised in irrigated market gardening, the agri-food industry, coastal tourism, logistics and energy production. Extreme heat, increasing evapotranspiration and chronic water scarcity directly threaten this economic engine; coastal storm surges menace the Cartagena-Escombreras petrochemical hub and seasonally crowded beach tourism; flash floods disrupt a road network that already moves an above-average share of freight. Without an integrated risk-assessment the region risks mounting losses in GDP, employment and ecosystem services, undermining national food supply chains and EU single-market logistics (Table 2-1).

Table 2-1 Key economic sectors in CARM and expected climate impacts

Sector	Current weight	Principal climate stresses	Expected impact
Irrigated agriculture & agri-food	4.6 % of GVA; > 11 % employment	Chronic drought; heatwaves	Water-deficit yield loss, quality downgrades, higher cooling & fertigation costs
Coastal & cultural tourism	10.3 % GDP; highly seasonal	Heatwaves; coastal flooding; beach erosion	Thermal discomfort, loss of beach width, damage to second-home stock
Petro-chemical & energy hub	11.3 % GVA (oil refining, power)	Coastal surge; heat stress	Infrastructure downtime, safety hazards, supply-chain delays
Freight transport & logistics	12 % of vehicle fleet are trucks/vans	River floods; heatwaves	Road closures, higher maintenance & fuel consumption

2.1.2.1 Climate hazards in the CARM: assessment and management to date

The CARM has historically faced a variety of interrelated climate hazards, particularly intense in recent decades: extreme heatwaves, prolonged droughts, and both river and coastal floods. These risks have been evaluated through scientific studies and civil protection plans and managed through reactive and preventive measures with varying degrees of effectiveness. In recent decades, the regional average temperature has increased by more than 2°C since 1981, and tropical nights (>20°C) have become more frequent (Espín-Sánchez, 2017). Regional health authorities, in coordination with the Ministry of Health, implement heatwave alert plans each summer, using a four-level warning system (green, yellow, orange, red) to protect vulnerable populations (elderly, children, sick people) (Ministerio de Sanidad, 2024). These campaigns include recommendations to avoid sun exposure, stay hydrated, and provide climate shelters.

Regarding droughts, Murcia experiences structural water scarcity and a form of "chronic drought" due to its semi-arid Mediterranean climate. Historically, the region has addressed this issue through significant investment in water infrastructure. Since the 1980s, it has developed desalination plants and wastewater reuse systems, positioning Murcia as a national leader in reclaimed water usage (Pérez Morales et al., 2014). Currently, more than 90% of treated wastewater is reused, and drip irrigation is applied to about 90% of the farmland (Sala-Garrido, R., Molinos-Senante, M., Fuentes Pascual, R., Hernández-Sancho, 2020). These measures have helped avoid severe water restrictions even during intense droughts. However, challenges remain: illegal groundwater extraction and water losses due to insufficient maintenance continue to be problems (Simón and Oller, 2024). An integrated approach to reducing water footprints across sectors is still lacking, leaving the region vulnerable to increasingly intense droughts.

River floods are a historic risk in the CARM due to the torrential rainfall patterns of the Segura basin. Murcia has a Special Civil Protection Plan for Flood Risk (CARM and DGPC, 2007), which identifies flood-prone areas and coordinates emergency responses. Despite this, high exposure persists: nearly 800 critical points (urban areas, dry streambeds, and agricultural lands) face severe flood risks under intense rainfall events (CHS, 2023). Past urban planning decisions have allowed construction in flood-prone areas, increasing vulnerability (Pérez-Morales et al., 2018). The floods caused by the 2019 DANA event severely impacted the region, resulting in seven fatalities and over €1.3 billion in damages (Romero-Díaz and Pérez-Morales, 2021). These events have led to strengthened emergency protocols and investments in drainage infrastructure. Coastal flooding, while less frequent to date, is emerging as a threat due to sea level rise and intensified maritime storms. Several sections of the Murcian coast are projected to lose beaches in the coming years, impacting tourism and residential areas (CARM, 2019).

In summary, climate risks in Murcia have been partially assessed and managed through sectoral plans (health, water, emergency), but responses remain fragmented. The region has demonstrated both strengths (e.g., leadership in water adaptation) and weaknesses (e.g., inadequate urban planning, lack of integration between adaptation and land use). These challenges define the problem this project aims to address.

2.1.2.2 Problem addressed and broader context

The central issue targeted by this project is the CARM's growing vulnerability to climate change impacts, especially more frequent and intense heatwaves, droughts, and floods. These hazards already affect quality of life, economic productivity, and regional ecosystems (Calvin et al., 2023; IPCC, 2022). For instance, rising temperatures and heatwaves increase summer mortality and reduce labor productivity; chronic drought threatens irrigated agriculture, a key sector; and floods damage infrastructure, housing, and crops, causing significant economic losses.

The project operates within the broader regional and national development context. CARM plays a key role in agricultural exports, coastal tourism, and renewable energy. However, these development drivers are highly sensitive to natural resource availability and climate stability. Known as the "orchard of Europe," the region's agriculture depends on fertile soil and reliable water. Desertification is advancing rapidly, with the region losing up to 19 million tonnes of soil annually due to erosion (Eekhout et al., 2021). Projections show decreasing rainfall and rising temperatures, potentially leading to further land abandonment (Andrade et al., 2021).

Rapid and sometimes unregulated urbanization has increased exposure to climate risks. Cities like Murcia, Cartagena, and Lorca experience significant urban heat island effects due to limited greenery and extensive pavement (Gómez et al., 2023). Construction in flood-prone areas has placed thousands of homes at risk: around 17% of homes in the region are located in flood hazard zones (Cánovas-García and Vargas Molina, 2024). At the national level, CARM shares similar vulnerabilities with other Mediterranean regions (e.g., Andalusia, Valencia), aligning the project with Spain’s broader climate adaptation priorities and the National Climate Change Adaptation Plan (PNACC) (MITECO, 2020).

2.1.2.3 Governance context for climate risk assessment

CARM’s climate governance has evolved in recent years, establishing institutional and regulatory frameworks for climate risk assessment and adaptation. In 2020, the regional government declared a Climate and Environmental Emergency and adopted the Regional Strategy for Mitigation and Adaptation to Climate Change of the Region of Murcia (ERMACC) (CARM, 2019). The strategy sets out 15 action lines, including integrating adaptation into territorial and urban planning, protecting the coastline from sea level rise, strengthening public health responses to heat, and supporting local adaptation through the Covenant of Mayors.

The Regional Observatory for Climate Change acts as a participatory body involving scientists, government agencies (including AEMET, the CHS Authority, Coastal Authority), businesses, and civil society (AdapteCCa, 2025). This observatory channels scientific knowledge into policy and monitors the progress of regional strategy. Within the administration, the Environmental Promotion and Climate Change Service coordinates adaptation implementation.

Murcia complies with national and international frameworks, including Spain's Climate Change Law and the EU Floods Directive. The region's flood risk management aligns with national civil protection and the CHS (CARM and DGPC, 2007) flood plans. On drought management, the Segura Basin's Special Drought Plan outlines indicators and actions that Murcia implements in coordination with users. The region mobilizes its own budget and European funds (e.g., ERDF, Next Generation EU) to support resilience investments. Despite this, studies highlight shortcomings in implementation, including gaps in integrating adaptation into all urban and water planning instruments and a lack of interdepartmental coordination.

2.1.2.4 External influences and synergies

The Climate-Risk Assessment will be embedded in—and benefit from—several external initiatives. It will adopt the methodological benchmarks and forthcoming "regional resilience contracts" of the EU Mission on Adaptation, draw on transferable tools for urban drainage, drought management and stakeholder engagement developed by LIFE-ADAPTATE and Interreg NEXT MED, and serve as the technical reference for investment decisions foreseen in the Segura River Basin Management Plan 2022-27 (CHS, 2023) and the REPowerEU solar-irrigation programme. This alignment ensures consistency with EU policy, unlocks complementary funding streams, and accelerates the uptake of best practice in CARM.

2.1.2.5 Strategic scope of CLIMAAX_REGMURCIA

A distinguishing feature of CLIMAAX_REGMURCIA is its regional scale and institutional anchorage. Unlike many CRA pilots focused on a single municipality or catchment, this assessment spans the entire territory of the Region of Murcia, applying several CLIMAAX workflow—drought, heat-wave and river and coastal flood—within a single, integrated frame. Because the project is steered by the regional administration, which holds legal competence over land-use planning, civil protection and water management, its outputs will feed directly into high-level instruments such as the Spatial Plan (PORM), municipal general plans and forthcoming climate-resilience bylaws. Rather than prescribing isolated "hard" measures, the CRA will generate framework strategies, technical guidelines and, where necessary, proposals for regulatory amendments that enable local authorities, businesses, farmer cooperatives and civil-society organisations to mainstream adaptation in their decisions. It will also map the financing landscape—ERDF, LIFE, CAP eco-schemes, Next-Generation-EU, private green bonds—so that priority actions identified by the assessment can move rapidly from concept to funded implementation.

2.1.3 Participation and risk ownership

The CLIMAAX-REGMURCIA participation plan is organised in two concentric tiers so that those who own the risk can work continuously with a wider community of information users, vulnerable groups and external experts.

- Tier 1 – Risk-Ownership Committee (mandatory semi-structured interviews). This tier circle comprises:
    - regional line departments with statutory competence for water management, civil protection, spatial planning, public health and agriculture;

- the river-basin management authority.
- the national meteorological service.
- public and private operators of critical transport-logistics and energy infrastructure.
- leading research universities and applied research centres.
- most widely established environmental NGOs.
- apex business organisations representing agriculture, industry, commerce and tourism.

Members of this committee will validate the analytical methods and review interim findings through one-to-one interviews and ad-hoc technical meetings.

- Tier 2 – Consultation Panel (survey / Delphi).

  The outer circle brings together local governments, professional institutes, environmental and neighbourhood NGOs, chambers of commerce and transport associations. These stakeholders will be engaged mainly via an online questionnaire and a two-round Delphi exercise to comment on exposure maps, acceptable-risk levels and draft adaptation guidelines, complemented by webinars and sector-specific co-creation sessions.

A full list of stakeholders, showing their engagement mode and thematic linkage, is presented in Table 2-2. The CLIMAAX-REGMURCIA stakeholder landscape consists of 145 organisations grouped into fourteen categories. Local administrations (45 municipalities) and regional government bodies (29 line departments and autonomous agencies) form the largest blocks, followed by professional bodies (19), environmental NGOs (13), research institutions (10) and a balanced mix of business associations, federations, consortia, community-transformation offices and public- or private-sector operators of critical infrastructure. Each entity has been matched to an engagement modality aligned with its institutional mandate and expected participation: 46 semi-structured interviews will secure the active involvement of the principal risk owners and land-use planners; 34 questionnaire/Delphi contacts will gather expert judgement for the validation of hotspot maps and risk-acceptability thresholds; and 65 surveys will ground-truth the outputs at local and regional scale. More than half of the stakeholders are linked to multiple CLIMAAX workflows, ensuring that drought, heatwave, river and coastal-flood risks are addressed in an integrated manner.

Table 2-2 Stakeholder Engagement Matrix for CRA

Entity Name	Engagement mode	Primary Hazard /Workflow
Instituto Murciano de Acción Social (IMAS)	Interview	Heatwaves
Instituto Murciano de Investigación y Desarrollo Agrario y Medioambiental (IMIDA)	Interview	All workflows
CTCON (Centro Tecnológico Construcción Región Murcia); CETENMA; OTRIS UMU; OTRIS UPCT; OTRIS UCAM; OTRIS CEBAS CSIC; OTRIS IMIDA	Delphi	Cross-sector
CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas)	Interview	Coastal Floods & Heatwaves
Dirección General de Presupuestos y Fondos Europeos; Dirección General de Economía, Estrategia y Contratación Centralizada/ Servicio de Estadísticas Demográficas, Sociales y Difusión; Dirección General de Administración Local; Dirección General de Seguridad Ciudadana y Emergencias; Dirección General de Política Agraria Común/Subdirección General de Desarrollo Rural; Dirección General de Producción Agrícola, Ganadera y Pesquera; Subdirección General de Montes, Caza y Pesca Fluvial; Dirección General de Medio Ambiente; Dirección General de Recursos Humanos, Planificación Educativa e Innovación; Dirección General de Centros Educativos e Infraestructuras; Dirección General de Litoral y Puertos; Dirección General de Vivienda; Dirección General de Movilidad y	Interview	Cross-sector

Entity Name	Engagement mode	Primary Hazard /Workflow
Transportes; Dirección General de Ordenación del Territorio y Arquitectura; Dirección General de Industria, Energía y Minas; Dirección General de Mar Menor; Dirección General de Universidades e Investigación; Dirección General de Competitividad y Calidad Turísticas; Dirección General de Juventud; Instituto de Turismo de la Región de Murcia; Dirección General de Planificación, Farmacia e Investigación Sanitaria; Dirección General de Formación Profesional, Enseñanzas de Régimen Especial y Educación Permanente; Instituto De Fomento De La Región De Murcia (Info)		
Dirección General del Agua; Confederación hidrografica del Segura (CHS)	Interview	Drought & River Floods
Dirección General de Industria Alimentaria y Asociacionismo Agrario	Interview	All workflows
Dirección General de Salud Pública y Adicciones	Interview	Heatwaves
Servicio Murciano de Salud	Interview	Heatwaves
Colegio Oficial De Ingenieros Agrónomos De La Región De Murcia; Colegio Oficial De Médicos De La Región De Murcia; Colegio Oficial De Ingenieros Industriales De La Región De Murcia; Colegio Oficial De Arquitectos De La Región De Murcia; Colegio Oficial De Aparejadores, Arquitectos Técnicos E Ingenieros De La Edificación De La Región De Murcia; Colegio Oficial De Trabajo Social De La Región De Murcia; Colegio Oficial De Biólogos De La Región De Murcia; Colegio Oficial De Ingenieros Técnicos Industriales De La Región De Murcia; Colegio Oficial De Veterinarios De La Región De Murcia; Colegio Oficial De Ingenieros Técnicos Agrícolas Y Graduados En Ingeniería Agrícola De La Región De Murcia; Colegio Oficial De Enfermería De La Región De Murcia; Colegio Oficial De Economistas De La Región De Murcia; Colegio Profesional De Ambientólogos De La Comunidad Autónoma De La Región De Murcia; Colegio Oficial De Geógrafos; Colegio Oficial De Ingenieros De Montes; Colegio Oficial De Ingenieros Técnicos Forestales; Colegio Oficial De Químicos De La Región De Murcia; Colegio De La Abogacía De Murcia	Delphi	Cross-sector
Colegio de Ingenieros de Caminos, Canales y Puertos	Delphi	Drought, River and Coastal Floods
FAVMURCIA, Federación de Asociaciones Vecinales de la Región de Murcia	Interview	Cross-sector
Dirección General de la Costa y el Mar - MITERD	Delphi	Coastal Floods
AEMET; Instituto Español de Oceanografía. CSIC. Murcia ; Fundación Biodiversidad. Ministerio para la Transición Ecológica y el Reto Demográfico.	Interview	Cross-sector
Autoridad Portuaria de Cartagena	Interview	Coastal Floods & Heatwaves
AMETSE; METEONOROESTE	Delphi	Cross-sector
Ayuntamiento Águilas; Ayuntamiento Cartagena; Ayuntamiento Los Alcazares; Ayuntamiento Mazarrón; Ayuntamiento San Javier; Ayuntamiento San Pedro del Pinatar	Survey	All workflows
Ayuntamiento Abanilla; Ayuntamiento Abarán; Ayuntamiento Albudeite; Ayuntamiento Alcantarilla; Ayuntamiento Aledo; Ayuntamiento Alguazas; Ayuntamiento Alhama de Murcia; Ayuntamiento Archena; Ayuntamiento Beniel; Ayuntamiento Blanca; Ayuntamiento Bullas; Ayuntamiento Calasparra; Ayuntamiento Campos del Río; Ayuntamiento Caravaca de la Cruz; Ayuntamiento Cehegín; Ayuntamiento Ceutí; Ayuntamiento Cieza; Ayuntamiento Fortuna; Ayuntamiento Fuente Álamo de Murcia; Ayuntamiento Jumilla; Ayuntamiento La Unión; Ayuntamiento Las Torres de Cotillas; Ayuntamiento Librilla; Ayuntamiento Lorca; Ayuntamiento Lorquí; Ayuntamiento Molina del Segura; Ayuntamiento Moratalla; Ayuntamiento Mula; Ayuntamiento Murcia; Ayuntamiento Ojos; Ayuntamiento Pliego; Ayuntamiento Puerto Lumbreras; Ayuntamiento Ricote; Ayuntamiento Santomera; Ayuntamiento Torrepacheco; Ayuntamiento Totana; Ayuntamiento Ulea; Ayuntamiento Villanueva del Río Segura; Ayuntamiento Yecla	Survey	Drought, River Floods & Heatwaves
FECOAM (Federación de cooperativas agrarias de Murcia)	Interview	All workflows
Federación de Municipios Región de Murcia	Interview	Cross-sector
Asociación de Naturalistas del Sureste (ANSE)	Interview	Cross-sector
Ecologistas en acción	Interview	Cross-sector
WWF; Asociacion Naturalista de Jumilla (STIPA); ANIDA; Asociación para la Defensa de la Naturaleza (CARALLUMA); MELES; ULULA; Asociación Calblanque; ADELA; NaturActúa; AMACOPE; Asociación Hippocampus	Survey	Cross-sector

Entity Name	Engagement mode	Primary Hazard /Workflow
FED EMPRES COMERCIO Y COMERCIO ELEC; HOSTEMUR(Federacion regional de empresarios de hosteleria); ASHOMUR(Asociacion regional de hoteles y alojamientos turisticos); HOSTETUR(Asociacion de empresarios de hoteles y alojamientos turisticos)	Survey	All workflows
Consorcio para el Servicio de Extinción de Incendios y Salvamento de la Región de Murcia	Interview	Cross-sector
Consorcio de Compensación de Seguros	Delphi	Drought, River and Coastal Floods
OTC - Coitirm; OTC FUNDACIÓN DESARROLLO SOSTENIBLE; OTC ALEM	Survey	Cross-sector
Consejo Asesor Regional de Participación Ciudadana	Delphi	All workflows
Consejo Regional de Cooperación Local	Delphi	Cross-sector
Comisión Regional de Protección Civil	Interview	Cross-sector
COAG (Coordinadora de Organizaciones de Agricultores y Ganaderos); ASAJA (Asociación Agraria Jóvenes Agricultores)	Delphi	Drought & Heatwaves
FRECOM (federación Regional empresarios construcción); Asociación de Empresas de Medio Ambiente de la Región de Murcia; Confederación Empresarial de la Región de Murcia	Interview	Cross-sector
Complejo petroquímico Cartagena-Escombreras	Interview	Coastal Floods & Heatwaves
Asociación de Empresas de Energías Renovables (APPA)	Survey	Coastal Floods & Heatwaves

Note: The colors in the Entity Name column correspond to Stakeholder Type according to the following color key: Business Associations; Collegiate Bodies / Advisory Councils; Community Transformation Offices (CTOs); Consortia; Consumer Associations; Environmental NGOs / Environmental Associations; Federations / Umbrella Organisations; Local Government / Municipal Administration; Meteorological Societies; National Government Bodies / Central Public Administration; Neighbourhood Associations; Professional Associations; Regional Government Bodies / Regional Public Administration; Research Centres & Universities

Initial contact through invitation letters and/or direct phone calls has already been made with all the stakeholders listed above. Many have confirmed their willingness to contribute data and collaborate on the project. We are currently preparing for a first in-person meeting with all of them to formally introduce the project and plan the activities for phases 2 and 3.

By combining a dedicated risk-ownership core with a broader consultative panel, the CRA will deliver region-wide framework strategies, technical guidelines and, where required, regulatory proposals that the regional administration—endowed with land-use planning powers—can translate into binding instruments. The process will also map the relevant funding landscape so that the guidelines generated can be swiftly transformed into financed adaptation actions by authorities, businesses and civil society.

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

The Region of Murcia, located in one of the most arid areas of Europe, is particularly vulnerable to three climate-related hazards: river and coastal floods, droughts and heatwaves. These risks are not only expected to intensify under future climate change scenarios, but they are already producing significant socio-economic and environmental impacts today. Therefore, the decision to focus on floods and droughts responds to three criteria:

1. High historical impact (e.g., deaths, damage, emergency declarations).
2. Increasing exposure and vulnerability due to urbanization, tourism pressure, and agricultural practices.

3. Strategic importance of the affected sectors (e.g., agriculture, housing, health, energy) for regional resilience and economic stability.

Additionally, these hazards are interconnected: droughts and heatwaves amplify wildfire risk and water-system stress, while floods and droughts represent opposite expressions of the same hydrological variability spectrum.

2.2.1.1 Current situation of drought risk in the CARM

Regarding drought and aridity these are critical issues in the CARM, a traditionally agricultural area highly sensitive to water scarcity. Although historically addressed through storage and irrigation infrastructure—dubbed the “Murcian miracle”—current strategies are proving insufficient against in a CC context (Chazarra-Zapata et al., 2020; Grindlay et al., 2011). Repeated and severe droughts, along with rising temperatures, signal a transition from semi-arid to arid conditions, posing significant risks to sustainable socio-economic development and accelerating desertification (Andrade et al., 2021; Beguería et al., 2025).

Murcia has one of Europe’s driest climates, especially along its southern coast, with annual precipitation barely exceeding 270 mm. Climate indices based on 20th-century data classify most of the region as semi-arid, but recent decades show a sharp decline in rainfall and a marked increase in evapotranspiration, shifting large areas into arid classification (Martínez-Valderrama, 2024).

Meteorological droughts—defined by long periods of below-average precipitation—have historically affected Murcia. Since 1963, at least eleven major drought events have been recorded, with the 2023–24 drought exhibiting rainfall levels under 50 mm in most of the region. Indicators like SPI, SPEI, and PDSI show rising frequency and severity of extreme dry spells (Gil-Guirado and Pérez-Morales, 2024), consistent with patterns across the Mediterranean basin under climate change scenarios (Sousa et al., 2011; Spinoni et al., 2018). In the case of the longest precipitation time series in the Region of Murcia (CARM), corresponding to the city of Murcia, a considerable increase in the duration of dry periods has been observed from 1863 to the present. During this time, average annual precipitation has decreased by approximately 90 mm, with the most pronounced reductions occurring in autumn and spring—seasons typically associated with the highest rainfall and closely linked to the rainfed agricultural production cycle in the region (Gil-Guirado and Pérez-Morales, 2019). As illustrated in Figure 2-1, the spatial patterns of the 1970 and 1981–1984 drought periods show that southeastern Spain—particularly the CARM—experienced intense and persistent rainfall deficits. These extreme events were characterized by annual precipitation below 200 mm and anomalies exceeding −50% in key agricultural areas. The duration and spatial extent of these deficits underscore the region’s high sensitivity to climate variability and the urgent need to implement robust adaptation strategies.

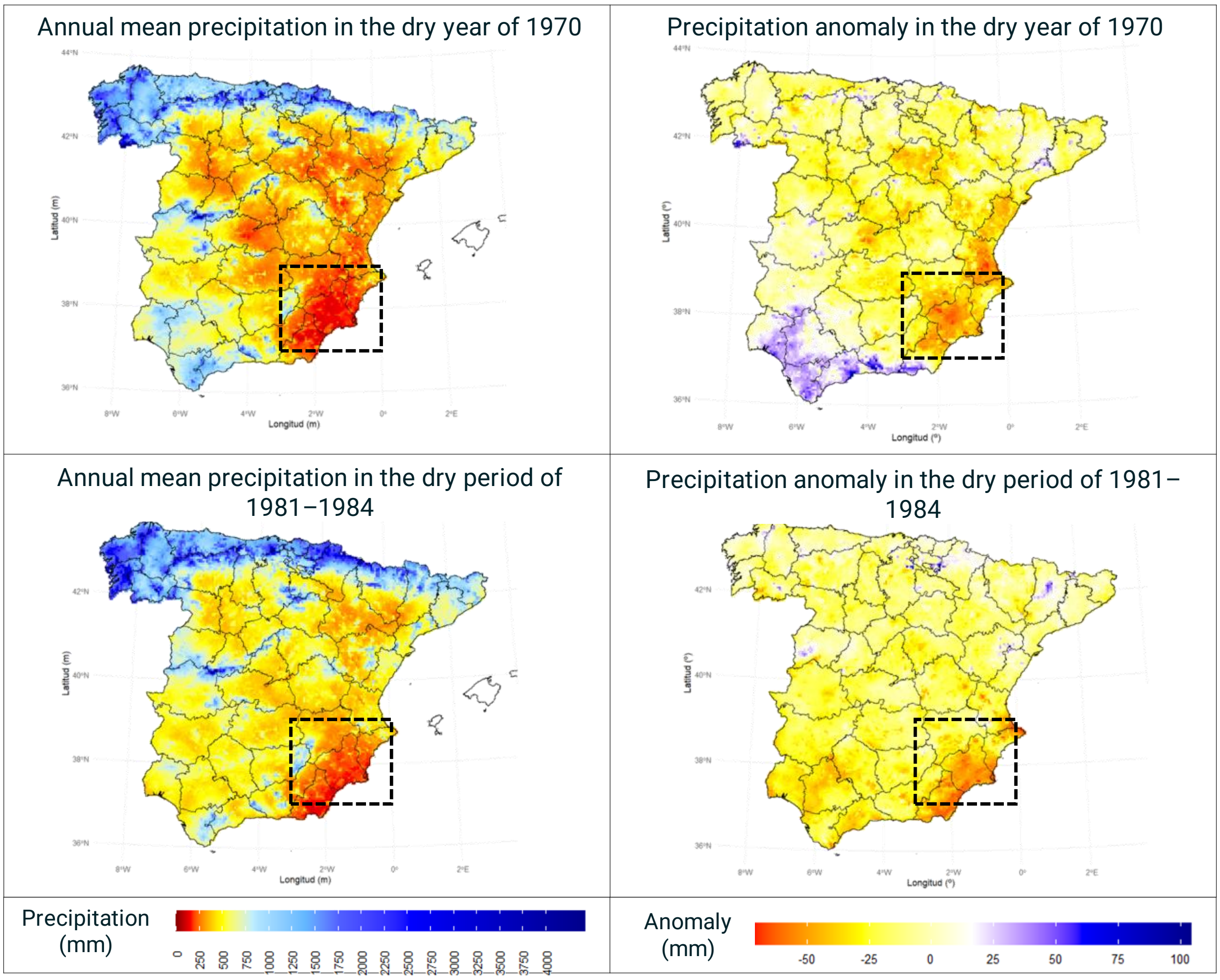


Figure 2-1 Observed Spatial Patterns and Anomalies of Precipitation in Spain During Historical Drought Periods (1970 and 1981–1984). Source: Serrano-Notivoli et al., 2017.

Hydrological droughts—when reservoir and groundwater levels drop below normal—are increasingly common, especially as climate change affects both local rainfall and water transfers like the Tajo-Segura aqueduct. The Segura basin currently has Spain's lowest reservoir levels (17% in Sept 2024; MITECO, 2024). Though previously mitigated by inter-basin transfers, more frequent and intense droughts are causing operational interruptions and greater reliance on aquifers, risking long-term hydrological imbalance (Torelló-Sentelles and Franzke, 2022).

Despite a recent exceptionally wet spring in the Segura River Basin District (CHS), current water reserves in the Segura basin remain among the lowest in the country. As of the last week of July 2025, reservoir storage stood at 28.7% of total capacity (MITECO, 2025a). While this figure does not represent a historical minimum, it reflects a persistent pattern: both currently and historically, the Segura basin consistently registers the lowest water availability among all river basins in Spain. Out of a total capacity of 1,140 hm³ across CHS reservoirs, only 327 hm³ are currently available for agricultural, industrial, and domestic use—excluding environmental flow requirements. The strong dependency of the Region of Murcia's (CARM) agricultural and socioeconomic systems on these limited water resources highlights the region's structural vulnerability to hydrological stress.

Agricultural droughts, exacerbated by high evaporative demand, increasingly threaten crop yields. Studies project substantial yield reductions under prolonged water stress (Karrou and Oweis, 2012), particularly in light soils with low water retention. Phenological changes and soil degradation further compromise agricultural sustainability (Peña-Gallardo et al., 2019).

The Copernicus Interactive Climate Atlas highlights a marked escalation across the three core drought dimensions considered in the CLIMAAX Drought & Water Scarcity workflow. In the Segura River Basin, projections for 2041–2070 indicate a substantial increase in Consecutive Dry Days (CDD), with durations extending by 5–10 days per year under SSP2-4.5 and by 12–18 days under SSP5-8.5. At the same time, the SPEI-12 index trends increasingly negative, pointing to longer, more persistent meteorological droughts. When translated into hydrological terms, these changes reduce the recurrence interval of critical reservoir inflow shortages, representing a significant escalation in drought hazard. In the CARM, where 46% of cultivated land relies on irrigation and agri-food exports exceed €6.9 billion annually, such intensification collides with extreme exposure: high-value, water-intensive crops, rapid urban expansion dependent on desalinated water, and a dense agro-industrial network responsible for a quarter of regional exports. This exposure is further amplified by systemic vulnerabilities, including ageing farming populations, economically fragile smallholders, and aquifers facing annual overdrafts. As such, the future scenarios point not only to rising irrigation costs, but to deepening structural risks to the region's economy, employment base, and food security—underscoring the urgency of integrated water-efficiency targets and multi-scalar drought preparedness frameworks.

However, the CLIMAAX toolbox agricultural exposure modules are based on the SPAM (2010, 2020) (IFPRI, 2024) and GAEZ v4 datasets, which provide physical area, harvested area, and production maps for 42 crop categories on a fixed 5-arc-minute (~10 km) grid, differentiated by irrigated/rainfed system and input level, with baseline data from 2010 and 2020 (FAO, 2025; Yu et al., 2020). The fact that GAEZ and SPAM inputs are potential/modeled data obtained through agroecological simulation and statistical downscaling, not observed plot statistics, in addition to the low resolution, the age of the data, and the low correlation between these 42 crop types and the most widely established crops in the CARM, result in a poor CRA for drought in the CARM.

These databases group crops into broad categories of major crop types, such as almond, peach, etc. In addition, pixels of ~10 km mask the spatial variability of agriculture in the CARM.

In addition, the availability of new databases, like CROPGRIDS 2020 (Tang et al., 2024) offers a contemporary, high-resolution alternative to legacy global layers such as SPAM. CROPGRIDS supplies 0.05° (~5 km) raster maps of harvested and physical area for 173 individual crops—among them almond, olive, grapevine, citrus, tomato, lettuce and barley—covering virtually the full portfolio cultivated in the CARM. Its finer spatial grain and 2020 time stamp align better with the drought-monitoring period of interest, while its data format allows the dataset to be ingested into the existing CLIMAAX toolbox pipeline using the same resampling, masking and attribution routines already developed. Incorporating CROPGRIDS therefore bridges remaining gaps in crop representation, enhances the spatial accuracy of exposure estimates and strengthens the robustness of the CRA without adding methodological complexity.

However, despite the leap in spatial detail and the greatest adjustment between crop types that CROPGRIDS offers, a quick comparison with the official statistics of the CARM (Table 2-3) reveals that large divergences persist. For woody crops the contrast is striking: CROPGRIDS under-represents almond by a factor of four (19,506 ha versus 81,106 ha) and inflates olive to more than quadruple the regional total (90,743 ha versus 22,495 ha). Barley, by contrast, is reasonably close in all sources, yet even here CROPGRIDS overestimates the harvested area by about 20 % relative to official data (27,107 ha versus 22,362 ha). Similar distortions emerge for vineyards (-14 %) and are most pronounced for the irrigated specialities that dominate the CARM: citrus virtually disappears in CROPGRIDS (33 ha versus 40,135 ha) while tomato and potato are halved. The production side tells the same story: SPAM 2020 reports only 74 kt of citrus where the regional yearbooks register > 880 kt, and undershoots tomato by 50 kt.

Table 2-3 Alignment of Global and National Agricultural Data Sources for Operational Use in the CLIMAAX Toolbox. Values in hectares.

	CROPGRIDS	SPAM 2020	SIOSE AR	Agricultural Statistical Yearbook (MAPA)
Almond	19,506		81,145	81,106
Olives	90,743		22,586	22,495
Barley	27,107	22,063		22,362
Vineyard / Grapevine	25,678		29,636	28,812
Citrus	33	4,092	28,144	40,135
Tomato	1,363	1,899		2,470
Potato	1,949	4,690		4,541

Figure source: IFPRI, 2024; MAPAMA, 2025; MITMA, 2025; Tang et al., 2024.

These discrepancies underscore an inherent limitation of global crop masks: they rely on harmonised, cross-country priors that cannot fully capture the fine-grained irrigation mosaics and permanent-crop belts that define Murcian agriculture. To resolve this mismatch, the next phase of CLIMAAX will generate a bespoke raster atlas in which each 10–30 m pixel is attributed with crop type, harvested area and mean yield derived directly from the MAPA/ESYRCE time series (2010-2024). The workflow will (i) intersect the official polygon records with the highest-resolution land-cover layer available (SIOSE-AR 2018) (MITMA, 2025), (ii) weight the polygons by reported production and area to distribute crop statistics proportionally across the pixel grid, and (iii) resample the resulting layers to 250 m and 1 km for seamless ingestion into the CLIMAAX CRA. This hybrid approach retains the spatial fidelity of remote sensing while anchoring every hectare and every tone to audited regional figures, thereby eliminating the residual bias seen in current global datasets and delivering exposure surfaces that truly reflect the agricultural reality of the CARM.

These gaps in spatial granularity and mapped acreage become mission-critical for flagship crops such as citrus (Figure 2-2). Citrus orchards span > 40,000 ha—about 13 % of all farmland—and deliver roughly one quarter of the CARM's total agricultural tonnage, making the region Europe's—and arguably the world's—top citrus grower and exporter. Yet, under the current CLIMAAX configuration, the CRA cannot provide a reliable estimate of drought impacts on this high-value sector.

While SPAM suggesting low, diffuse citrus presence—the SIOSE-AR layer exposes the true pattern: dense irrigated belts hugging the Segura valley and coastal plain and large gaps in the interior plateau.

Both SPAM and, especially, CROPGRIDS fail to reflect either the intensity of use or the actual distribution patterns of citrus in the CARM. This is especially critical because they locate citrus crops in areas where low temperatures during the winter months prevent citrus production (northeast and northwest of the CARM). Even after spatially harmonising the layers, SPAM still deviates by > 500 % in the highest-occupancy pixels when benchmarked against SIOSE-AR. The CROPGRIDS output is even less reliable, yielding figures that bear no relation to the observed citrus footprint.

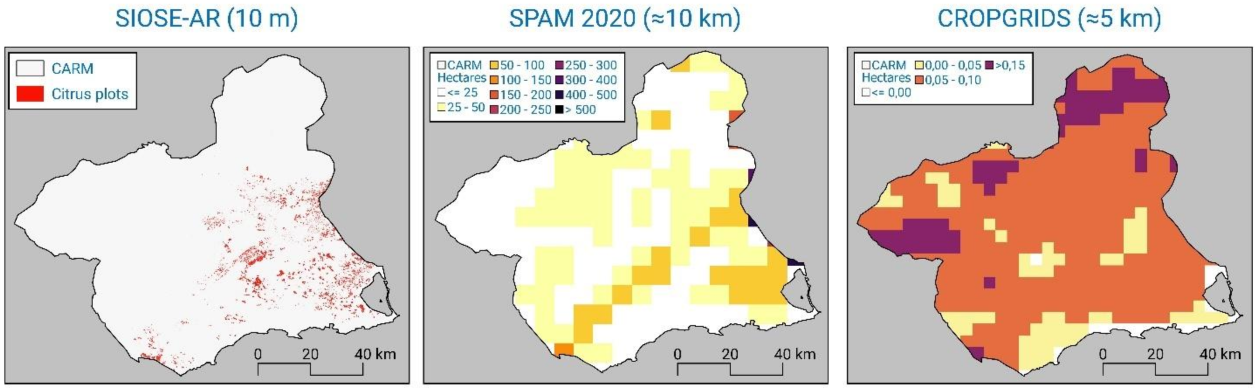


Figure 2-2 Spatial portrayal of citrus in the CARM: side-by-side comparison of SIOSE-AR (10 m), SPAM 2020 (≈10 km) and CROPGRIDS (≈5 km) layers. Source: IFPRI, 2024; MITMA, 2025; Tang et al., 2024.

As a complement to the pixel-level crop atlas, the SIOSE-AR layer will be harnessed to pinpoint the exact footprint of irrigated land, freeing the agricultural CRA for the CARM from the coarse, national irrigation ratios embedded in GAEZ v4. By merging this high-resolution irrigation mask with an updated Aggregate Crop Production Value surface—re-priced with MAPAMA´s, (2025) farm-gate series—the CRA will retain both the true spatial pattern of water use (vulnerability modifier) and the current economic value at risk (exposure metric).

In parallel, the drought-hazard module will replace the outdated, single-value Ky factors inherited from Doorenbos and Kassam (1979)—ill-suited to Murcian crops—with phase-specific response coefficients from Steduto et al. (2012) and locally calibrated curves for lemon, lettuce and almond derived from IMIDA trials, such as: del Amor et al. (2001); Romero et al. (2016, 2023). Taken together, these upgrades will deliver a high-resolution CRA that captures more than 85 % of the CARM's cropped area and production, ties every euro of potential loss to audited regional statistics, and explicitly accounts for the protective effect of modern irrigation practices.

2.2.1.2 Current situation of river flood risk in the CARM

In the southeast of the Iberian Peninsula, specifically in the CARM, an increase in economic losses due to river flooding has been observed over the past sixty years, despite the fact that the trend in the frequency of torrential rainfall events remains unclear in the Mediterranean region. This has been confirmed by (CEDEX, 2021) in its report on the impact of climate change on rainfall patterns in eastern Spain for the 1971–2000 period. However, according to CMIP6 ensemble maps in the Copernicus Interactive Climate Atlas, south-eastern Spain—including the Segura River basin that drains most of the CARM—shows a consistent intensification of the river-flood hazard component of the CLIMAAX River & Inland Floods workflow. The Atlas projects that the annual maximum one-day rainfall (Rx1day) will increase by ≈ 10 % in 2041-2070 under the intermediate SSP2-4.5 scenario and by 20-25 % under the high-end SSP5-8.5 pathway, relative to the 1991-2020 baseline. Likewise, the frequency of very-wet days (R20mm index) is expected to nearly double by the late century in the high-emissions case, implying that cloudburst-type DANA events will occur more often and with greater spatial extent. In hydrological terms, these changes translate into shorter return periods for peak discharges: what is now a 1-in-50-year flow at key Segura gauges could occur every 20–25 years by mid-century, escalating the hazard module of the risk equation. When this heightened hazard intersects with the region's high exposure and with persistent socio-economic vulnerability, the overall river-flood risk for CARM rises sharply, underscoring the need for integrated adaptation measures identified through the CLIMAAX CRA (Copernicus and ECMWF, 2025). However, it is necessary to emphasize the discrepancy between these results and those of (CEDEX, 2021), which, using high-resolution regional models, show that the future scenario is statistically significant towards a decrease in intense rainfall in the CARM. This invites the application of higher-resolution regional models in the CLIMAAX tool for a correct estimation of river flood hazard.

Preliminary results align with these findings, as shown in Figure 2-3. According to Gil-Guirado et al., 2019, the number of episodes capable of causing floods does not display a statistically significant trend. However, the ratio of affected municipalities or flood cases per episode has increased.

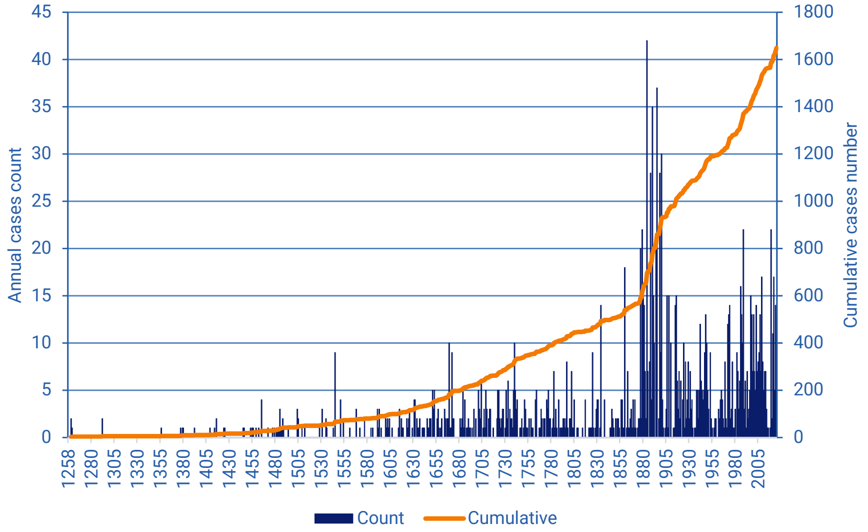


Figure 2-3 Evolution of the number of flood cases in the CARM. Source: Barriendos et al., 2019; Tuset et al., 2023.

This suggests that socio-economic growth—reflected in widespread, and in many cases unregulated, housing construction—and land-use planning models that fail to properly integrate flood risk are driving a growing exposure, and with it, increased damages. This is further evidenced by the rising number of exposed buildings in the Region of Murcia, according to cadastral data combined with the National Flood Hazard Mapping System (SNCZI) for return periods (RP) of 10, 100, and 500 years (Figure 2-4).

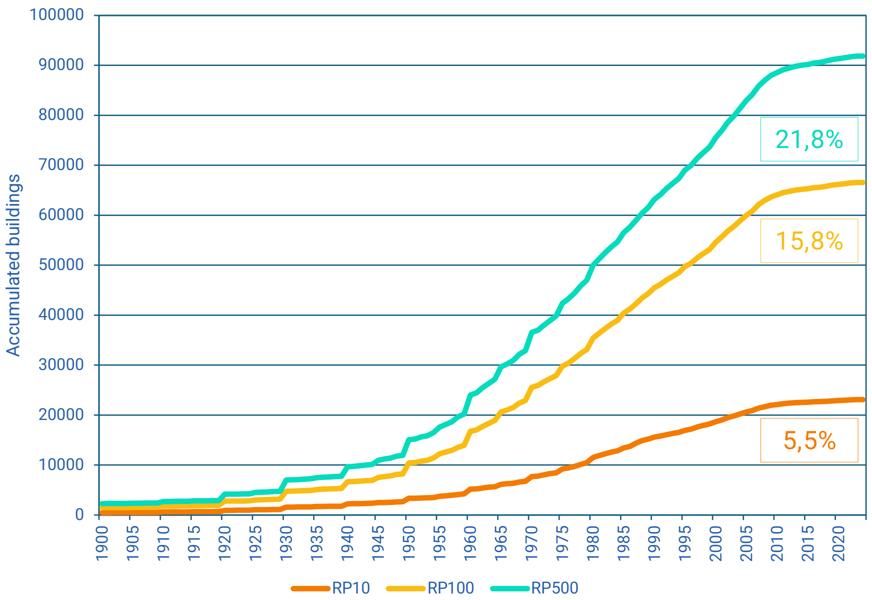


Figure 2-4 Evolution of exposed buildings in the CARM by Return Period (RP) (N=420,513 buildings). Source: MITECO, 2025.

From a land surface perspective, this increase in exposure, as measured using the 2018 CORINE Land Cover database (Copernicus, 2025), corresponds to approximately 46.77 km^2 affected by the 500-year RP, representing 10.9% of the CARM's artificial surface (Figure 2-5). The most worrying figures correspond to RP10, with more than 11 km^2 affected, representing 2.6% of the artificial surface in the CARM.

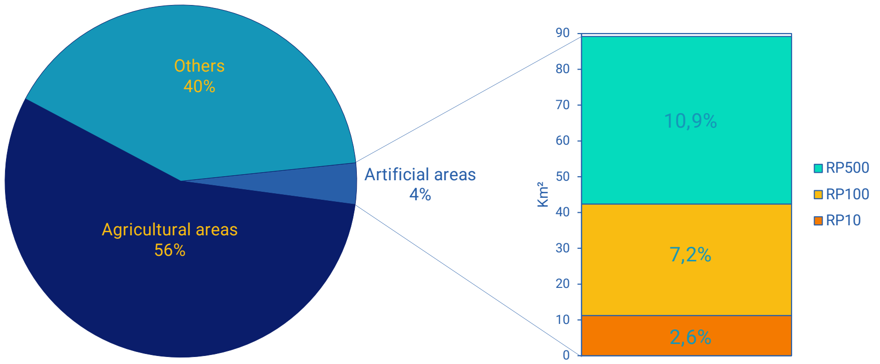


Figure 2-5 Percentage of total surface area in the Region of Murcia (11,316 km²) (Left). Affected surface area and percentage of "Artificial Surfaces" (under each RP of the SNCZI) (Right). Source: Copernicus, 2025; MITECO, 2025.

In light of these reflections on the causes and consequences behind the rising—mainly economic—losses, and thus the overall risk, adaptation strategies in semi-arid areas like the CARM must urgently address the challenges of spatial planning and land management in order to achieve effective adaptation to projected climate change scenarios related to flood hazard.

A comparative analysis of alignment and discrepancies has been conducted between the flood hazard zone outputs generated by the CLIMAAX toolbox and those provided by the SNCZI (MITECO, 2025). For this purpose, we used the official SNCZI maps, which provide flood hazard data for 10-, 100-, and 500-year return periods, in both raster and vector formats, with a of 2 meters. This high resolution offers a considerably greater level of detail and accuracy than the CLIMAAX hazard assessment tool, making SNCZI a technically robust reference for detailed flood risk analysis. As a first step, a comparative table of affected surface areas was created, along with a mosaic of figures for the Region of Murcia, in order to illustrate the main discrepancies in surface extent between the two data sources (Table 2-4). The results show that CLIMAAX data underestimates flood extent by −33%, −64%, and −70% for the 10-, 100-, and 500-year return periods respectively, highlighting significant discrepancies across RP.

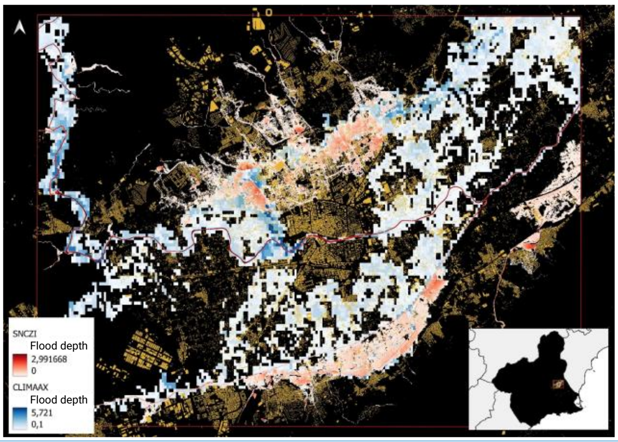
Table 2-4 Comparison of floodable areas modeled by SNCZI and CLIMAX for different return periods (in km²)

Return Period (RP)	SNCZI (KM²)	CLIMAX (KM²)	DIF (CLIMAX-SNCZI)
10	179,6	120,7	-58,9
100	406,6	145,4	-261,2
500	549,1	165,6	-383,5

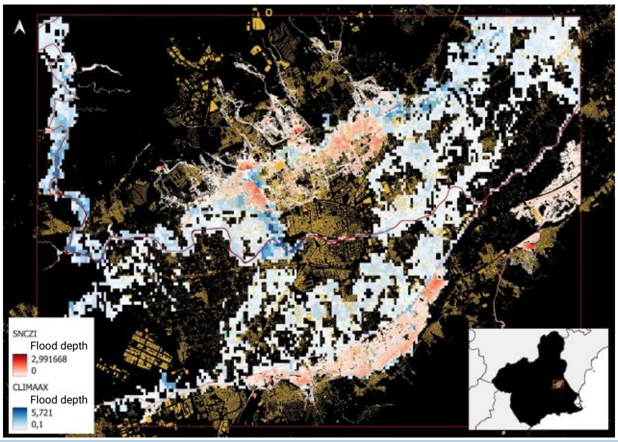
Source: MITECO, 2025.

Additionally, the area with the highest concentration of assets and population exposure, and flood hazard — the Metropolitan Area of the City of Murcia — was selected for a more detailed assessment of spatial consistency between the flood zones identified by CLIMAAX outputs and those provided by the SNCZI. The maps corresponding to the three return periods provided by the SNCZI clearly reveal spatial mismatches (Figure 2-6)—namely, underestimation by CLIMAAX in flood extent and overestimation by CLIMAAX in flood depth—which may significantly influence flood risk classification and assessment.

RT10



RT100



RT500

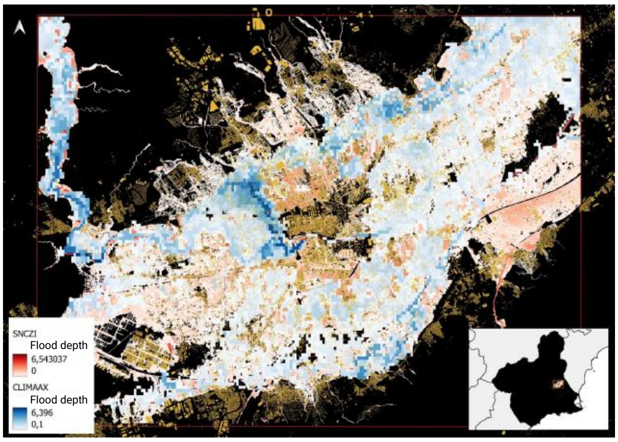


Figure 2-6 Spatial comparison of flood hazard extent and depth between CLIMAAX and SNCZI models for the Metropolitan Area of Murcia by Return Periods (RP10, RP100, and RP500 years). Source: MITECO, 2025.

The discrepancies are primarily due to the higher resolution of the hydrological models used in the SNCZI, compared to the data available in the CLIMAAX toolbox. While SNCZI provides flood hazard data at a spatial resolution of 2 meters for all available return periods, CLIMAAX data is based on coarser input resolutions, typically 90 meters. These differences result in a significant underestimation of river flood hazard within the CLIMAAX toolbox. This limitation is particularly problematic in high-impact and vulnerable areas such as the Campo de Cartagena and the municipality of Lorca (Garcia-Ayllon and Radke, 2021; Gil-Guirado et al., 2022), where the CLIMAAX toolbox identifies almost no flood-prone zones, in contrast to the tens of square kilometers designated as floodable by SNCZI. This spatial mismatch is clearly illustrated in Figure 2-7, where SNCZI flood zones (in blue) far exceed the extent of those identified by CLIMAAX (in green), especially in coastal and urbanized basins. The overlapping areas (in red) remain limited, reinforcing the importance of integrating higher-resolution models for more accurate hazard mapping.

In this regard, the next phase of the project will involve integrating SNCZI hydrological models into the CLIMAAX toolbox. This step is especially relevant given that SNCZI is legally binding in strategic environmental assessments and urban and hydrological planning procedures within the CARM.

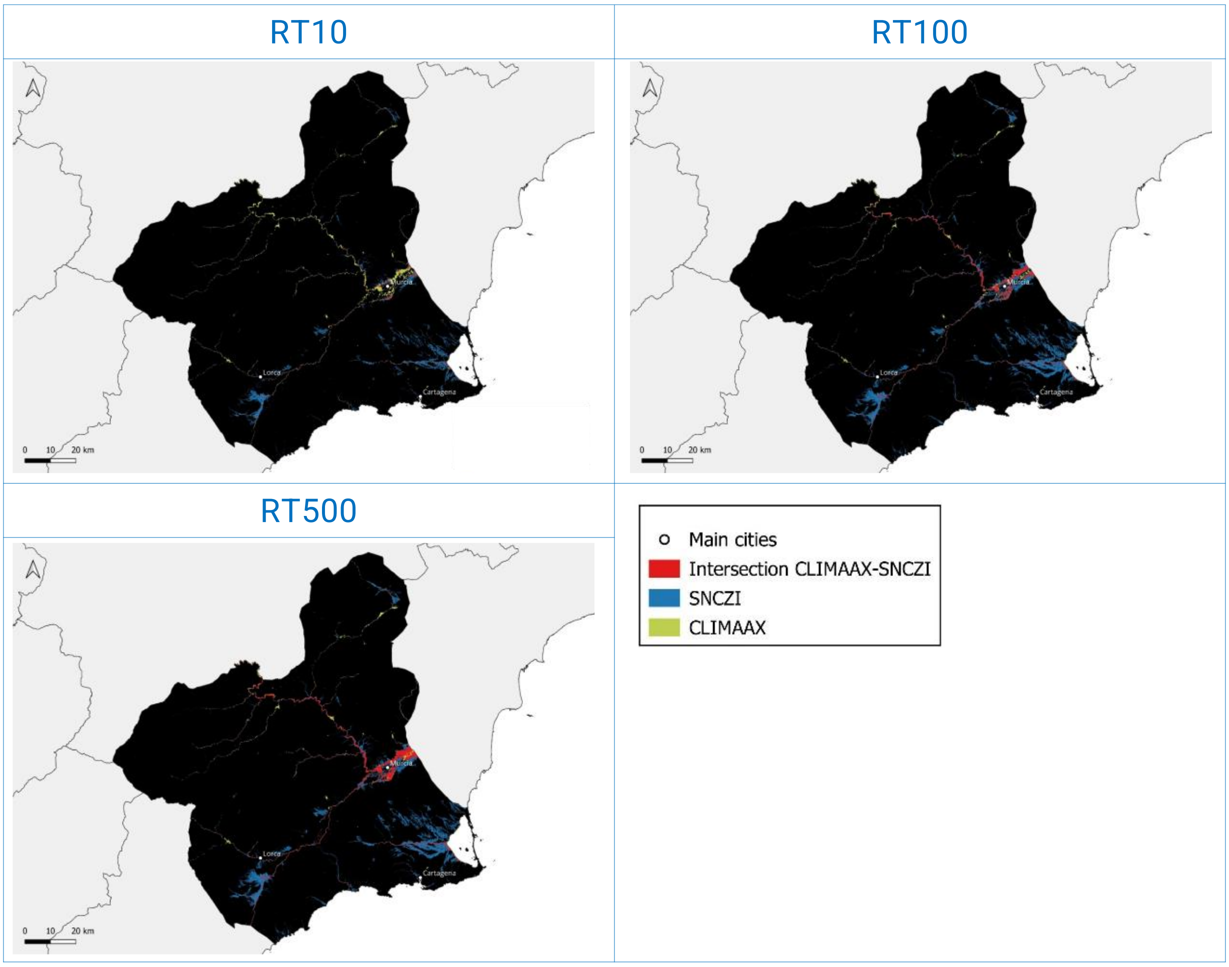


Figure 2-7 Spatial intersection between CLIMAAX and SNCZI flood hazard zones for the CARM by Return Periods (RP10, RP100, and RP500 years). Source: MITECO, 2025.

2.2.1.3 Current situation of coastal flood risk in the CARM

Planning and preparation for the predicted CC-induced sea level rise (SLR) is crucial for optimal adaptation of society and the economy in the CARM. This is especially true when considering the high levels of vulnerability and exposure of goods and services, as well as the high population density along the region's coasts. This phenomenon, driven by anthropogenic climate change (CC), threatens, among other things, frequent and/or permanent flooding, coastal erosion, and the loss of vital ecosystems. Furthermore, the regional economy, heavily dependent on coastal tourism and maritime activities, could suffer significant impacts. Therefore, anticipating these changes through adaptation and mitigation strategies is not only an essential preventive measure to protect lives and property, but also a strategic action to ensure the sustainability and resilience of the CARM in the face of future climate challenges. However, sea level rise projections face numerous sources of uncertainty, which hinder and limit sound coastal planning in the medium and long term. These sources of uncertainty come from five main components (Vousdoukas et al., 2018b): (1) the inclusion and interaction of different hydraulic components that model extreme sea level, (2) the underlying uncertainty in the digital elevation model (DEM), (3) flood defense information, (4) the assumptions behind the use of depth-damage functions that express vulnerability, and (5) different climate change projections. Uncertainties 2, 3, and 4 are the most important and introduce extreme dispersion in the different probabilistic scenarios. These additional biases, which do not support other climatic extremes, make correct planning difficult, since adaptation decisions are preferably based on specific solid and socioeconomic scenarios (Lincke and Hinkel, 2018).

A recent study (Tebaldi et al., 2021) concluded that by 2100, approximately 50% of the global coastline would experience at least once a year extreme coastal flooding events currently considered very unlikely (100-year return period under current conditions), even with warming below 1.5°C. At the societal level, SLR is expected to induce forced population displacement and huge economic losses on a global scale (Jones and O'Neill, 2016). With the global coastal population projected to exceed one billion people this century, SLR could become one of the most costly and permanent future consequences of climate change, with direct impacts on populations (Hauer et al., 2021), commercial activities and services (Verschuur et al., 2023), the coastal real estate market (Murfin and Spiegel, 2020), aggregate economic losses (Lincke and Hinkel, 2018), cultural heritage (Sesana et al., 2021), and a significant impact on coastal ecosystems and landscapes (McNutt, 2013).

Regarding the expected socioeconomic impact of SLR, projections also face the uncertainty associated with different shared socioeconomic pathways (SSPs) (Jones & O'Neill, 2016). This uncertainty, which also affects other extreme events associated with anthropogenic climate change (CC) (Changnon et al., 2000), is particularly relevant in the case of SRL (Kirezci et al., 2020). Unlike other risks such as droughts, the difference between an inaccurate estimate can lead to a location being categorized as fully affected (flooded under all conditions) or unaffected (not flooded). This is an added difficulty for decision-makers, as they must manage the territory with the uncertainty of taking measures that may never be necessary, or assume the risk of doing so (López-Martínez et al., 2017).

Recent literature indicates that extreme sea levels in Europe could rise by more than one meter by the end of this century, posing significant challenges for coastal communities. However, the benefit-adaptation relationship varies significantly, being more efficient in high-emission scenarios and strong socioeconomic growth (Vousdoukas et al., 2020).

Mediterranean sea level has shown significant increases in recent decades. Recent studies indicate that between 2000 and 2018, sea level in the Mediterranean region rose approximately 7 cm, a trend that exceeds the rates of increase observed during the 20th century (Calafat et al., 2022). Projections for the end of the 21st century vary depending on the greenhouse gas emissions scenario. According to (Vousdoukas et al., 2020), Mediterranean sea level is expected to rise between 0.79 m and 1.92 m under extreme high-emission scenarios. In addition to the average sea level rise, extreme events such as storm surges and storm surges are becoming more frequent and severe (Anzidei et al., 2024). Despite the significant expected impacts of SLR in Spain, the country does not consider SLR levels above 1 meter in its planning strategies by the end of this century (Vousdoukas et al., 2018a). In this situation, there is a risk of costly long-term adaptation, or of not having enough time to adapt if the SLR rate accelerates. In the context of the Spanish Mediterranean Coast, this issue takes on a crucial dimension due to the high population density, the economic value of infrastructure, and the ecological richness of its coasts (Estrela-Segrelles et al., 2021).

Additionally, the literature on the impact of sea level rise on the Spanish Mediterranean autonomous communities is scarce and scattered, with a significant gap for the provinces between Málaga and Castellón (Portillo Juan et al., 2022). This situation makes improvements urgently needed, enabling both the acquisition of a realistic current picture and the generation of future scenarios tailored to that reality.

The Copernicus Interactive Climate Atlas indicates that the *relative sea-level change* variable for the western Mediterranean—including the Murcian littoral—will rise by about 0.25–0.35 m by mid-century under SSP2-4.5 and by 0.45–0.55 m under SSP5-8.5, reaching 0.57 m and 0.79 m respectively by 2100 (baseline 1995-2014). Such vertical shifts, when fed into the CLIMAAX Coastal Floods workflow, amplify the *hazard* module by lowering the return period of extreme total water levels: a storm tide that today has a 1-in-100-year probability could occur every 20–30 years under the intermediate pathway and as often as once a decade under the high-end scenario. When this rising hazard intersects with Murcia's high *exposure*—densely built tourist resorts, the Cartagena-Escombreras petro-industrial hub, and critical port and road links—and with existing *vulnerabilities* (subsiding reclaimed land, limited natural buffers), the overall coastal-flood risk escalates sharply, underscoring the urgency of shoreline-management plans and resilience investments identified in the CLIMAAX CRA. (Copernicus and ECMWF, 2025).

Regarding the CARM coastline, Martínez-Graña et al., (2018) carried out a high-resolution study for the Mar Menor coast where they obtained SLR (permanent occupation of the water sheet) ranges for the extreme emissions scenario of up to 0.92 meters, to which is added an extreme wave of 4.1 meters for the RP100. This would give rise to extreme events of permanent occupation of marine water for the land located below 0.92 meters and at least one coastal flooding in 100 years for the land located between 0.92 and 5.82 meters.

The coastline of the Region of Murcia (CARM) – only 274 km long but hosting a petrochemical hub, highly seasonal beach tourism, and 32% of the regional population – is already experiencing measurable impacts from coastal flooding that will be amplified by SLR and storm surge intensification.

According to 2023 data (Atlas Digital de las Áreas Urbanas de España, 2024), almost 490,000 inhabitants live in the eight coastal municipalities of the CARM. The sociodemographic conditions of these municipalities differ from the national average due to the economic dynamism and specialization in tourism functions of the study area (Gil-Guirado et al., 2022). The main demographic variables for 2023 (Atlas Digital de las Áreas Urbanas de España, 2024) speak for themselves: compared to a national municipal population density of 178 inhabitants/km^2 in the coastal municipalities of the CARM, this value is 524; the national average sex ratio is 117 women for every man, compared to 15 points less in the study area; while for the average Spanish municipality, the percentage of the population under 14 years of age compared to the total population is 9%, in the study area this value rises to 17%. Regarding the percentage of the population over 65 years of age, these values are 30% and 17% respectively; compared to a median municipal age of 49 years at the national level, this value drops to 41 years in the CARM coast. Finally, compared to a national average of 8% of the population not born in Spain, this figure rises to 23% in the study area. These figures reflect a demographically diverse population. However, these demographic considerations have not been considered so far in studies on the impact of the level at the regional level.

In this context, for the second phase of the project, we aim to improve the reliability and resolution of the CRA in the flood coastal risk workflow by implementing the following high-resolution databases in the CLIMAAX Toolbox. These data have been generated within the framework of the PIMA Adapta-MURCIA programme (MITERD and CARM, 2025), promoted by the Spanish Ministry for the Ecological Transition and the Demographic Challenge (MITERD) under the provisions of Law 2/2013 on the protection and sustainable use of the coast, in cooperation with the regional government of CARM. As part of this initiative, the project "High-resolution evaluation of exposure, vulnerability and climate change risk of the coastline in the Region of Murcia and development of adaptation plans," carried out by the Fundación Instituto de Hidráulica Ambiental de Cantabria, assessed in detail the climate risks facing the Murcian coast. The resulting datasets —including hazard, impact, exposure, and vulnerability layers— are already available and ready to be integrated into the CLIMAAX Toolbox. These datasets include regionalized projections of key marine variables (such as wave climate, sea surface temperature, and sea level rise) under RCP4.5 and RCP8.5 scenarios, applying a probabilistic approach that incorporates uncertainty chains and enables the design of robust adaptive pathways. These maps provide information on the extent of the flooded area and water depth above ground level at a 3-meter resolution, representing a significant improvement compared to the 90-meter resolution of the internal datasets currently available in the CLIMAAX Toolbox. This enhances the capacity for spatial planning and coastal management, and provides a strong technical foundation for developing region-specific adaptation strategies.

As shown in the comparative image (Figure 2-8), for RP10 under current conditions, the PIMA Adapta-MURCIA dataset captures sea flood extents and water depth gradients with significantly greater detail and less overestimation compared to the MERITDEM and NASADEM models included by default in the CLIMAAX Toolbox. The flood-affected areas delineated by the CLIMAAX datasets do not accurately reflect the current reality of coastal flooding in the Region of Murcia (CARM). The lower resolution of the default CLIMAAX datasets, particularly MERITDEM, leads to overestimations of both flood extent and water depth, especially in low-lying and urban coastal areas.

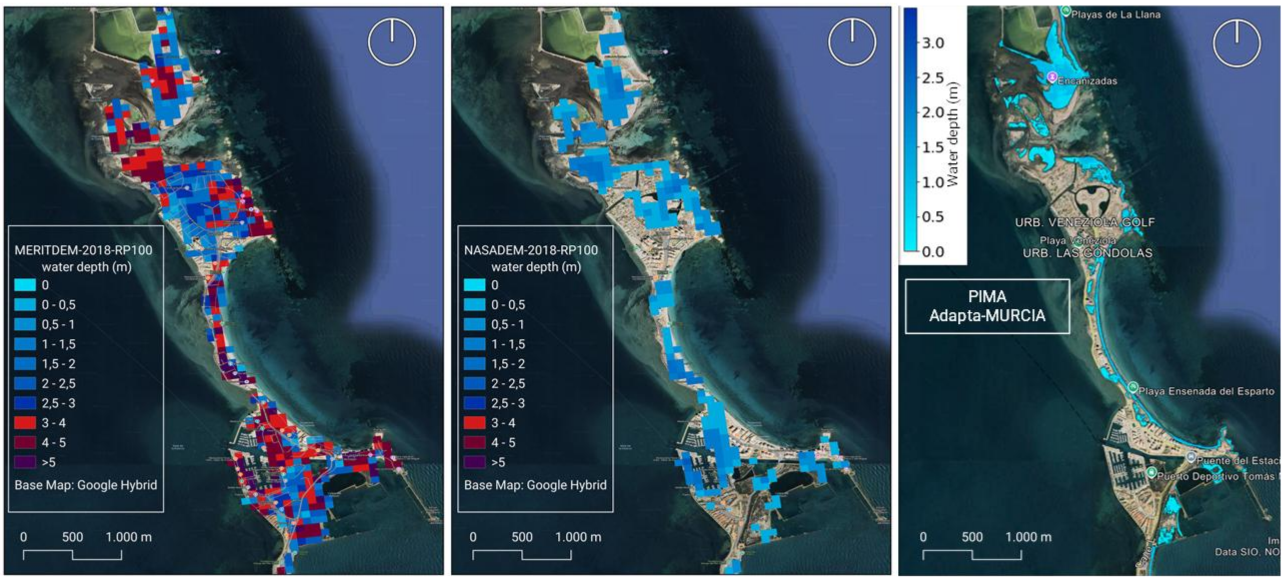


Figure 2-8 Comparison of Maximum Water Depth and Flooded Area for Coastal Flooding under RP10 in the Current Scenario, using MERITDEM, NASADEM, and PIMA Adapta-MURCIA Datasets. Focus on the Central Area of La Manga (CARM).

Additionally, to ensure an accurate interpretation of present and future risk, we will incorporate the cartography of General Urban Planning Plans (PGOU) in order to refine future exposure and vulnerability in accordance with current legal spatial constraints. This ensures that future projections take into account legal limitations on urban development and planned land-use changes.

The integration of current, georeferenced sociodemographic data will allow for more detailed and accurate projections of future impacts. This methodological approach will address the spatial variability of predicted risks and provide a solid foundation for informed decision-making in territorial planning and the implementation of adaptation strategies.

Economically, this CRA will contribute significantly in several ways:

1. Accurate knowledge of assets and people exposed to SLR: By detailed mapping of exposed areas and vulnerable communities under different emission scenarios, the project will provide crucial data for planning more effective protection and mitigation measures.
2. Realistic estimation of the needs and costs of adaptation measures: A detailed assessment of risks and exposure will allow for an accurate estimate of the investments required to implement adaptation measures.

From a social perspective, the goal is to protect the most vulnerable coastal communities and ensure their resilience to climate change. The participation of local communities in the planning process will foster informed populations in the face of natural hazards, strengthening the collective capacity to respond to the challenges of climate change.

2.2.1.4 Current situation of Heatwaves risk in the CARM

The CARM has become increasingly exposed to extreme heatwaves that exceed both historical norms and human tolerance thresholds (Sherwood and Ramsay, 2023). Recent summers have broken records repeatedly: the heatwaves of 2003, 2012, 2015, 2018 and especially 2022–2023 produced maximum temperatures above 43 °C in Murcia city and surrounding areas, along with tropical nights where minima remained above 25–26 °C. Exposing about a million inhabitants to this risk.

The 2015 episode was the longest since at least 1975, spanning 26 days, while July 2022 brought unprecedented daily highs of 45.1 °C. The summer of 2023 was catalogued by AEMET as “extremely hot,” with anomalies exceeding +2.5 °C relative to the 1991–2020 climatological baseline. In 2024, although coastal areas were less directly affected, a surge in tropical nights was recorded along the Murcian coastline.

The summer of 2025 has now confirmed the acceleration of this trend. During July and August, maximum temperatures again surpassed 45 °C, and several nights failed to drop below 30 °C. Preliminary data reflect an alarming situation, with temperatures exceeding 40°C for days and values exceeding 35°C for more than 10 hours during those days. At the Alcantarilla Air Base (10 km from the city of Murcia), the summer of 2025 was the warmest in the historical record (data since 1950). Furthermore, at this same location, compared to an annual average of 5 days with temperatures above 35°C during June, this value reached 21 days in June 2025. An absolute record, it highlights the high exposure of the regional population. The Carlos III Health Institute reported 22 heat-related deaths in Murcia over the summer, more than double the total of 2024, with 13 fatalities concentrated in a single week of August. Nationally, Spain registered a 57 % increase in heat-related mortality compared to the previous year (ISCIII, 2025). This has led climate services and the national press to classify the 2025 episode among the three most extreme heatwaves ever observed in Spain. These figures underscore that heatwaves are not only meteorological anomalies but direct threats to public health, economic productivity, and regional stability.

In this regard, Espín-Sánchez and Conesa-García (2021) identified an increase in the total number of heatwaves between 1950 and 2018 of 0.5 events/decade at the Alcantarilla station (Murcia) and 0.3 events/decade at the San Javier station (Figure 2-9). Since 2013, there has been a marked increase in the number of events, raising this ratio to approximately 1 event/decade. According to these authors, the average heatwave sequence duration increased by around 2 days every 10 years at both stations. The temporal trend of these extremely hot sequences has shown a high correlation with the evolution of the East Atlantic Index (EAI), particularly in Mediterranean coastal areas like San Javier (Kendall correlation > 0.53; p-value < 0.05) (Espín-Sánchez and Conesa-García, 2021) (Figure 2-9).

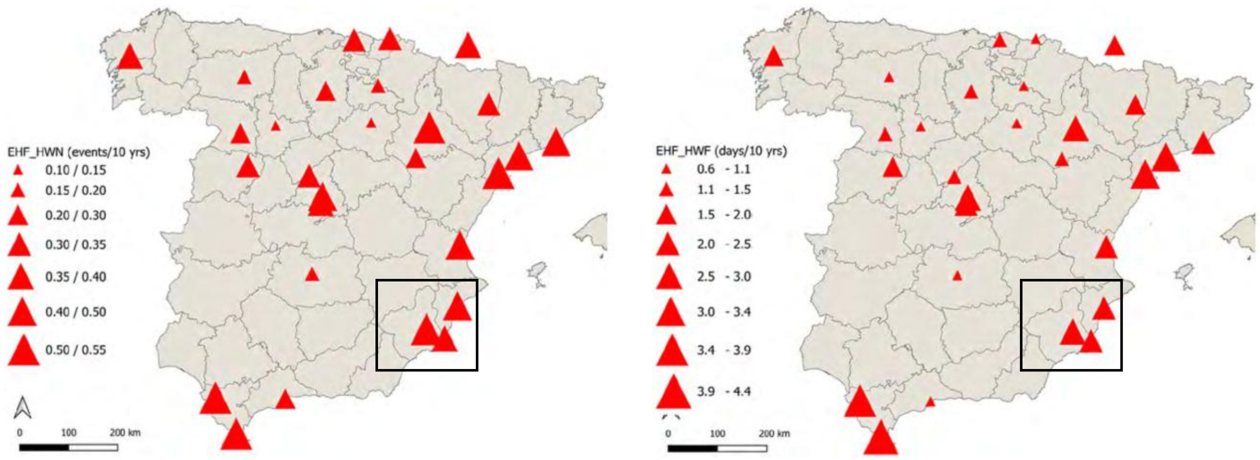


Figure 2-9 Map of Temporal Trends in the Frequency (EHF_HWF) and Number (EHF_HWN) of Heatwaves per Decade in Spain (1950–2016). For the CARM, the observed trend is shown for the stations of Alcantarilla and San Javier. Source: Espín-Sánchez and Conesa-García (2021).

Future projections reinforce this risk. According to the Copernicus Climate Atlas (Copernicus and ECMWF, 2025), the CARM will experience a marked rise in the number of tropical nights and extremely hot days under all emissions scenarios. Between 2041 and 2070, the duration of consecutive tropical nights is expected to increase by 5–10 days per year under SSP2-4.5, and by 12–18 days under SSP5-8.5. Heat stress indices, such as the Universal Thermal Climate Index (UTCI), similarly project more frequent days above critical comfort thresholds. These changes imply more persistent physiological stress, reduced labour productivity, and accelerated degradation of both urban and rural systems.

Despite the clear evidence, the CLIMAAX toolbox currently relies on coarse gridded datasets and generic thresholds to define heatwave hazard. While useful for pan-European comparability, these inputs under-represent the Murcian context. Specifically, they fail to capture nocturnal heat persistence, which is central to mortality, and overlook microclimatic differences between irrigated cropland, urban heat islands, and coastal breezes (Cataldi et al., 2024; Illán-Fernández et al., 2025; Jiménez-Gutiérrez et al., 2021).

In addition, tropical nights—arguably the most relevant hazard dimension for public health and water demand—are underrepresented in global reanalyses. This creates a disconnect between the observed reality of extreme nights in CARM and the hazard metrics available in the current workflow.

To close this gap, the next phase of CLIMAAX will integrate local high-resolution data. This includes long-term station series from Alcantarilla, San Javier, and Murcia, as well as Copernicus Atlas projections of tropical nights and extreme heat stress days. Combined with land-use maps such as SIOSE-AR, which differentiate urban, irrigated, and rural surfaces, these inputs will allow the development of hazard maps that reflect not only daytime extremes but also the persistence of night-time heat. Such refinements are critical in a region where urban populations, irrigated crops, and agro-industrial systems all rely on nocturnal cooling to recover from daytime stress. By combining station observations, Copernicus projections, and high-resolution land-cover data, the CRA will be able to characterise heatwave hazard in a way that is both scientifically robust and directly actionable for regional planning and adaptation.

2.2.1.5 Data and knowledge available and needed for CARM CRA

For the CRA at CARM has access to high-quality historical and scientific data, including (Table 2-5):

Table 2-5 High-resolution Climate-Risk Data available for the CRA in the CARM

Risk	Database And Format	Source	Spatial Coverage	Temporal Coverage
Floods	Flood events and historical records (CSV)	AMARNA (Tuset et al., 2023)	CARM	1258-
Floods	Insurance loss records (Excel and PDF)	MECE and CCS (2025)	Spain	1971-
Other	High-Resolution Assessment of Exposure, Vulnerability, and Climate Change Risk (Raster and vectorial)	MITERD and CARM (2025)	CARM	2024
Other	High-Resolution Assessment of Exposure and Vulnerability (Excel)	MVAU (2024)	Spain	1960-
Other	High-Resolution Assessment of Exposure and Vulnerability (Raster/ vectorial/Excel)	MITMA-IGN (2025)	Spain	1960-
Drought	CSIC Drought Observatory (Excel)	Vicente-Serrano et al. (2017), AEMET, CSIC and MITECO	CARM	1960-
Multi-risk	SPREAD (Raster)	Serrano-Notivoli et al. (2017)	Spain	1950-2012
Multi-risk	Cadastral (Vectorial and Excel)	MHAC (2025)	CARM	1900-
Multi-risk	Local and regional land management plan (Vectorial and Excel)	MIVAU (2025)	Spain	1983-
Other	Updated High-Resolution Socioeconomic and Sociodemographic Information Vectorial and Excel)	ESRI	Spain	2024-2025
Drought	National Hydrological Bulletin (PDF and Excel)	MITECO (2025a)	CHS	2005–
Temperatures	Daily Climate Data (Temperature, Precipitation) (CSV)	AEMET	CARM	1970–
Floods	Automatic Hydrological Information System (SAIH) (Web / API / CSV)	CHS (2025)	CHS	2000–
Floods	Flood prone areas (river and coastal areas): area and depth (Raster and vectorial)	SNCZI (MITECO, 2025b)	Spain	2015-
Coastal Floods	PIMA Adapta-MURCIA high-resolution coastal hazard, exposure & vulnerability layers (Raster and vectorial)	MITERD and CARM (2025)	Coastal strip of CARM (274 km)	2018 (baseline)+ RCP4.5 & 8.5 (2050, 2100)
Agriculture / Drought	MAPA Agricultural Statistics Yearbooks (ESYRCE codes) (CSV)	MAPAMA (2025)	Spain → municipal focus on CARM	2000 – 2023
Multi-risk	SIOSE-AR (Raster and vectorial)	MITMA (2025); SIOSE (2021)	Spain; high-res CARM	2018, 2020, 2022
Agriculture / Drought	SIGPAC / GSAA parcel layer (Raster / vectorial /ATOM)	MAPA (2025)	Spain; CARM recintos	2017-2024
Agriculture / Drought	CROPGRIDS	Tang et al. (2024)	Global	2020
Multi-risk	Climate change projections at 1km resolution (all variables) for SSPS8,5 and 2.6	GMAR group	CHS	1980-2020 (present)/2020-2100

Note: The colors in the Database and Format column correspond to the type of data access according to the following color key: Public; Own; Private.

The table consolidates a multi-hazard data catalog that covers, with varying granularity, the three pillars of the CLIMAAX flow—hazard, exposure, and vulnerability—for the CARM. For floods, we have a nearly thousand-year-old timeline (AMARNA) and economic loss records (CCS) that anchor the damage curves; the block is completed with real-time hydrometry (SAIH) and hazard mapping from the SNCZI, sufficient to generate probabilistic scenarios and validate recent events. For drought and extreme heat, the CSIC Observatory, hydrological bulletins, and AEMET data provide the climate signal, while the MAPA yearbooks and the SIOSE-AR raster bring agricultural and other uses' exposure to land plot resolution and allow for estimating monetary losses with observed prices and yields. In terms of socioeconomic vulnerability, the combination of Cadastre + SIGPAC + Land-Use Plans offers geometry and official regulations down to the parcel scale, reinforced by ESRI socio-demographic layers to assess impacts on vulnerable populations.

Prioritizing these databases will close the data gap and align the drought and flood CRA with the productive and water reality of the CARM, providing CLIMAAX with a true mirror for regional decision-making.

However, there are still critical knowledge gaps, especially in:

- Downscaled climate projections for specific catchments and coastal areas.
- Real-time hydrometeorological data accessible for public and institutional decision-making.

The CARM has recognized these vulnerabilities and is engaged in several initiatives to improve climate adaptation, civil protection, and environmental planning. The CLIMAAX project represents a key opportunity to strengthen the evidence base and spatial resolution of climate risk assessment, thus supporting more robust and targeted policy responses at the municipal and regional levels.

2.2.2 Workflow selection

Based on the hazard screening and the specific context of the Region of Murcia (CARM), three workflows from the CLIMAAX Toolbox have been selected as most relevant to the Climate Risk Assessment (CRA): Agricultural Droughts, River and Coastal Floods, and Heatwaves. These workflows are particularly pertinent given the semi-arid climate, the hydro-climatic extremes, and the socio-economic characteristics of the region.

2.2.2.1 Workflow #1: Droughts

The agricultural drought workflow is essential for CARM, where 46% of cultivated land is irrigated and agri-food exports exceed €6.9 billion annually. The exposure component is dominated by high-value, water-intensive crops (citrus, vegetables, vineyards, olives, almond, barley) and a dense agro-industrial sector that underpins regional employment and exports. Vulnerable groups include smallholders with limited adaptive capacity, ageing farming populations, and rural communities reliant on groundwater resources. Irrigation-dependent systems in the Segura basin are particularly exposed, while socio-economic vulnerability is heightened by aquifer overexploitation and rising production costs. In this workflow, both the relative and agriculture cases were executed; however, we present here only the results for the agriculture case, as they are more directly relevant for assessing the impacts on regional risk and vulnerability. The results obtained for the relative droughts workflow are provided in Relative-Droughts-Annex-REGMURCIA (see the project's ZENODO repository) for completeness.

2.2.2.2 Workflow #2: River and Coastal Floods

The river and inland flood workflow are highly relevant to the Segura River basin, where torrential rainfall and flash-flood events intersect with high levels of exposure in urban and peri-urban areas. Key hotspots include the Metropolitan Area of Murcia, Lorca, and the Campo de Cartagena, where socio-economic losses have escalated despite no significant upward trend in triggering episodes. Vulnerability is concentrated in municipalities with unregulated or poorly planned housing development, and in socio-economically disadvantaged neighbourhoods with limited coping capacity.

For coastal floods, exposure is acute along the 274 km Murcian littoral, where 32% of the regional population resides and where economic assets include mass-tourism resorts, critical petro-industrial infrastructure (Cartagena-Escombreras), ports, and transport corridors. Vulnerable groups include seasonal workers in tourism, immigrant populations concentrated in coastal towns, and elderly residents in flood-prone neighbourhoods.

2.2.2.3 Workflow #3: Heatwaves

The heatwave workflow is relevant given the consistent intensification of extreme heat events projected for southeastern Spain. The urban heat island effect in the City of Murcia, Cartagena, and other dense municipalities exacerbates exposure. Vulnerable groups include elderly populations, children, outdoor workers (particularly in agriculture and construction), and socio-economically disadvantaged households with limited access to cooling. Critical infrastructure at risk includes health facilities, schools, and energy systems facing peak electricity demand during extreme heat episodes.

2.2.3 Choose Scenario

Whenever possible, we have considered 30-year periods, both in the near and far future, in order to filter out natural variability. We have consistently analyzed all available scenarios, or at least a representative selection of them, by choosing both the least pessimistic and the most pessimistic cases, in order to capture the range of uncertainty associated with different assumptions regarding climate change, socio-economic developments, and their potential impacts. The scenarios available in the workflows are acceptable for an initial risk assessment, as they provide a broad picture of potential future conditions. However, many of the underlying datasets lack the precision and spatial resolution required for more detailed analyses, which means that while the results are useful for a first evaluation, further studies would benefit from higher-resolution and more region-specific data.

2.3 Risk Analysis

2.3.1 Workflow #1: Agricultural droughts

Table 2-6 Data overview workflow for agricultural droughts

Component	*Data Used & Source*	*Purpose / Role in Workflow*
Hazard data	Climate variables (daily precipitation, Tmax, Tmin, relative humidity, solar radiation, wind speed) from CORDEX regional climate models; soil available water capacity, elevation, thermal climate zone (as provided in workflow) We use combinations 1,2,3,4, for rcp2.6 and rcp8.5 and time slices 2031-2060 and 2071-2100.	Potential yield losses due to water scarcity

Component	*Data Used & Source*	*Purpose / Role in Workflow*
Exposure data	Global production data for 42 crops (2020) from MapSPAM; aggregated crop value (US$) from FAO-IIASA GAEZ. We added Olive data form the 2015 version. We also applied the workflow to the 2010 version.	To represent the economic value of the agricultural sector exposed to drought risk, quantified via production and revenue at risk.
Vulnerability data	Distribution of fully-irrigated cropland (2010) from GAEZ.	To capture how vulnerable each area is to precipitation deficits, using the presence of irrigation systems as a proxy.
Risk output	Maps estimating 'lost-opportunity cost' under non-irrigated conditions as well as share of irrigated cropland per grid cell.	Provides spatial quantification of potential revenue loss due to drought and identifies the most vulnerable areas to inform adaptation priorities.

2.3.1.1 Hazard assessment

The selected study area is the Region of Murcia (CARM) (E62). The climate zoning analysis of the workflow revealed that the entire Region of Murcia corresponds to Climate Zone 3, which is characteristic of a Mediterranean climate. As is standard in climate research, we used 30-year periods for the assessment. The selected periods were the near future (2031–2050) and the far future (2071–2100), which are also used in other workflows assessment. The selected periods were the near future (2031–2050) and the far future (2071–2100), which are also used in other workflows. The workflow has been tested with several model configurations (1, 2, and 3, see Table 2-6) and two climate scenarios (RCP 2.6 and RCP 8.5). The crops assessed in this study were olive, almond, and barley. Accordingly, the crop table was updated to include olive and almond. We also attempted to retrieve values for wine grapes. The new entries added to the Table 2-7 are as follows.

Table 2-7 Crop table used for the assessment in the CARM

FAO_Code	Crop	Clim	Kc_ini	Kc_mid	Kc_end	lgp_f1	lgp_f2	lgp_f3	lgp_f4	Season Start	Season End	RD1	RD2	DF	Type	Ky
260	Olives	3	0.65	0.70	0.70	0.082	0.240	0.164	0.507	60	180	1.5	2.0	0.65	1	0.85
221	Almond	3	0.40	0.90	0.65	0.055	0.164	0.082	0.699	30	180	0.9	1.8	0.65	1	1.05

We modified parts of the workflow to ensure proper saving of figures and files with meaningful filenames. Additionally, we adjusted the scale of the figures and selected a pixel-based representation for visualization.

The results indicate (Figure 2-11 and Figure 2-10) that yield losses are significant across all scenarios and time periods and analysed rainfed crops. that yield losses are significant across all scenarios and time periods and analysed rainfed crops. Olives is the most affected crop, with losses reaching mean spatial losses up to 42.4% under RCP 8.5 (2071–2100 mpi-smhi experiment). Almond also shows high losses, slightly below those of olive. Barley is the least affected but still shows considerable reductions, especially in severe scenarios. As expected, the RCP 8.5 scenario in the far future (2071–2100) presents the most severe impacts. There is also noticeable spatial and inter-model variability, reflecting both internal climate variability and differences in crop sensitivity across the region. Some areas reach values over 50% while some other in high land reduce the yield loss under 10%.

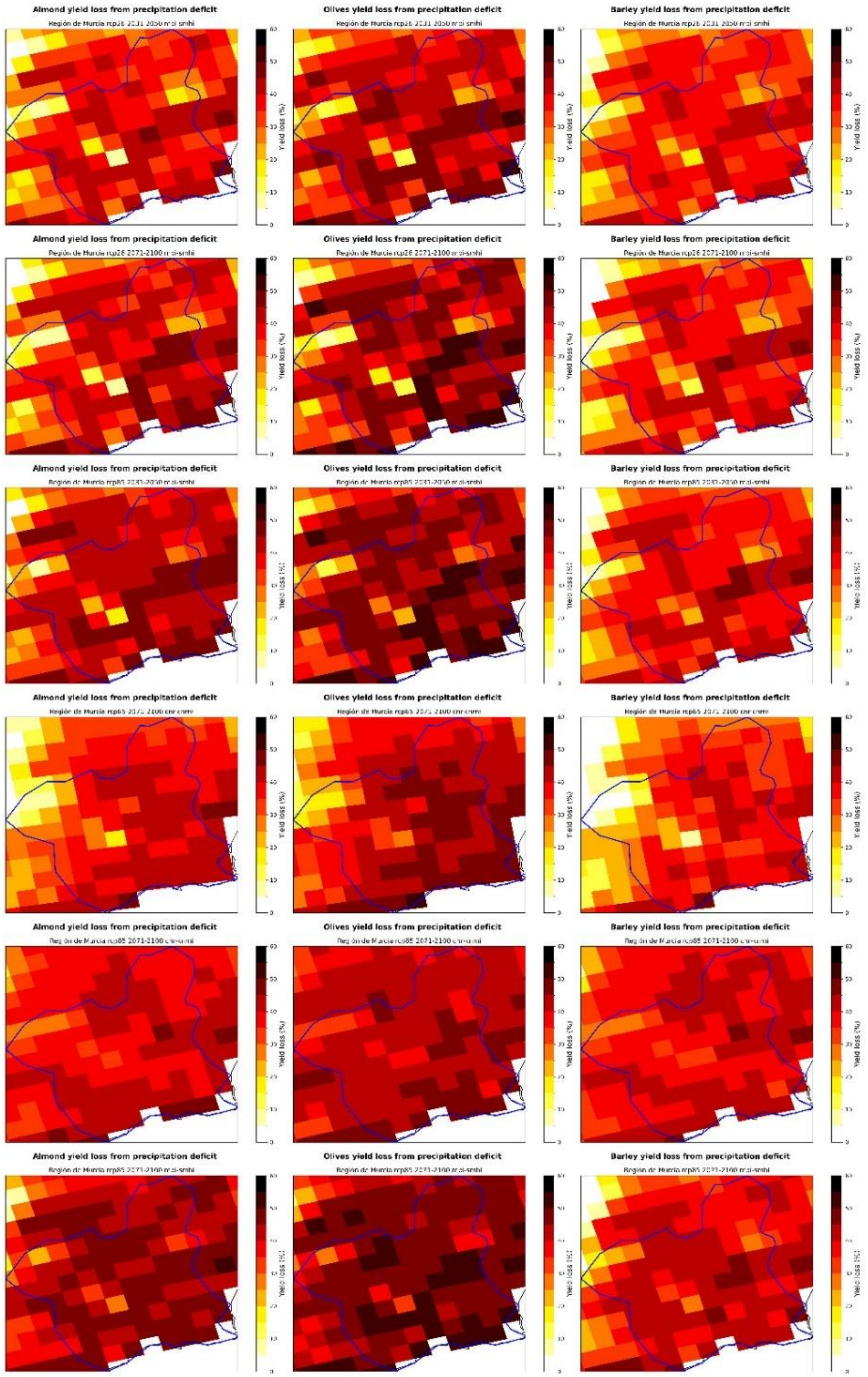


Figure 2-10 Yield loss for almond (left), olives (center) and barley (right) under the rcp85 scenario.

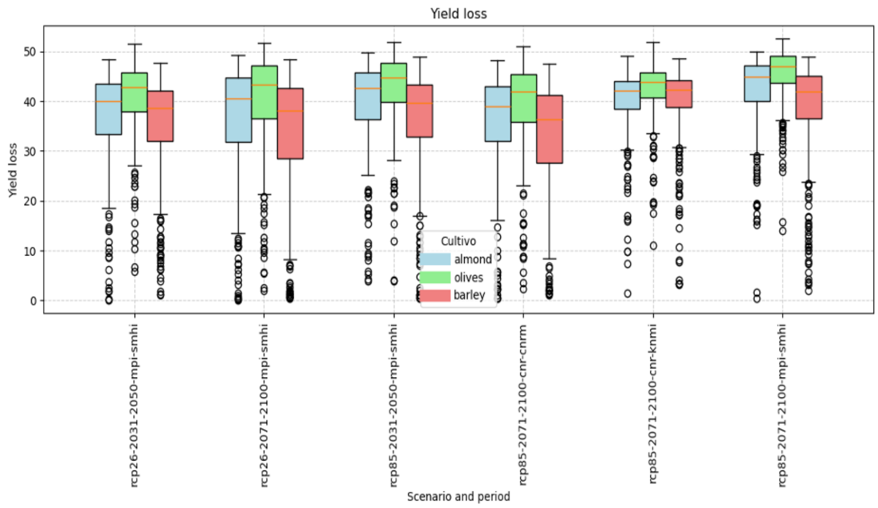


Figure 2-11 Yield loss for scenario and period for each type of crop assessed in the region of Murcia.

2.3.1.2 Risk assessment

We assessed agricultural drought risk for two key rainfed crops in Murcia: olive and barley. The input data for olives were successfully integrated using the file spam2010V2r0_global_P_OLIV_A.tif, extracted from FAO (2025). Unfortunately, no production data were found for almonds, which could be addressed in a future phase. For the loss assessment, and in order to ensure accurate visualization and calculation, we masked the Region of Murcia, avoiding distortion from high-production areas outside the region. This allowed us to compute total integrated losses and better assess the realism of the results. The workflow was updated accordingly. All intermediate fields involved in the loss calculation were also visualized to better understand spatial patterns. As an example, we present results for the RCP 8.5 scenario at the end of the century (2071–2100) using the MPI-SMHI model (Figure 2-12):

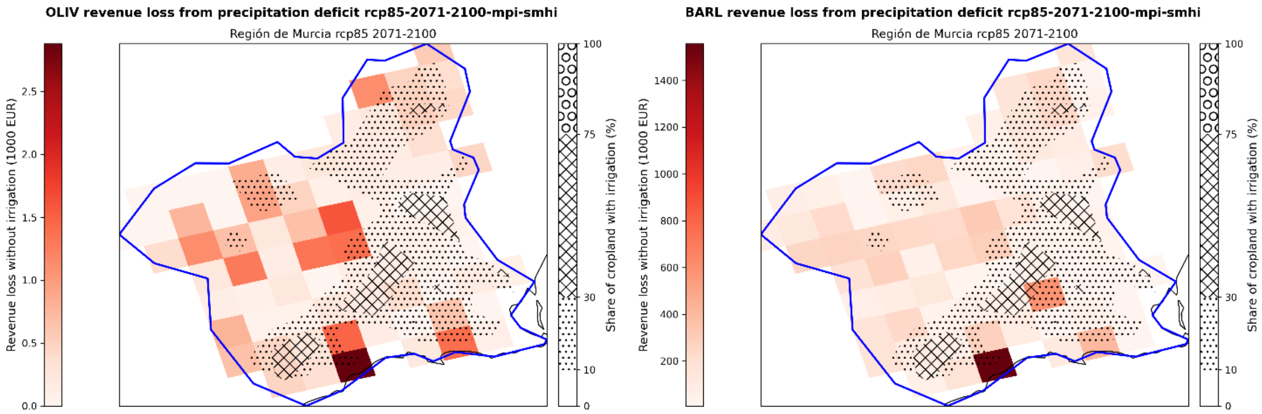


Figure 2-12 Olive (left) and barley (right) revenue loss from precipitation deficit under the rcp85 scenario.

- Olive (Figure 2-12, left): Losses reach up to €2500 4,000 per pixel, totaling approximately €30,000 across the region. The production values used underestimate recent real data.
- Barley (Figure 2-12, right): Losses are more modest, up to 1400 k per pixel, with total losses over 10 million. In this case, the SPAM database appears to estimate reasonabily the current production

We focused on drought-prone rainfed crops typical of the region: olive, almond, and barley. Multiple models, periods, and scenarios were tested to assess projection uncertainty. As key messages, we could summarize:

- Yield losses are substantial. Olive is the most affected, with projected losses above 45%, while barley and almond show losses near 40%.
- Economic impacts are moderate, mainly because these crops occupy relatively small areas in Murcia.
- Economic losses for almond could not be estimated due to missing production data.

Future work should include, Higher-resolution climate projections, Improved crop-specific climate characterization, Inclusion of other key crops, such as vineyards and almonds.

2.3.2 Workflow #2: Coastal and river floods

Table 2-8 Data overview workflow for coastal and river floods

Component	*Data Used & Source*	*Purpose / Role in Workflow*
River floods		
Hazard data	River flood depth maps for various return periods (e.g., 10, 100, 500 years) from the Joint Research Centre (JRC) covering Europe and the Mediterranean.	To represent flood hazard by estimating inundation depth under different return period scenarios.
Exposure data	Land use maps at ~100 m resolution from Copernicus Land Monitoring Service (LUISA/JRC).	To define which land-use types (e.g., infrastructure, agricultural land) are exposed to flooding.
Vulnerability data	Depth–damage (damage) curves for infrastructure and land use from JRC; country-specific economic parameters and assigned land-use	To quantify expected economic damage as a function of flood depth and land use type.
Risk output	Spatial maps of estimated economic damage to infrastructure, combining flood depth, land use, and country-specific damage functions. Hotspot maps for different return periods.	To identify regional hotspots of flood risk by illustrating projected economic losses across scales.
Coastal floods		
Hazard data	Extreme coastal water levels from GTSMv3.0 (global tide & surge model), driven by ERA5 reanalysis. Sea level rise projections from IPCC AR6, retrieved via the NASA Sea Level Projection Tool. Global Flood Maps (Deltares) for present (~2018) and mid-century (~2050 under RCP8.5), across return periods (2, 5, 10, 25, 50, 100, 250 years), with 90m resolution. Applied “bathtub” inundation model with DEM (we use both: MERIT-DEM or NASADEM)	To estimate coastal flood hazard by producing flood maps and time series of extreme water levels and sea level rise under different climate scenarios and return periods.
Exposure data	Land cover/use maps from Copernicus Land Monitoring Service (LUISA/JRC).	To identify which land-use categories (e.g., infrastructure, residential areas) are exposed to potential inundation.
Vulnerability data	Flood damage curves (depth–damage relationships) from JRC, expressed as relative damage percentages, augmented with country-specific economic values and land-use data.	To quantify potential economic damage by combining flood depth, land-use type, and local economic parameters.
Risk output	Time-series plots of extreme water levels and sea level rise estimates. Flood maps showing depth and extent for various return periods and scenarios. Economic damage maps for the same cases.	To produce spatial outputs that indicate potential coastal flood hazards, flooded areas, and associated economic impacts—highlighting risk hotspots for adaptation planning.

We selected two large areas: Murcia–East Coast, which covers La Manga and the Mar Menor, and Murcia–South, which covers the entire southern coast of the Murcia Region. Our main focus is on the Murcia–East Coast area, as it is the most affected.

We ran the workflow for the two DEM databases (MERIT DEM and NASA DEM), both at 90 m resolution, and modified the code to store the generated data.

We analyzed the results for the available periods (2018 and 2050) and for return periods of 1, 100, and 250 years.

2.3.2.1 Hazard assessment

With respect to coastal floods, the results show that there are hardly any differences between return periods or years. However, there are significant differences in the flooded areas depending on the DEM database used. The total area flooded is presented in Table 2-9:

Table 2-9 Total area flooded in the CARM.

Year	*RP (years)*	*Number*	*Area*	*DEM Model*	*Total area (hm^2)*
2018	10	607	Murcia-East	NASADEM	109.3
2018	100	674	Murcia-East	NASADEM	121.3
2018	250	701	Murcia-East	NASADEM	126.2
2050	10	750	Murcia-East	NASADEM	135.0
2050	100	841	Murcia-East	NASADEM	151.4
2050	250	870	Murcia-East	NASADEM	156.6
2018	10	1965	Murcia-East	MERIT DEM	353.7
2018	100	2033	Murcia-East	MERIT DEM	365.9
2018	250	2076	Murcia-East	MERIT DEM	373.7
2050	10	2099	Murcia-East	MERIT DEM	377.8
2050	100	2186	Murcia-East	MERIT DEM	393.5
2050	250	2221	Murcia-East	MERIT DEM	399.8

The MERIT DEM systematically estimates a much larger flooded area than NASADEM, with absolute differences ranging from +242 to +247 hm^2. Relative differences are also very significant, exceeding +200% in 2018 and decreasing slightly in 2050, although still remaining above +150%. This suggests that the choice of digital elevation model (DEM) has a critical impact on flood risk assessment, likely due to differences in resolution, hydrological conditioning, or flow corrections between MERIT DEM and NASADEM.

For both NASADEM and MERIT DEM, the flooded area increases as the return period grows, which is expected: more extreme (less frequent) events lead to more extensive flooding. The growth is nonlinear, especially in NASADEM, where the increase is more pronounced between RP=10 and

RP=100 than between RP=100 and RP=250. In NASADEM, moving from RP=10 to RP=250 results in a +15.5% increase in flooded area, while in MERITDEM, the increase over the same interval is only +5.7%.

In the Flood Coastal Water Level workflow, we observe that extreme sea levels range from 0.4 m for RP=5 to 0.6 m for RP=100. After checking the database, we confirmed that it does not provide return periods beyond this range. This indicates that the severity of sea level rise depends only slightly on the return period.

Using NASA's tool, we find that in our study area, sea level rise is projected to reach around 30 cm by 2050 under the most pessimistic scenario, and to exceed 70 cm by 2100 (Figure 2-13).

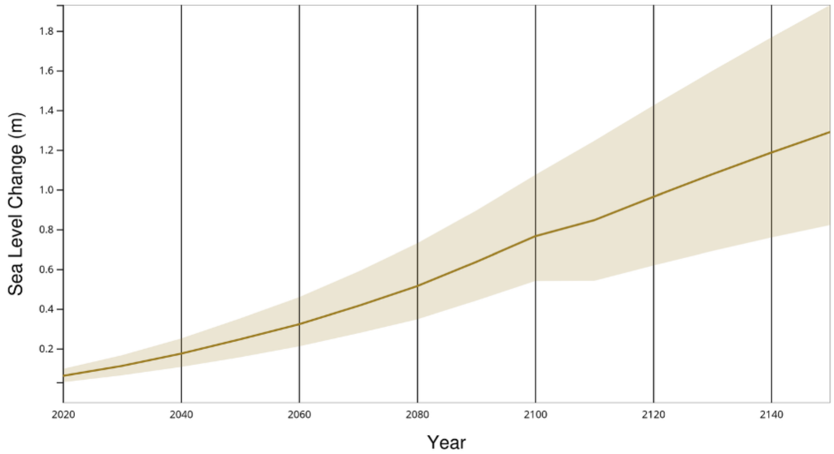


Figure 2-13 Sea level change projected in the CARM.

In the case of river floods, all cases were analyzed, and here we present and example (Figure 2-14) showing the results for the RCP 8.5 scenario and 250 years return level. In general, the results indicate a decrease in flood levels. However, the spatial extent of flooding remains of particular interest. To explore this, we modified the code to identify and map the areas where changes occur.

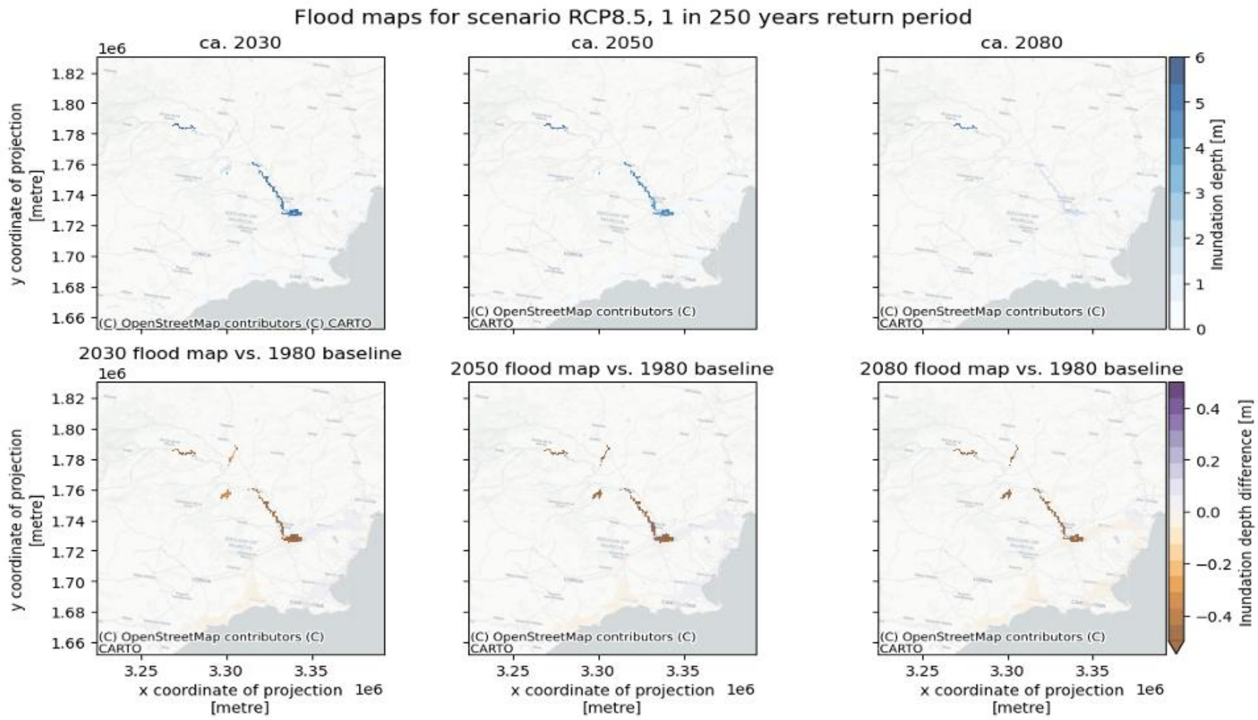


Figure 2-14 River flood level extension and depth (top panel) for the RCP 8.5 scenario in 2030, 2050 and 2080 for return period of 250 years and differences respect baseline (low panel).

Table 2-10 shows the differences in between baseline case and RCP and year. In summary, the total number of flooded pixels remains relatively stable across all scenarios and time horizons (around ~1,800 pixels).

Table 2-10 Summary of the differences between baseline case and RCP for river floods in the CARM.

Scenario	*Year*	*+Pixels*	*-Pixel*	*Flooded Pixels*
RCP 4.5	2030	236	-1551	1797
RCP 4.5	2050	65	-1722	1790
RCP 4.5	2080	18	-1769	1801
RCP 8.5	2030	828	-959	1791
RCP 8.5	2050	866	-921	1791
RCP 8.5	2080	217	-1536	1757

Under RCP 4.5, the vast majority of changes are negative, meaning that most areas experience reduced flooding compared to the 1980 baseline. This trend intensifies over time, suggesting a contraction of inundated areas. Although the total number of flooded pixels remains relatively stable (~1,800), their spatial distribution shifts, indicating redistribution rather than expansion of flood zones. Under RCP 8.5, the picture is more dynamic. In 2030 and 2050, increases and decreases in flooded pixels are more balanced, pointing to a stronger spatial reorganization of flooding. By 2080, however, the pattern converges with RCP 4.5, with flooding decreasing in most locations.

Overall, the total flooded area remains nearly constant (1750–1800 pixels) across all years and scenarios. In areas where the historical baseline shows deeper flooding, future floods tend to be less intense. The key change is therefore not the amount of flooding, in fact Depth decreases, but its location. RCP 8.5 produces more pronounced mid-century spatial redistribution of flooding, while by 2080 both scenarios show a general contraction of flood extent compared to the baseline. This may be linked to a redistribution of extreme precipitation events under climate change.

2.3.2.2 Risk assessment

For coastal floods, our analysis focused on the Murcia–East domain. Land-use types were derived from the LUISA dataset at 50 m resolution, and the classification of land-use categories was carried out using the JRC reference tables. We executed all simulation cases and evaluated the associated costs, both in total and disaggregated by land-use class. The workflow was modified to automatically produce a comprehensive summary of results for each case. As an illustrative example, Figure 2-15 shows the outcomes obtained for the Murcia–East domain.

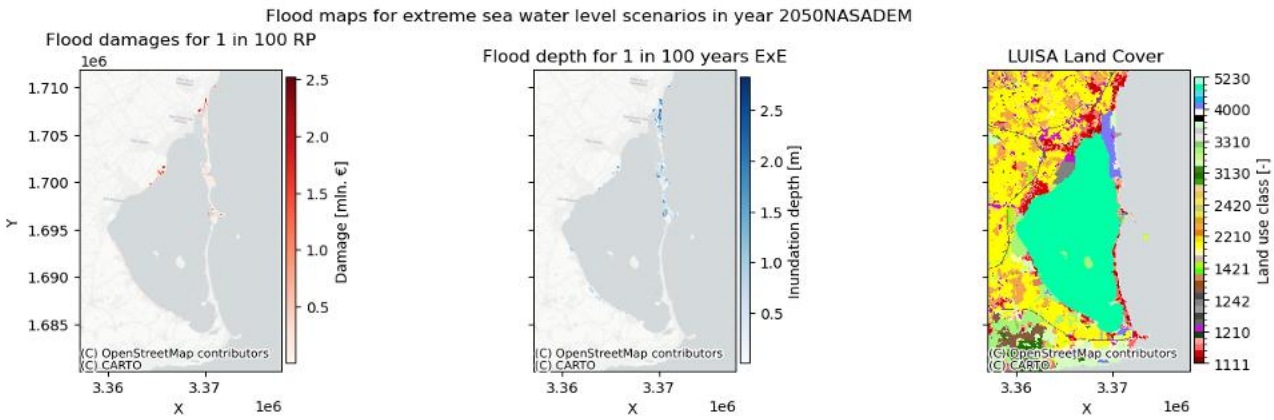


Figure 2-15 Example of the flood damages (left), flood depth for a return period of 100 years (center) and land cover (right).

A summary of all results is presented in the following figures. Figure 2-16 shows the total integrated losses for each DEM database, year, and scenario.

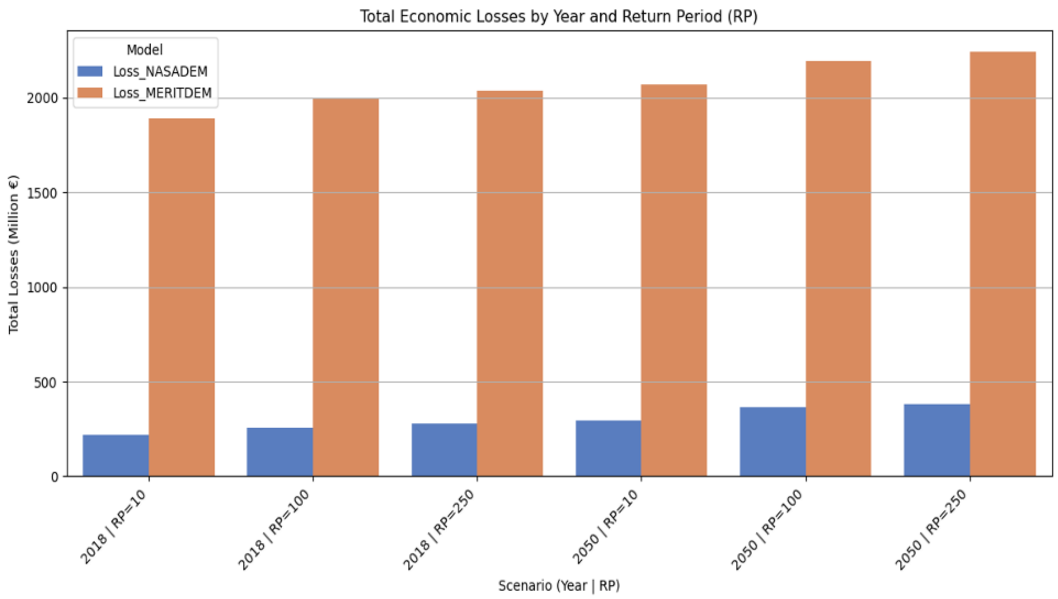


Figure 2-16 Summary of results. The panel shows the total integrated losses for each DEM database, year, and scenario.

MERIT DEM produces significantly higher estimates than NASADEM across all scenarios. In some cases, losses calculated with MERIT DEM are up to three times greater, reflecting the model's higher sensitivity to detailed topography. This highlights the substantial influence of the chosen elevation model on the estimation of flood-prone areas, and consequently, on economic risk assessments.

Economic losses increase markedly in 2050 compared to 2018 for both models, consistent with the potential aggravation of climate change impacts. NASADEM shows more pronounced increases in losses, although starting from lower baseline values. These increases depend slightly on the return period: for NASADEM, they range from about +30% to +10%, whereas for MERIT DEM the increases are around +10% for all return periods. Although MERIT DEM yields higher absolute values, it projects more moderate growth towards 2050. As expected, longer return periods (RP=10 → 100 → 250 years) result in higher estimated economic losses. More extreme, less frequent events generate more extensive flooding and, therefore, greater damages. For NASADEM, the increase in economic losses from RP=10 to RP=250 is about +30%, while for MERITDEM it is around +8%.

The spatial distribution of economic losses reflects the concentration of vulnerable assets in specific land-use categories. Figure 2-17 shows, based on the estimates for the 2050 | RP=100 scenario, the most affected land-use classes are, in descending order: medium-density urban fabric, airport areas, non-irrigated arable land, industrial or commercial units, and road and rail networks with associated land. These categories correspond to areas of high economic exposure, critical infrastructure, and densely populated zones. The magnitude of losses underscores the need for priority adaptation measures in these areas to reduce future flood risk. It should be noted that in this first step the loss curves were adopted as acceptable without further adjustment. Nevertheless, they represent a potential source of uncertainty that warrants closer examination and refinement in the next phase of the analysis.

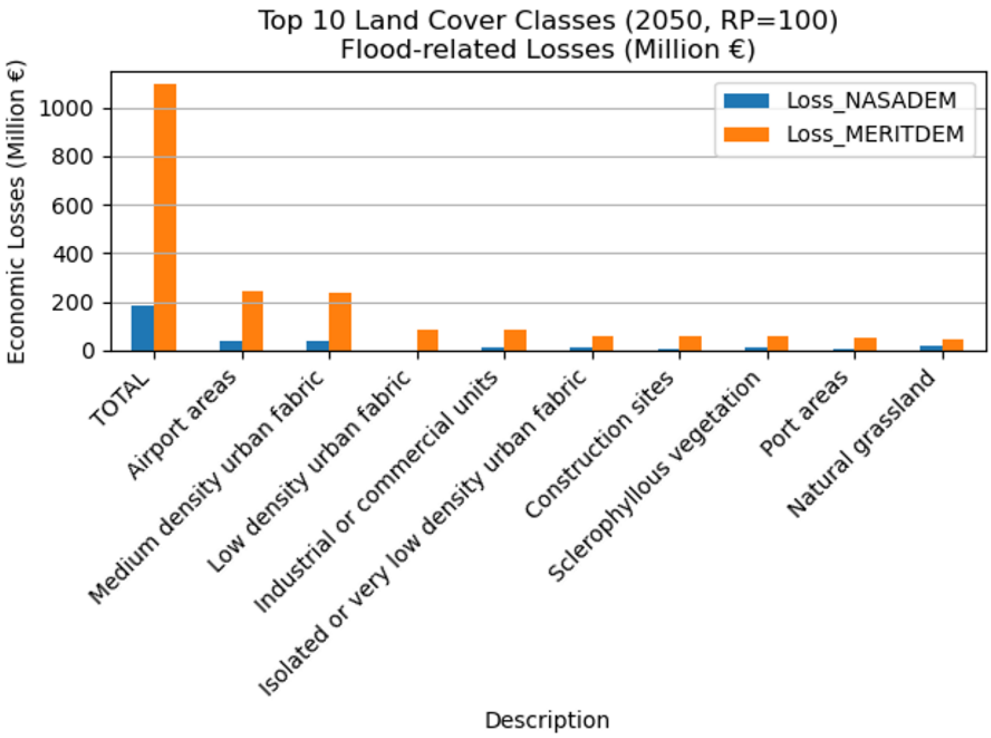


Figure 2-17 Distribution of economic losses across land-use classes in 2050 (RP=100).

In the case of river floods, all possible cases were analyzed, and the most affected land-use categories were selected for detailed assessment (Figure 2-18). This approach allows focusing on the sectors that concentrate the highest potential flood damages and provide the greatest insight into vulnerability patterns. The land-use categories most affected by flood damage are "Permanently irrigated land" and "Fruit trees and berry plantations", both exceeding €2,000 million in estimated losses under the most extreme scenario (RP500). Other highly impacted categories include "Industrial or commercial units" and urban fabrics of varying densities, highlighting the significant vulnerability of built infrastructure. By contrast, categories such as pastures, construction sites, and transport infrastructure present comparatively lower losses, though they are not exempt from measurable impacts.

Across all categories, economic damage increases steadily with the return period, confirming that rarer and more extreme flood events lead to substantially higher economic consequences. At the aggregate level, total damage rises from €7,614 million (RP10) to more than €11,100 million (RP500), underscoring the considerable scale of potential impacts.

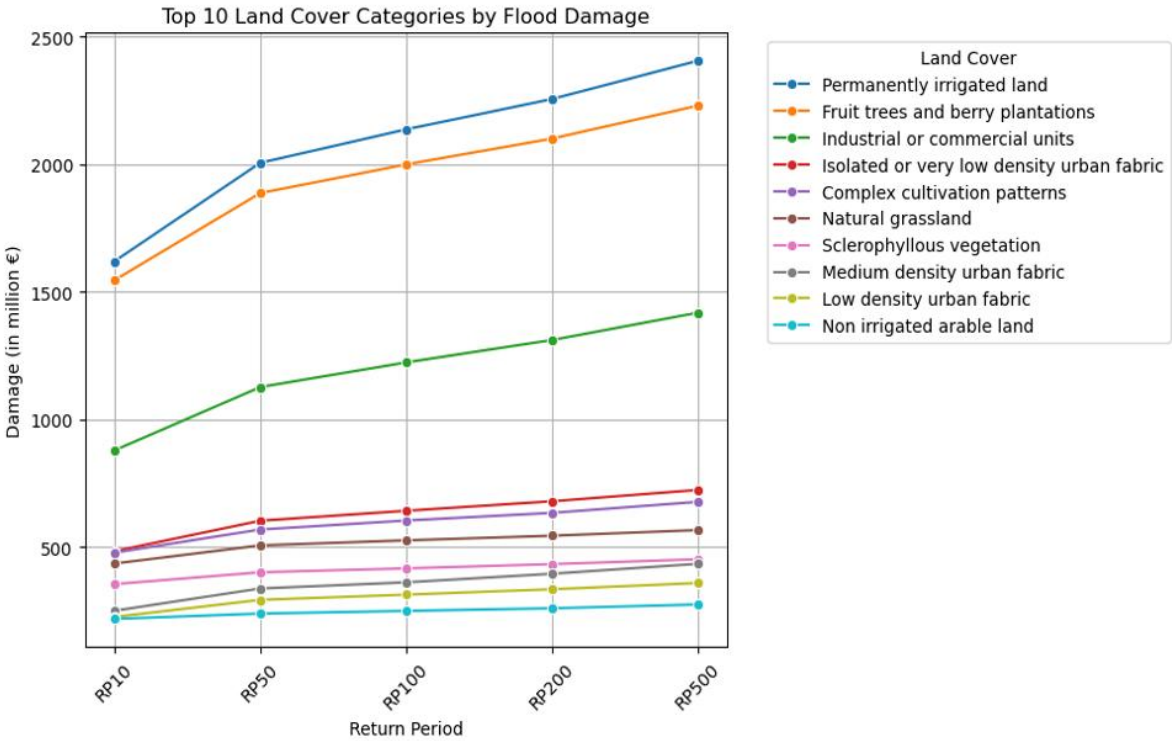


Figure 2-18 Damage by return period and land over category.

Regarding the Flood Damage and Population Exposure, the previous workflows, which identified the areas with the highest river flood hazard, the Murcia metropolitan area and its surroundings was selected as the case-study region. This area encompasses several medium-sized cities, including Molina de Segura, Alcantarilla, Alguazas, and Santomera. With an estimated population of more than 700,000 inhabitants, it concentrates nearly 50% of the total population of the CARM, making it a critical hotspot of exposure and vulnerability to flood risk.

Firstly, the flood Impact on Buildings and Population is analyzed. Figure 2-19 presents the flood hazard maps for the selected area. The results show that the zone with flood probability is extensive, ranging from 7,400 ha under RP10 to 9,500 ha under RP500, with maximum water depths exceeding 5 m (5.7 m for RP10 and 6.4 m for RP500) (Table 2-11).

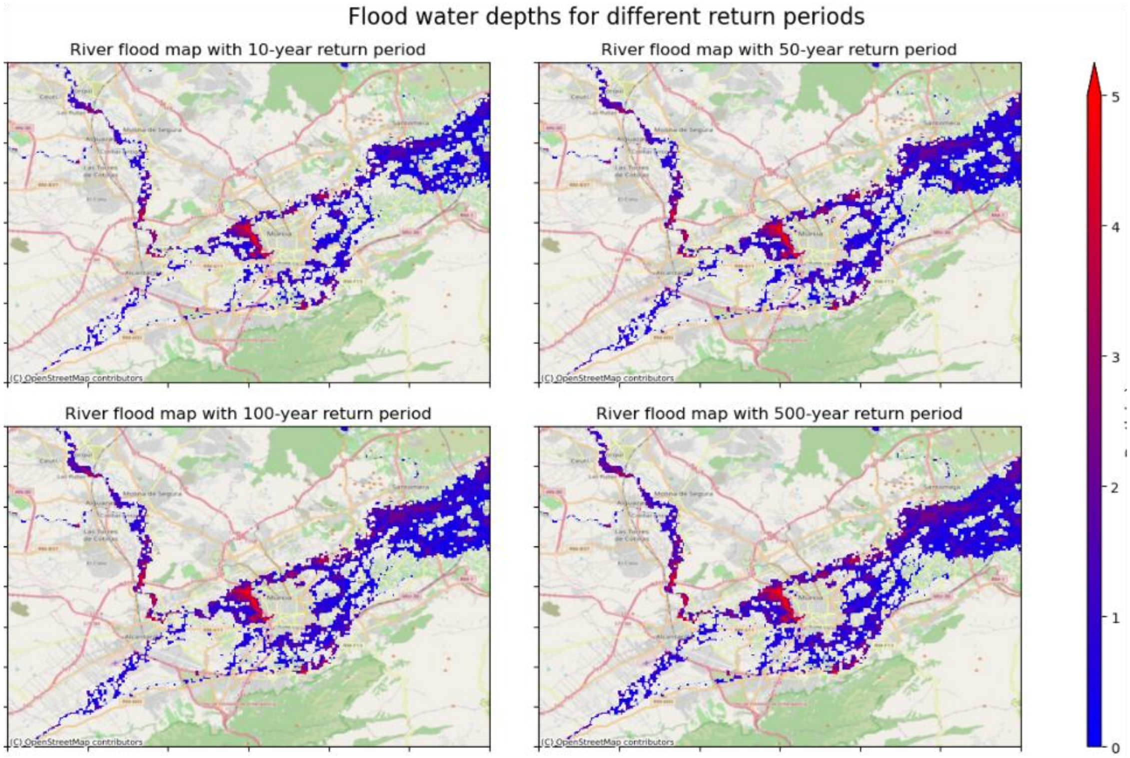


Figure 2-19 Flood water depths (m) for different return periods (RT) for the Metropolitan area of Murcia.

Table 2-11 Summary of the flood hazards for the region of Murcia.

RP (years)	*Flooded area (ha)*	*Flooded pixels*	*Max depth (m)*	*% flooded*
10	7,346.53	10,579	5.7	12%
50	8,481.94	12,214	6.1	14%
100	8,842.36	12,733	6.2	15%
500	9,497.92	13,677	6.4	16%

2.3.2.2.1 Risk assessment for flooding: building damage and population exposure

For the previously defined study area, we executed the full workflow in order to assess the Risk. Monetary losses were expressed in real 2022 euros, using a Consumer Price Index (CPI) of 123.6 (instead of the 2024 CPI of 131.5). This choice reduces short-term volatility and facilitates comparison across scenarios; note that a regional CPI (slightly lower than the national value) could be used in future iterations for finer calibration. For reference, translating results from 2022€ to 2024€ would scale values by approximately 131.5/123.6 ≈ 1.064 (≈ +6.4%).

Depth–damage relationships were taken from the default damage curves. A straightforward improvement for the next phase is to expand the set of asset/land-use classes and apply class-specific (and, where possible, region-specific) vulnerability curves, better reflecting local building typologies and contents.

Population exposure was assessed using the population dataset shown in Figure 2-20, which underpins the estimation of affected inhabitants and the distribution of risk across the metropolitan area. The estimated total population in selected area: 661,854 inhabitants 661,854 inhabitants, which is consistent with the real data.

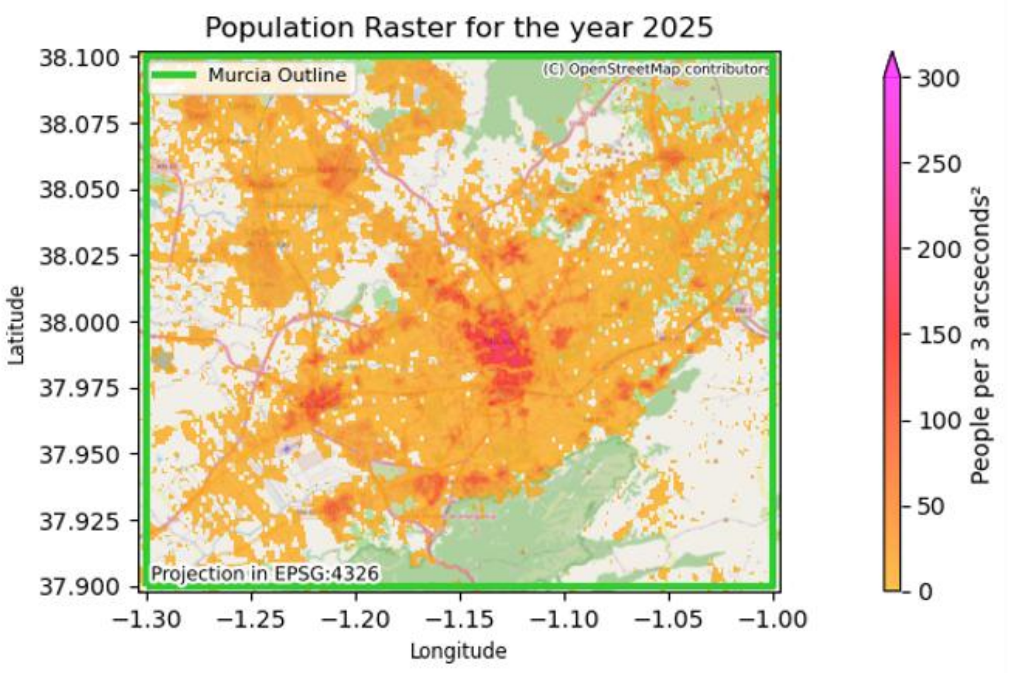


Figure 2-20 Population distribution used for exposure analysis in the Murcia metropolitan area.

In Figure 2-21, all resolved classes are presented. A potential improvement would be to include additional categories in the final analysis.

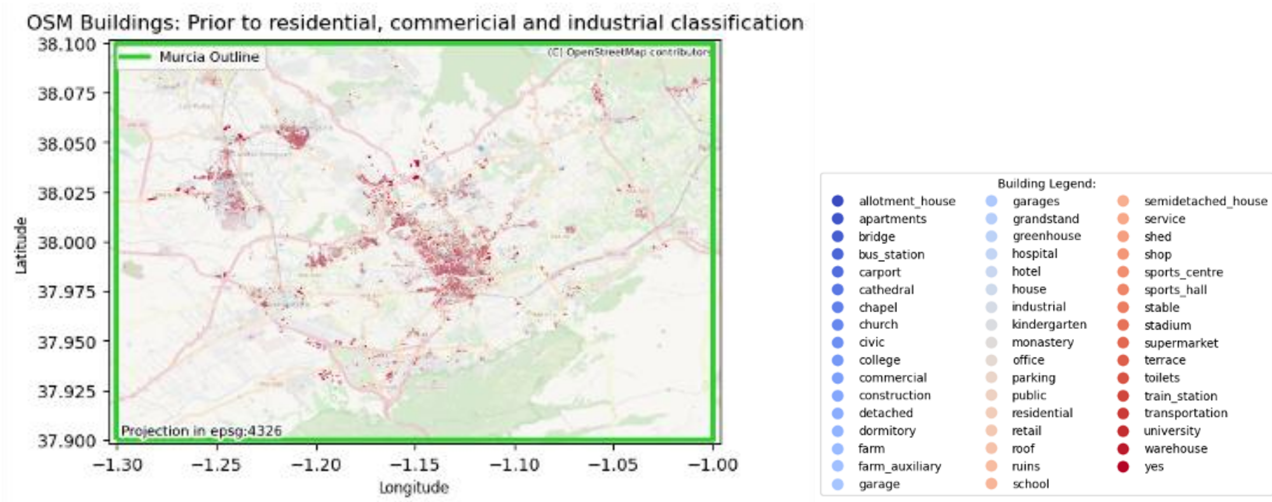


Figure 2-21 Population distribution used for exposure analysis in the Murcia metropolitan area.

We first estimated direct losses for buildings. Table 2-12 reports losses (million €) by building class and return period. Total damages increase monotonically with event severity, and the Universal class (aggregated/mixed or critical assets) dominates the totals. For RP500, aggregate losses exceed €1.0 billion. From RP10 → RP500, total losses rise by ≈ 41% (710 → 1,002 M€); class-specific increases are ≈ 35–42%. Assuming the figures are in million euros, the expected annual damage (EAD) across return periods is ≈ €79.5 million per year. Note that the Universal class contributes ~77% of total losses at RP500 (773/1,002 M€), followed by Residential (~11%), Commercial (~6.6%), and Industrial (~5.6%).

Table 2-12 Losses (million €) by building class and return period in the Murcia metropolitan area.

Building class	*10-yr*	*50-yr*	*100-yr*	*500-yr*
Residential	78	95	99	109
Commercial	49	59	60	66
Industrial	40	48	50	56
Universal	544	663	700	773
Total	710	864	910	1,002

In the next step, the exposure of critical infrastructure was analyzed. The workflow currently outputs PNG maps only; their resolution is insufficient for reliably quantifying affected assets. We therefore developed code to load the outputs into an interactive viewer, enabling visual identification of exposed infrastructure.

To obtain quantitative metrics, we extended the workflow to count affected assets by infrastructure type. The results (Figure 2-22) indicate that parking facilities are the most impacted (over 60 assets), followed by schools and fuel stations. These findings highlight the concentration of potential service disruptions in mobility and education networks. Figure 2-22 counts of critical infrastructure assets intersecting the flooded area, by type; parking facilities are most affected (>60), followed by schools and fuel stations.

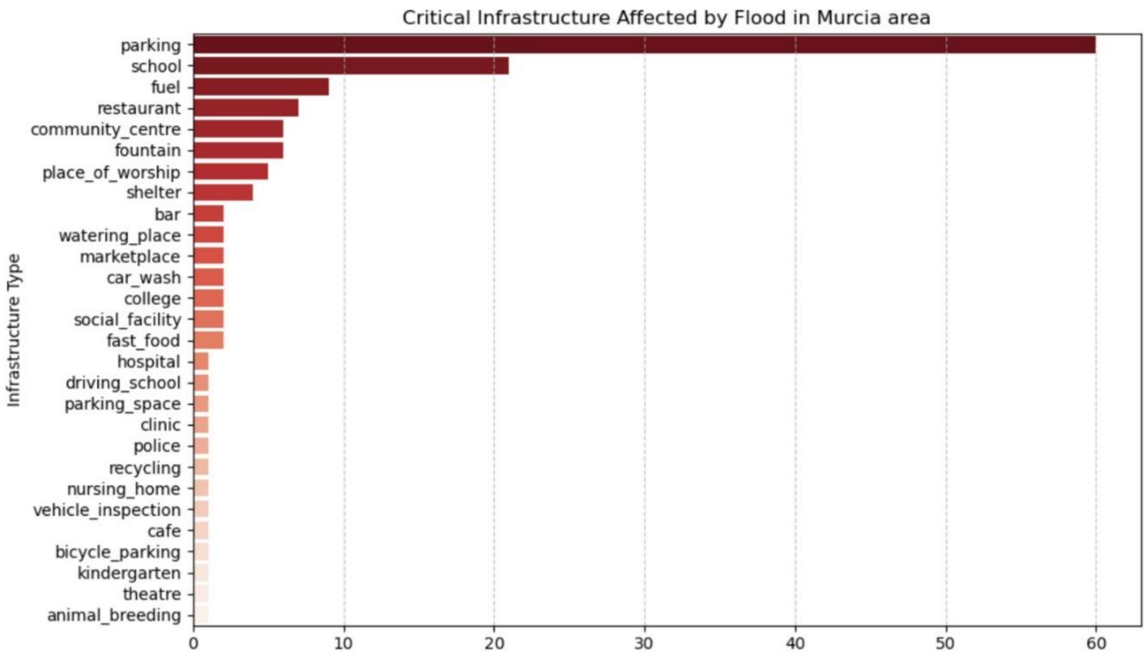


Figure 2-22 Critical infrastructure affected by flood in Murcia metropolitan area.

Note on limitations and next steps. Because raster PNG outputs constrain measurement accuracy, future iterations should export vector layers (e.g., GeoPackage/GeoJSON) and perform topology-aware intersections against authoritative infrastructure datasets to refine counts and reduce uncertainty.

Next, the population exposure and displacement are estimated by overlaying the flood extent (water depth > 0 m) with the population layer. Results range from approximately 115,000 people under

RP10 to just over 150,000 under RP500. The expected annual number of affected people (EAP) is ≈ 11,568, which is consistent with the RP10 count multiplied by its annual exceedance probability (0.1). We then estimated displaced population as residents located where flood depths exceed 1 m. Depending on the return period, displaced population ranges from ~30,000 to >50,000, with an annualized value of ≈ 4,009 people.

During post-processing, we identified a CSV export bug (the file overwrote displaced counts with exposure counts). This has been corrected: the final output now writes both exposure and displacement fields to facilitate plotting and QA.

To support inspection and validation, we added code for interactive map visualization. Spatially, potential displacement is concentrated in peri-urban areas outside the main urban cores, characterized by dispersed housing in formerly agricultural zones (Table 2-13 and Figure 2-23).

Table 2-13 People exposed and displaced in the Murcia metropolitan area.

RP(years)	*People Exposed*	*People Displaced*
10	104,743	33,981
50	125,251	44,427
100	130,647	48,143
500	141,517	54,419

Future work should integrate flood-defense infrastructure (levees, embankments, walls, gates, pumps) into the hazard modelling workflow, encoding crest elevations, operational rules, and (where relevant) breach/overtopping scenarios. In addition, for the next phase it would be desirable to include higher-resolution terrain (e.g., LiDAR) with hydrological conditioning to replace/coarsen-test the 90 m DEMs. Model calibration/validation against observed flood extents and water levels; report skill metrics. Uncertainty and sensitivity analysis, including defense performance, roughness, depth–damage curves, and CPI choices; provide EAD with confidence bands.

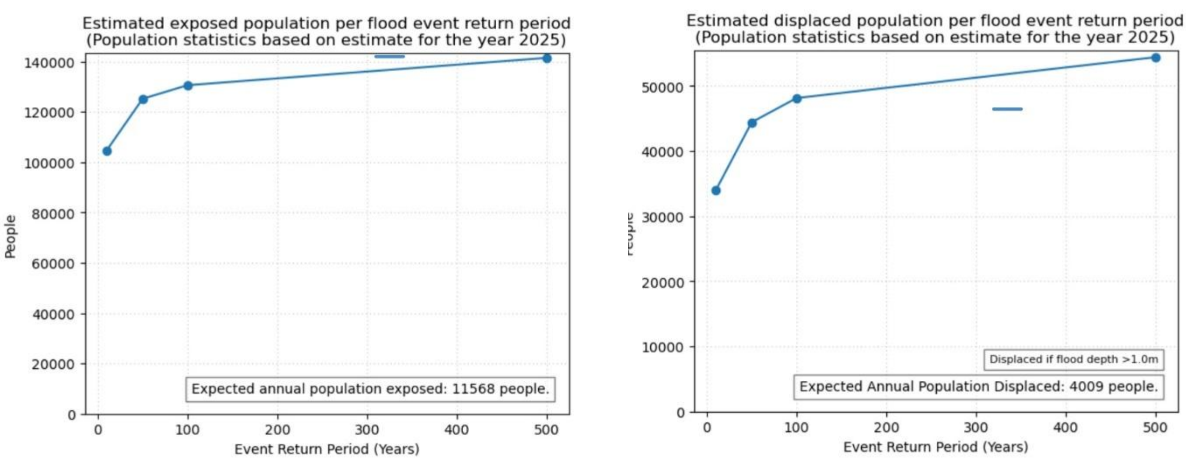


Figure 2-23 Affected (depth > 0 m) and displaced (depth > 1 m) population under selected return periods; interactive viewer enables asset-level inspection.

2.3.3 Workflow #3: HeatWaves

Table 2-14 Data overview workflow for heatwaves

Component	*Data Used & Source*	*Purpose / Role in Workflow*
Hazard data	EuroHEAT dataset (12 km grid): Heatwave days defined by maximum apparent temperature (Tappmax) and minimum temperature (Tmin) for July–August, with percentile thresholds. Scenarios RCP4.5 and RCP8.5, for periods 1971–2000, 2011–2040, 2041–2070, 2071–2100.	To estimate the frequency, intensity, and duration of current and future heatwaves, allowing for climate thresholds to be adapted to the regional context.
Exposure data	EuroHEAT regional data integrated with population distribution (WorldPop) to produce multi-scale risk maps.	To identify which areas are most exposed to extreme heat and where vulnerable groups are concentrated. Exposure is measured by the presence of overheated zones, while vulnerability is represented by the density of sensitive populations.
Vulnerability data	Risk maps generated through a matrix approach (e.g., 10 × 10), combining heatwave hazard metrics (frequency, intensity) with population exposure and vulnerability, producing both current and projected risk maps.	To highlight the most critical areas with a high probability of heatwaves and high concentrations of vulnerable populations, supporting prioritization of adaptation measures.
Risk output	EuroHEAT dataset (12 km grid): Heatwave days defined by maximum apparent temperature (Tappmax) and minimum temperature (Tmin) for July–August, with percentile thresholds. Scenarios RCP4.5 and RCP8.5, for periods 1971–2000, 2011–2040, 2041–2070, 2071–2100.	To estimate the frequency, intensity, and duration of current and future heatwaves, allowing for climate thresholds to be adapted to the regional context.

2.3.3.1 Hazard assessment

We perform the Heatwave Hazard Assessment with EuroHEAT. First, we selected a point centered on the Region of Murcia and visualized the EuroHEAT output (Figure 2-24), extending the original script to display the mean and ±1 standard deviation. Results indicate a dramatic increase in heatwave occurrence: at the beginning of the study period the rate is about 3 events per year, rising to >50 events per year by late century under RCP 8.5 (±10 events). Under RCP 4.5, the late-century occurrence is roughly half of the RCP 8.5 value.

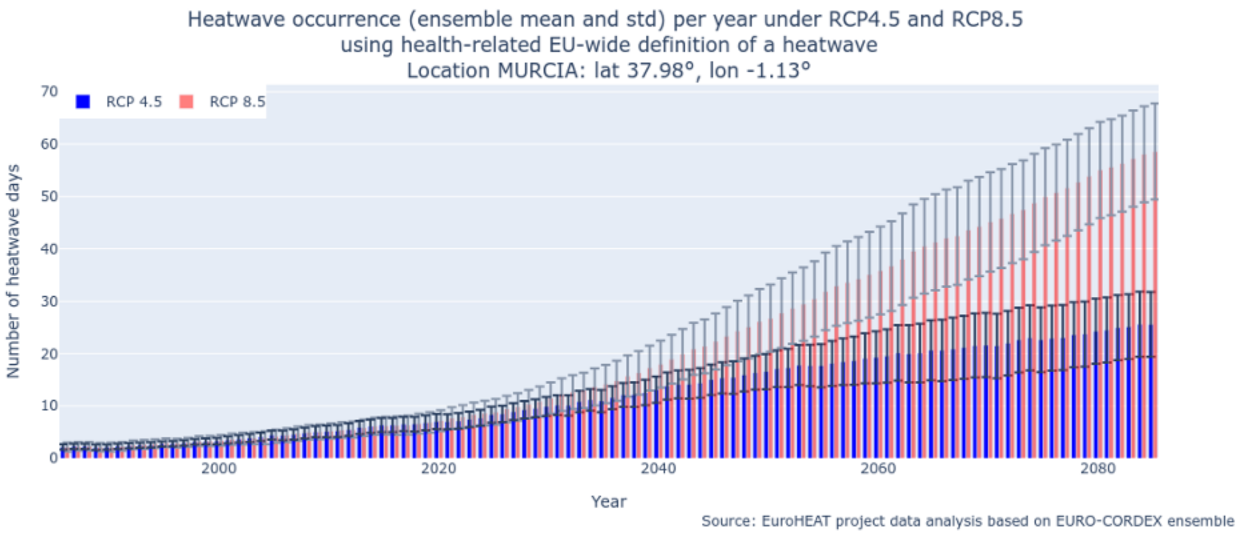


Figure 2-24 Annual time series of heatwave occurrence under RCP scenarios 4.5 (blue) and 8.5 (red) for a point located at the center of CARM.

A heatwave is defined here as ≥2 consecutive days with daily maximum temperature exceeding the 90th percentile of a reference period (typically 1986–2005 or 1961–1990) for that location and time of year. The accompanying map highlights the Region of Murcia as one of the European hotspots where the projected increase is largest. We conducted a spatial assessment relative to the 1986–2015 baseline, considering two future time slices—2036–2065(mid-century) and 2066–2095 (late-century)—under the same scenarios as above (RCP 4.5 and RCP 8.5). The figures XX and YY present the maps of projected heatwave occurrence and the corresponding changes with respect to the baseline for each scenario–period combination.

The results indicate a dramatic increase in heatwave occurrence under both scenarios (Figure 2-25). Under the pessimistic pathway RCP 8.5, late-century occurrence exceeds 50 ± 9 events yr^{-1}, implying an order-of-magnitude (~10×) increase relative to the early-period baseline (~3 events yr^{-1}). RCP 4.5 also shows a robust rise, reaching roughly half the late-century magnitude of RCP 8.5.

Focusing on the spatial distribution, interior counties are the most affected, with heatwave occurrence increasing by roughly an order of magnitude (~10×) relative to 1986–2015. Southern counties (near to see) are also strongly impacted, showing increases of about ~8×. This pattern holds across scenarios, with the largest absolute magnitudes under RCP 8.5 by late century.

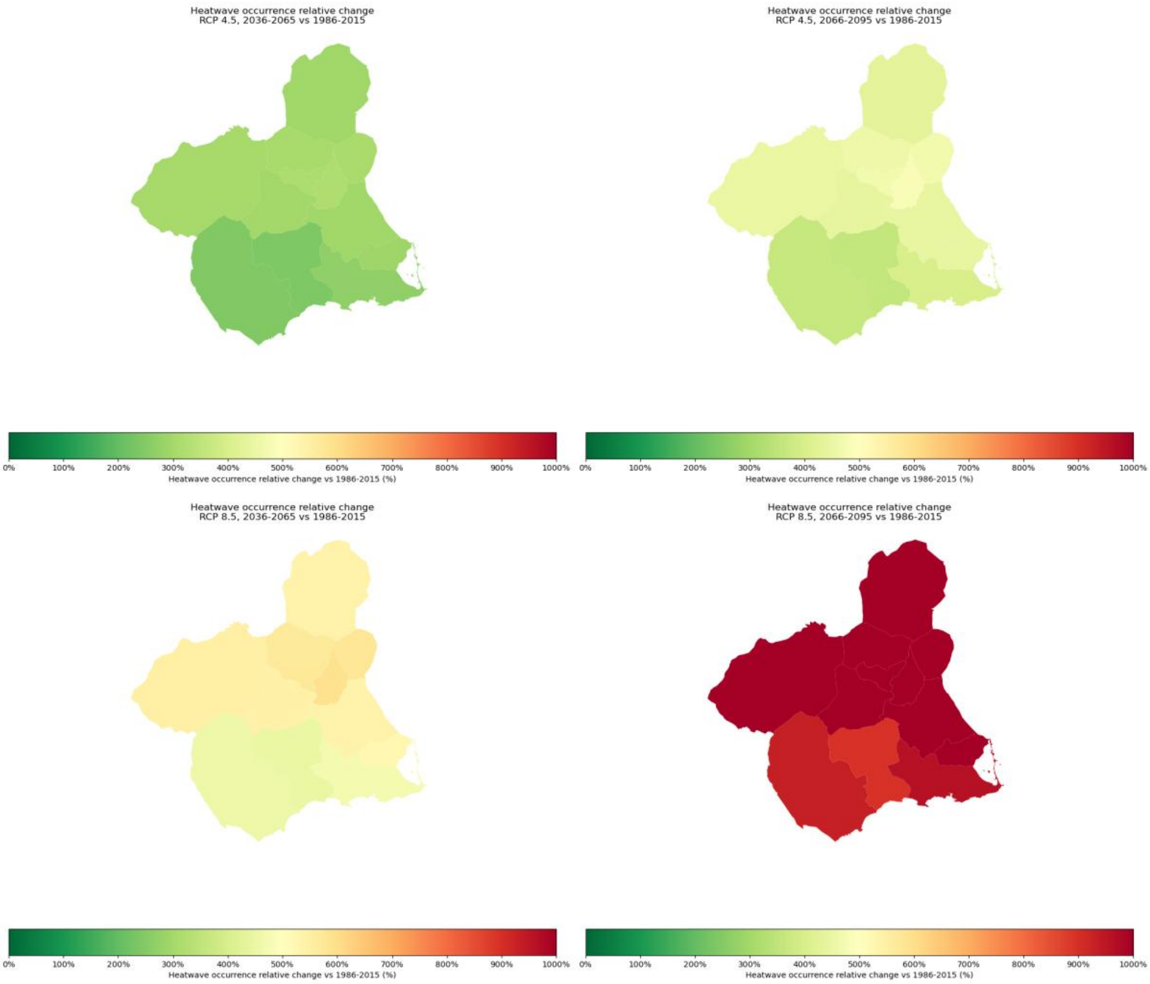


Figure 2-25 Heatwave occurrence relative change respect 1986-2015 for scenarios RCP 4.5 (left) and 8.5 (right) for near (top) and far (2066-2095) future in the CARM.

2.3.3.2 Risk assessment

For the vulnerability analysis we focused on older adults (≥75 years), using 2020 population-density rasters for men and women aged 75–79 and ≥80. We assumed a stationary age structure over time and overlaid these layers with the heatwave hazard fields.

The vulnerable population—and the population overall—concentrates in the south and southwest of the region, notably in Campo de Cartagena and along the Segura valley (Vega Media and Vega Alta) (Figure 2-26). Consequently, the highest risk levels are concentrated there. Projections indicate a marked escalation of risk in these areas, with nearly the entire Region exceeding medium risk by late century, and very high (extreme) risk emerging in densely populated interior segments of the Segura basin.

Note: Assuming a fixed 2020 age structure may underestimate future vulnerability in regions with accelerated ageing. Using demographic projections (e.g., INE/Eurostat) would make the analysis more robust.

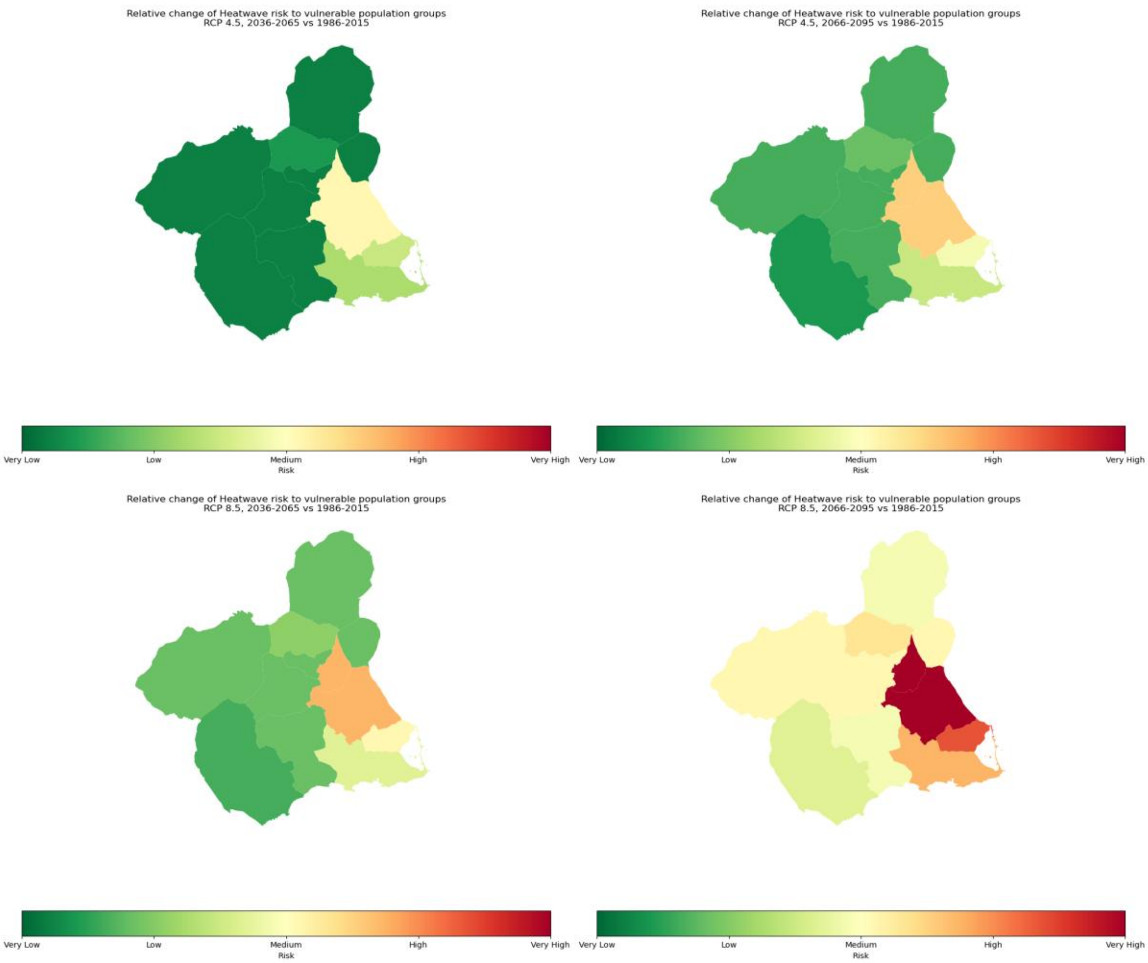


Figure 2-26 Relative change of heatwave to vulnerable population risk with respect 1986-2015 for scenarios RCP 4.5 (left) and 8.5 (right) for near (top) and far (2066-2095) future in the CARM.

2.4 Preliminary Key Risk Assessment Findings

The preliminary Key Risk Assessment under CLIMAAX for the CARM can be seen in Figure 2-27. It reflects droughts and heatwaves as very high priority hazards, river flooding as high, and coastal flooding as moderate. However, the preliminary analysis indicates that once high-resolution national datasets (SIOSE-AR, MAPA/ESYRCE, municipal planning layers) are incorporated in Phase 2, the balance will shift: river flooding is expected to be reclassified as Very High, while agricultural droughts may be downgraded to High, as more accurate exposure and vulnerability data refine the risk scoring.

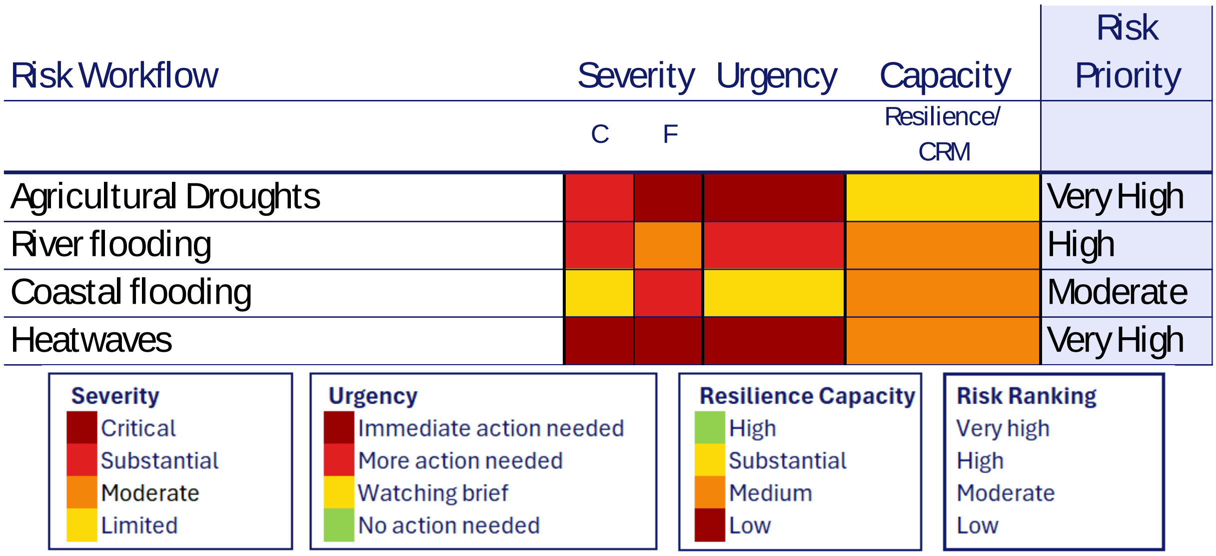


Figure 2-27 Preliminary Key Risk Assessment for the CARM through risk ranking, considering severity (of current – C and future – F risk), urgency and resilience capacity. Source: Adapted from EEA (2024).

2.4.1 Severity

Agricultural droughts are already classified as critical in severity. The Segura River Basin consistently registers Spain's lowest reservoir levels, while recurrent meteorological and hydrological droughts translate into agricultural losses above 40% for almonds and olives and repeated crises for citrus and horticultural crops. The exposure of more than 100,000 hectares of citrus and high-value horticulture creates systemic economic vulnerability, with annual agri-food exports at stake. The situation in dryland crops is even more severe. With more than 150,000 hectares of non-citrus fruit trees and cereals exposed to recurrent agroclimatic droughts. This seriously jeopardizes the survival of this activity, which connects and integrates the areas and represents traditional landscapes with high added value.

Future scenarios reinforce this criticality: projections of longer consecutive dry spells and increasingly negative SPEI indices point to prolonged drought conditions, maintaining agricultural drought as a severe and structurally destabilising hazard.

River flooding currently shows substantial severity. The 2019 DANA caused over €1.3 billion in damages and several fatalities, demonstrating the destructive power of extreme precipitation events. While not as recurrent as droughts, floods affect densely populated valleys and critical infrastructure, amplifying potential impacts. Although future projections for this hazard, derived from the CRA, show a lower future hazard than the current one, the situation will continue to be serious. Furthermore, this preliminary CRA should be viewed with caution in light of the significant discrepancy between current exposure data modeled by the CLIMAAX CRA and official flood mapping, as well as evidence from recent flooding.

Coastal flooding is assessed as moderate at present. Historical damages are localised in Cartagena, Mazarrón, and the Mar Menor lagoon, with limited systemic consequences to date. However, with sea-level rise projections of +30–50 cm by 2100, storm surges with today's 100-year recurrence could occur every 20–30 years by mid-century, elevating severity to substantial to critical in the future.

Heatwaves are already substantial to critical in severity. The record-breaking summers of 2022 and 2025 brought maximum temperatures above 45 °C and minimum night-time values above 30 °C, resulting in more than 20 heat-related fatalities in a single season. These events not only affect public health but also reduce labour productivity, increase energy demand, and place stress on urban infrastructure. Climate projections foresee 12–18 additional tropical nights per year by 2050 under SSP5-8.5, consolidating heatwaves as a hazard of critical severity in future scenarios.

2.4.2 Urgency

Agricultural droughts demand continuous and escalating action. While they unfold more slowly than floods or heatwaves, their cumulative and persistent nature means that the window for effective adaptation is closing. Without immediate investments in water-use efficiency, irrigation governance, and groundwater recovery, losses will become irreversible.

River flooding is a high-urgency hazard, since extreme rainfall events develop suddenly and leave little reaction time. Urbanisation of flood-prone areas and the concentration of assets in the Segura floodplain increase the stakes of every event. Urgent structural measures in drainage, green infrastructure, and planning are needed to avoid recurrent billion-euro losses.

Coastal flooding has low near-term urgency, as severe impacts are expected after mid-century. However, strategic urgency is still high: adaptation planning, coastal defence inventories, and land-use controls must be enacted now to avoid locking in future exposure. Urgency is therefore better described as deferred but inevitable, with present decisions determining risk levels in 2050 and beyond.

Heatwaves carry immediate urgency. Their rapid onset, coupled with increasing frequency and intensity, makes short-term preparedness essential. The mortality toll of 2025 shows that current measures are insufficient. Urgent actions are required in public health preparedness, labour protection, and urban cooling strategies.

2.4.3 Capacity

Agricultural droughts demonstrate substantial-to-medium capacity. CARM is globally recognised for advanced irrigation systems, desalination and wastewater reuse, providing a significant buffer against water scarcity. However, these measures are energy-intensive, costly, and insufficient to offset aquifer overdrafts and long-term structural water deficits. Natural capacity is low, undermining resilience despite technological progress.

River flooding capacity is rated as medium. The basin benefits from SAIH monitoring, SNCZI flood maps, and civil protection protocols, but gaps persist in drainage infrastructure, enforcement of floodplain zoning, and ecosystem-based buffers. Current measures reduce but do not neutralise high losses when extreme events occur.

Coastal flooding capacity is also medium. The PIMA Adapta-Murcia programme has improved hazard mapping and raised awareness, but full inventories of coastal defences are lacking, and ecosystem-based adaptation remains underdeveloped. Financial and technical resources are accessible, but institutional coordination is partial.

Heatwaves show medium-to-low capacity. Spain operates robust meteorological alerts, yet CARM lacks sufficient cooling shelters, social protection for vulnerable groups, and housing insulation to cope with persistent nocturnal heat. Human and institutional expertise is strong, but social and infrastructural adaptation measures lag behind hazard intensification.

2.5 Preliminary Monitoring and Evaluation

The first phase of the REGMURCIA CLIMAAX project has yielded several important insights regarding both the climate risks affecting the Region of Murcia (CARM) and the methodological and institutional requirements needed to address them effectively. The application of the CLIMAAX Common Methodology, combined with regional datasets and expert consultation, has enabled the identification of priority hazards and areas of high vulnerability. However, this initial phase has also revealed limitations that will need to be addressed in subsequent iterations to enhance the robustness and applicability of the assessment.

Key Lessons. The Phase 1 risk assessment confirmed that agricultural droughts, river/coastal flooding and heatwaves represent the most significant climate-related threats to the Region of Murcia, both under current conditions and in projected future scenarios. Preliminary mapping has shown that urban centres, irrigated agricultural areas, and coastal infrastructure are particularly exposed, with risks compounded by uneven adaptive capacity and past land-use decisions.

Nonetheless, several challenges were encountered in the execution of the workflows:

- Data integration across scales proved complex, especially when comparing global-standardised indicators from the CLIMAAX toolbox with high-resolution local datasets such as SNCZI flood zones, cadastral maps or agricultural registries. Discrepancies in spatial resolution and data formats required significant post-processing to ensure consistency.
- Estimating vulnerability remains one of the most uncertain aspects of the assessment. While exposure data is relatively abundant, information on the sensitivity and adaptive capacity of specific population groups is more difficult to obtain.
- Urban-scale analysis, especially in relation to heatwaves and urban heat islands, requires a very high level of detail which surpasses the data sets currently available in the CLIMAAX Common Methodology.

These methodological challenges highlight the need for enhanced data interoperability, improved social vulnerability indicators, and greater technical resolution in meteorological and hydrological modelling.

Stakeholder Feedback. Future engagement activities in Phase 2 should aim to broaden participation by involving local-level actors, community-based organisations and additional representatives from the private sector.

Data Availability. Phase 1 based on the access to a wide range of existing datasets, including national hydrological models (SNCZI), climatic indicators from Copernicus, land cover data (CLC 2018), and socioeconomic indicators from the Regional Statistics Centre (CREM). These resources enabled the development of an initial multi-hazard diagnostic aligned with the CLIMAAX methodology. Nevertheless, further refinement of the risk assessment will require high-resolution local climate projections, ideally downscaled to 1 km or less, particularly for variables such as maximum temperature, soil moisture and precipitation. In addition, updated flood hazard maps that account for projected sea level rise and urban development trends beyond the 2021 SNCZI baseline will be needed. Last, micro-scale demographic data, disaggregated by age, income, and housing conditions, to improve social vulnerability estimates will be strongly beneficial during Phase 2. Additional resources may be needed in the form of advanced GIS capabilities, integration with real-time monitoring systems, and access to expert facilitation for participatory workshops. Continued collaboration with regional research institutions and the use of HPC resources from the University of Murcia will support the technical feasibility of these refinements.

2.6 Work plan

Following the completion of Phase 1 of the REGMURCIA CLIMAAX project (centred on the screening and preliminary analysis of priority climate hazards), Phases 2 and 3 will build upon the foundations established during the Climate Risk and Vulnerability Assessment. These subsequent phases aim to refine the technical diagnosis and support the development of region-specific, stakeholder-led adaptation pathways. The overarching goal is to advance from initial risk identification to actionable and institutionally anchored adaptation planning.

Phase 2: Refinement Using Local Data (Months 7–16):

The main objective of Phase 2 is to enhance the accuracy and policy relevance of the initial risk assessment through the incorporation of local datasets and advanced modelling tools. The key activities will include:

- Technical meetings with stakeholders to validate the results of Phase 1 and identify refinements needed based on territorial, sectoral, and institutional knowledge. These meetings will support alignment with local policy frameworks and planning instruments.
- Incorporate high-resolution local data to enhance accuracy, including updated climate and meteorological data, digital elevation models, irrigation water demand records, cadastral data, and socio-demographic indicators. These inputs will allow more precise estimation of exposure and vulnerability in critical sectors such as agriculture, urban settlements, and coastal infrastructure.
- Develop technical studies or high-resolution maps using GIS data for precise impact estimation, focusing on projected hazard intensities under SSP2-4.5 and SSP5-8.5 pathways. These maps will provide a robust visual and analytical basis for stakeholder discussions and planning exercises.
- Stakeholder consultations to validate the refined outputs and gather expert judgment on risk thresholds and priority areas.
- Ongoing dissemination through the project's dedicated webpage and public-facing materials, ensuring transparency and knowledge sharing.

Phase 3: Exploration of Adaptation Options (Months 17–22):

The final phase of the project will focus on translating the refined risk assessment into concrete, stakeholder-informed adaptation strategies and policy recommendations. The goal is to provide sector-specific action plans that support the long-term resilience of the Region of Murcia. The main activities will include:

- Conduct participatory workshops with stakeholders to present and discuss results, including sectoral agencies, municipalities, civil society organisations, and the private sector. These workshops will be used to co-develop and prioritise adaptation measures tailored to local contexts.
- Development of a catalogue of adaptation measures, detailing the expected benefits, feasibility, and implementation requirements for each option. Measures will span areas such as sustainable land use, water efficiency, climate-resilient infrastructure, etc.

- Prepare a summary document with actionable steps and sectorial plans, including prioritized measures, timelines, responsibilities, and budgets. These will be designed for integration into existing planning and regulatory frameworks, including the ERMACC and local general plans.
- Final dissemination activities, including the publication of results and participation in the closing CLIMAAX workshop in Brussels.

Phase 3 will not involve the physical implementation of adaptation measures or the drafting of legislative texts. Instead, it will generate stakeholder-validated proposals for action that public authorities, economic sectors, and communities can adopt using appropriate funding instruments.

3 Conclusions Phase 1- Climate risk assessment

The first phase of the REGMURCIA CLIMAAX project has enabled a comprehensive climate risk assessment in the Region of Murcia, focusing on three key hazards: agricultural drought, flooding (coastal and river), and heatwaves. Using harmonised methodologies across workflows, this phase provides a solid analytical foundation for informed climate adaptation planning at regional and sub-regional levels.

In the agricultural drought assessment, the analysis confirms that climate change poses a significant threat to key rainfed crops. Yield reductions are substantial across all scenarios, time horizons, and crops. Olives emerge as the most affected, with losses of up to 45.4% under RCP 8.5 for the 2071–2100 period. Almond and barley also show losses close to 40%, although the latter is less economically exposed. In monetary terms, olive revenue losses reach up to €16 million across the region by 2100, whereas barley losses remain below €1 million, largely due to lower market value and cultivated area. These projections point to a structurally increasing risk that particularly threatens the long-term viability of Mediterranean rainfed agriculture.

Regarding coastal and river flooding, the results reveal strong dependencies on the digital elevation model (DEM) used. MERIT DEM estimates flooded areas up to 3× larger than NASADEM, with differences exceeding +200% in 2018 and remaining above +150% by 2050. Under NASADEM, flooded area in the East Coast domain increases from 109.3 hm² (RP10, 2018) to 156.6 hm² (RP250, 2050), while MERIT DEM estimates growth from 353.7 hm² to 399.8 hm² over the same period. Economic damages increase markedly by 2050: for example, under NASADEM, flood losses grow by up to +30% between RP10 and RP250. In the case of river floods, total damages across land-use categories escalate from €7,614 million (RP10) to over €11,100 million (RP500). The most affected classes are irrigated lands, fruit plantations, and critical urban infrastructure.

In the Murcia metropolitan area, which houses nearly 50% of the region's population, flood exposure and displacement risk are also substantial. Up to 141,517 people could be exposed under RP500, with 54,419 potentially displaced. Buildings show similar sensitivity: losses increase from €710 million (RP10) to €1.0 billion (RP500), with 77% of damages attributed to the "Universal" building class, which includes mixed and critical assets.

The heatwave risk assessment reveals an even more dramatic trend. Annual heatwave frequency increases from ~3 events/year at baseline to over 50 events/year by 2100 under RCP 8.5—a tenfold increase. Spatially, inland areas show the strongest relative rise, with risk levels increasing by ~10× in the interior and ~8× along the southern coastal belt. Vulnerable populations, especially adults over 75 years of age, are concentrated in areas such as Campo de Cartagena and the Segura basin, leading to widespread projected high and very high risk by late century. Nearly the entire region is expected to exceed medium risk levels by 2100 under both scenarios.

In summary, the Phase 1 analysis provides clear evidence that all three hazards studied are projected to intensify, though in different ways:

- Drought risk will structurally affect traditional crops, demanding urgent adaptation in agricultural planning and water governance.
- Flood risk will increasingly threaten both economic assets and population centres, with urban and coastal areas being the most exposed.
- Heatwave risk will multiply drastically, especially for older populations and inland communities, creating serious public health and energy demand challenges.

These findings support the prioritisation of high-risk areas and sectors and highlight the urgent need for targeted adaptation interventions. The next phases of the project will be critical for integrating higher-resolution data, refining economic damage modelling, and engaging stakeholders in the co-design of feasible adaptation pathways.

4 Progress evaluation and contribution to future phases

This deliverable marks the successful completion of Phase 1 of the REGMURCIA CLIMAAX project (Table 4-1 and Table 4-2), which focused on the initial Climate Risk and Vulnerability Assessment of the Region of Murcia. The outputs produced during this phase lay a solid basis for the more detailed tasks planned for Phases 2 and 3, where refined risk estimates and actionable adaptation strategies will be developed.

The present deliverable has met all expected objectives for the first stage of implementation as outlined in the Individual Follow-Up Plan. Through the application of the CLIMAAX Common Methodology, the Region of Murcia has completed a harmonised screening of its main climate hazards (here the deliverable focuses on droughts and river and coastal floods), supported by preliminary spatial analyses and stakeholder engagement.

The risk assessment was carried out using both Copernicus-based workflows and local datasets, and included an initial identification of risk hotspots. These findings have been summarised according to the CLIMAAX framework criteria and will guide the focus of more detailed analyses and stakeholder engagement in subsequent phases.

In terms of project integration, this deliverable ensures continuity with future phases by: (1) Establishing a clear risk typology and exposure profile at regional scale; (2) Producing reference maps and data layers to be refined during Phase 2; (3) Defining a participatory architecture that will be scaled up in upcoming workshops; (4) Aligning the outputs with key regional policy frameworks, particularly ERMACC; and (5) identifying institutional entry points for mainstreaming adaptation.

The outputs produced here will be revisited and enriched through technical meetings and high-resolution modelling (Phase 2) and subsequently used to inform the participatory co-design of adaptation options and policy proposals (Phase 3). This document thus serves as both a diagnostic tool and a strategic anchor for the next steps of the REGMURCIA CLIMAAX roadmap.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
Number of workflows applied in Deliverable 1	Al least 2 workflows completed: droughts, river/coastal floods and heatwaves analysed using the CLIMAAX methodology.
Number of stakeholders contacted	145 organisations identified and contacted across all relevant categories (regional government, municipalities, research, NGOs, etc.).
Climate risk assessment report (Deliverable 1) completed	Delivered on time (August 2025), including full Phase 1 CRA, visualisations, preliminary key risk findings and scoping for future actions.
Project webpage creation and content dissemination	Webpage launched under MurciaNatural portal.
Number of dissemination activities conducted	Two activities: internal dissemination workshop (June 2025) and public communication via website and press note.

Table 4-2 Overview milestones

Milestones	*Progress*
Project introduction via email to key stakeholders	Achieved. All stakeholders received introductory communication by end of Month 1.
Creation of project webpage	Completed. Project webpage created on murcianatural.carm.es, includes description, contacts and first results.
Reference document output	Finalised in Month 3. Internal working paper on climate risk criteria produced to guide workflows and stakeholder engagement.
Attendance at CLIMAAX Workshop (Barcelona)	Successfully attended. Project team participated and presented project context and planned methodology.
Toolbox outputs (preliminary)	Generated through CLIMAAX workflows; initial results visualised and analysed for integration in the CRA.
First participatory workshop	Postponed to early Phase 2. Stakeholder engagement transitioned to contacts in Phase 1; workshop preparation underway.
First deliverable (CRA report)	Achieved. Deliverable 1 completed and submitted by the required deadline.

The outputs generated in this phase directly inform the next project milestones. In Phase 2, these include the refinement of workflows using high-resolution GIS data, further technical validation with key stakeholders, and updated risk maps. In Phase 3, they will support the development of adaptation measures and sectoral action plans through participatory processes.

5 Supporting documentation

- D1-REGMURCIA-CLIMAAX_Phase1_CRA Report.pdf: This document presents the Phase-1 Climate Risk Assessment for the Region of Murcia (CARM), developed under the CLIMAAX project. It outlines the regional context, priority hazards (agricultural droughts, floods, and heatwaves), data landscape and stakeholder framework. The document establishes the basis for high-resolution risk analysis and engagement in subsequent project phases.

- DROUGHT.zip – Contains the workflow files for the analysis of drought hazard and risk using the CLIMAAX tool. Including results and some modifications of code to obtain additional calculations.

- FLOODS.zip – Contains the workflow files for the analysis of flood hazard and risk with the CLIMAAX tool. Including results and some modifications of code to obtain additional calculations.

- HEATWAVES.zip – Contains the workflow files for the analysis of heatwave events within CLIMAAX. Including results and some modifications of code to obtain additional calculations.

- PressRelease-REGMURCIA.zip – Press release material related to the information of the project to society.

- Reference document-CARM-REGMURCIA CLIMAAX.pdf: Internal working paper on climate risk criteria produced to guide workflows and stakeholder engagement.

- REGMURCIA CLIMAAX_Barcelona_poster.pdf: Poster presented at the Barcelona CLIMAAX Workshop. 10-11 June 2025. Barcelona, Spain.

- Relative-Droughts-Annex-REGMURCIA.pdf: Results obtained for the relative droughts workflow (see page 38 of REGMURCIA-CLIMAAX_Phase1_Climate Risk Assessment Report.pdf).

- Stakeholder_References_Communication-REGMURCIA.zip: This folder compiles the reference documentation on key stakeholders identified in Phase 1 of the REGMURCIA CLIMAAX project. It includes institutional profiles, organisational references, and the proposed communication model to support stakeholder engagement and risk-ownership processes in the Region of Murcia.

The Zenodo CLIMAAX community and this supporting documentation are accessible at the following link: https://doi.org/10.5281/zenodo.17048788

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