Deliverable Phase 2 – Climate risk assessment

ClimateSmart Pomorie: "Charting a Sustainable Future" (CSP-Future)

Bulgaria, Pomorie Municipality

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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 2 – Climate risk assessment
Brief Description	The ClimateSmart Pomorie project focuses on conducting a Climate Risk Assessment (CRA) based on the CLIMAAX Framework to assess, and prioritise responses to key climate risks affecting Pomorie municipality. Building on the analysis and findings of Phase 1, the project moves on to conduct a multi-risk assessment to integrate local data and develop climate scenarios, with a focus on the most relevant hazards for the municipality such as floods, droughts, heavy rainfall, strong winds and heatwaves. The ultimate goal is to inform and support municipal administration and the local community in their efforts to integrate specific adaptation measures into the strategic planning and ensure long-term climate resilience. The project applies available scientific data, local data and knowledge, and stakeholder perspectives to analyse climate hazards, exposure, and vulnerability, thus enabling a deeper awareness of current and future climate risks under different climate scenarios, identifying critical hotspots and vulnerable sectors and promoting proper planning responses.
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Abbreviations and acronyms

Abbreviation / acronym	Description
AR6	Sixth Assessment Report (IPCC)
CDS	Climate Data Store
FAO	Food and Agriculture Organization
GAEZ	Global Agro-Ecological Zones

Executive summary

This deliverable presents the Phase 2 Climate Risk Assessment for Pomorie Municipality under the ClimateSmart Pomorie project. It builds on Deliverable 1, where coastal flooding was identified and tested as the initial priority workflow, and expands the assessment into a multi-hazard analysis covering coastal flooding, heavy rainfall, drought, heatwaves and windstorms. The purpose of this phase is to provide Pomorie Municipality with a clearer evidence base for identifying priority climate risks, understanding their local drivers and preparing targeted adaptation measures in the final phase of the project.

The assessment applies the CLIMAAX methodology and combines European climate datasets, CLIMAAX workflow outputs, local observations, municipal planning information and stakeholder input. The analysis considers both current and future climate conditions, as well as relevant socio-economic factors such as tourism development, agricultural activity, ageing population, concentration of assets in coastal zones and pressure on water resources.

During Phase 2, the initial coastal-flooding analysis was expanded into a regionalised multi-risk assessment. The main actions included screening and confirming the five priority hazards, selecting climate and socio-economic scenarios, running or interpreting hazard-specific CLIMAAX workflows, integrating local monitoring data, assessing severity and urgency, reviewing resilience capacity and defining an overall risk priority ranking. Stakeholder engagement was carried out through a workshop, media communication and a structured survey with 52 respondents. The survey confirmed high local concern regarding very strong winds, heatwaves, extreme precipitation and droughts, while also revealing gaps in public preparedness, including limited awareness of evacuation procedures.

The regionalised analysis confirmed that coastal flooding is a locally significant risk concentrated in low-lying coastal areas, the Old Town peninsula, the isthmus, beaches, tourism assets and areas around Pomorie Lake and the salinas. Local water-level observations showed episodic high-water conditions, with elevated levels linked particularly to low atmospheric pressure and northeasterly/easterly onshore winds. Heavy rainfall was assessed as a threshold-based risk. Although the recent local record did not include events above 50 mm/24 h, short-duration rainfall episodes demonstrated the importance of 30-minute, 1-hour and 3-hour intensities for urban drainage and rapid runoff. Under the future RCP8.5 scenario, the current 50 mm/24 h threshold is expected to become more frequent.

Drought emerged as one of the most important long-term risks for the municipality. Local observations identified a 51-day completely rain-free period in summer 2025 and several additional dry spells lasting around or above one month. These findings are directly relevant for agriculture, irrigation demand, ecosystems, urban green areas, tourism landscaping and water-resource management. Heatwaves were also assessed as a very high priority. The local coastal station recorded no classical daytime heatwaves during the recent observation period, but it recorded 78 tropical nights and several persistent heat–humidity episodes. This shows that Pomorie's heat risk is strongly linked to warm nights, humidity and reduced night-time recovery, especially for elderly residents, children, tourists and outdoor workers. Windstorms remain relevant because of short-duration damaging gusts. Local observations recorded gusts up to 30 m/s, with the most hazardous gusts mainly linked to northeastern and northwestern wind directions.

The final prioritisation identifies droughts and heatwaves as very high-priority climate risks. Coastal flooding and heavy rainfall are assessed as high-priority risks due to their potential impacts on tourism, infrastructure, public safety and coastal assets. Windstorms are assessed as a moderate-priority risk in the integrated ranking, despite strong stakeholder concern, because municipal response capacity is comparatively stronger and future trend evidence is less pronounced than for drought, heat, flooding and heavy rainfall.

The main conclusion is that Pomorie Municipality is already exposed to multiple interacting climate risks, and these risks are expected to intensify under future climate conditions. The most important adaptation needs concern water-resource resilience, heat-health protection, coastal flood preparedness, drainage capacity and gust-based windstorm preparedness. Existing municipal systems provide a functional response baseline, but current financial, technical, infrastructural and public-awareness capacities are not sufficient for the projected level of climate risk.

Phase 3 will use the results of this assessment to support practical adaptation planning. The main tasks will be to review and propose updates to municipal strategic documents, including the Municipal Plan for Integrated Development and the Municipal Disaster Risk Reduction Program, prepare a Climate Adaptation Strategy, and present the project results to stakeholders and the wider public. Adaptation work will focus primarily on the highest-priority risks identified in Phase 2.

1. Introduction

1.1. Background

Located along the Black Sea coast in Bulgaria's Burgas Province, Pomorie municipality features a diverse landscape ranging from coastal lowlands to mountainous terrain (Figure 1-1). The region benefits from a continental-mediterranean climate moderated by the sea, resulting in mild winters, warm summers, and abundant sunshine with relatively low precipitation. A key ecological and economic asset is Lake Pomorie, an ultrasaline lagoon utilized for ancient salt production and therapeutic mud balneotherapy. It is also a protected wetland and a vital stopover for hundreds of bird species along the Via Pontica migratory route.

The municipality's favorable climate and natural resources create ideal conditions for its primary economic drivers: recreational tourism, wellness resorts, and viticulture. However, the region is becoming increasingly vulnerable to the impacts of climate change, experiencing rising temperatures, decreasing rainfall, and more frequent extreme weather events. Projected sea level rise of up to 0.5–0.8 m by 2100 could result in significant losses of beach and dune areas — a critical factor for tourism, salt production facilities, and protected wetlands. The severe threat to the critical beach and dune ecosystems presents a significant challenge that is further compounded by the demographic vulnerability of the area's aging population (a significant proportion aged 65+), coupled with a relatively small younger cohort.

Figure 1-1 Geographical location of Pomorie municipality

1.2. Main objectives of the project

The main objective of the ClimateSmart Pomorie project is to increase the knowledge and awareness about the climate risks and support local policies for climate resilience of Pomorie municipality, focusing on multi-risk climate assessment and targeted adaptation strategy. The specific objectives are related to **stakeholder engagement:** boost awareness and proactive climate adaptation among residents, businesses, and policymakers, **scientific advancement:** generate precise, high-resolution local climate data and predictive models and **policy integration:** use evidence-based insights to embed climate resilience into urban planning, infrastructure development, and disaster management.

The expected benefits of applying the CLIMAAX approach and Handbook are increased climate risk knowledge and awareness of the local authorities and population, e.g. by workshops and knowledge-sharing sessions with key stakeholders. A desired result will be a strengthened community resilience, stakeholder engagement and policy integration, incl. by collaboration with climate scientists, urban planners, and disaster management professionals to ensure scientific accuracy in risk assessments and development of policy recommendations and action plans for climate adaptation. The scientific and technical contributions by completion of a multi-risk climate assessment based on CLIMAAX methodology, high-resolution GIS maps and local datasets will enhance local capacity to analyse the climate risks and use climate models and scenario simulations to assess long-term impacts of climate change in Pomorie. This could lead to alignment of municipal climate adaptation planning with updated climate models and risk projections and identification of funding opportunities and mechanisms to sustain long-term climate resilience efforts.

1.3. Project team

The ClimateSmart Pomorie project's team consists of experts who combine scientific and policy expertise with knowledge and understanding of the local circumstances. The team includes: Georgi Petkov - project manager responsible for overall project management, quality control and reporting functions; Dessislava Boneva - financial expert; Prof. Dr. Zoya Mateeva - climate expert, Plamen Peev (PhD) - environment and climate legal and policy expert; and municipal environmental experts responsible for data collection, communication activities, coordination of information with external services - Nadezda Ilieva and Marin Todorov. A public procurement procedure has been carried out to support the municipality in the project and the company Dand D Consulting Ltd. was selected.

1.4. Outline of the document's structure

This document is organized following the CLIMAAX deliverable template and the logical sequence of the CLIMAAX Common Methodology Framework. The introductory section outlines the background information on Pomorie municipality, as well as the project objectives, and team composition. The second part of the document presents the Climate Risk Assessment for Phase 2, focusing on the risk analysis and risk evaluation steps of the CLIMAAX methodology, incl. scoping, risk exploration and screening, selection of main hazards, climate scenarios, regionalized risk analysis fine-tuned to local context, key risk assessment findings, monitoring, evaluation and work plan for Phase 3. The final sections of the document present the main conclusions of Phase 2, reflect on progress achieved and remaining limitations, and outline the planned activities for Phase 3, with a focus on the identification and assessment of potential climate adaptation options.

2. Climate risk assessment – phase 2

2.1. Scoping

2.1.1. Objectives

The second phase of the Climate Risk Assessment for the Municipality of Pomorie seeks to expand upon the initial risk analysis of coastal flooding developed during Phase 1 to other risks: heavy rainfall, droughts, heatwaves and strong winds. By applying the CLIMAAX methodology, this stage synthesizes localized data, stakeholder perspectives, and forward-looking climate scenarios to formulate a comprehensive view of the interactions between climate hazards, exposure, and vulnerability, and the necessary institutional responses.

Moving beyond preliminary scoping, Phase 2 elevates the spatial and thematic precision of the analysis. It rigorously examines the complex interplay between climate hazards, physical exposure, and systemic fragility. Ultimately, this assessment equips municipal authorities with a structured evaluation of risk severity, urgency, and resilience capacity. It is designed to serve as a foundational tool for Pomorie's municipal climate adaptation efforts, sectoral planning processes, and emergency preparedness, while ensuring coherence with regional, national, and European climate resilience objectives.

During the implementation of this assessment, the analytical team navigated several operational bottlenecks—most notably the scarcity of high-resolution local data, a lack of historical damage records, and inconsistent stakeholder participation across different sectors due to the relatively low capacity of local stakeholders beyond municipal administration and state institutions. To overcome these data and engagement limitations, the team supplemented local gaps by downscaling harmonized European datasets and employing scenario-based predictive modeling. Furthermore, the second workshop with stakeholders was utilized to qualitatively validate the modeled scenarios, ensuring that any remaining uncertainties and informational gaps are transparently documented throughout the report to guide accurate decision-making.

2.1.2. Context

The municipality of Pomorie, a relatively small municipality of about 27 000 people, possesses limited legal powers and administrative capacity in assessment and management of climate hazards and their impacts on the population, nature, businesses and infrastructure. The local planning documents like the integrated development plan and the municipal disaster risk reduction program outline primarily reactive measures. Local efforts have been centered on standard emergency response planning, routine infrastructure maintenance, and established civil protection mechanisms. Because these approaches have predominantly focused on isolated hazards and past events, there has been limited integration of climate projections or systematic climate risks consideration.

The formal climate risk assessments at the municipal level have been constrained in both scope and depth, leaning heavily on historical observations rather than comprehensive, scenario-based modeling. With the increasing frequency and intensity of climate variability and extreme weather events, this retrospective approach is no longer sufficient to guide strategic planning and ensure long-term resilience in the region.

The key strategic document of Pomorie municipality is the Municipal Plan for integrated development of Pomorie 2021-2027 (MPID). The MPID has a special section on climate change mitigation and adaptation measures and disaster risk reduction. Among the adaptation measures are increasing green areas to reduce "heat islands" effects and to increase the capacity to absorb rainwater; development of afforestation and reforestation programs; renewal and maintenance of water supply, sewage, land reclamation infrastructure; increasing the readiness of the population, operators or users to deal with the occurrence of natural risks, because the population and infrastructure operators do not have historical experience and do not have good practices in floods and droughts and are therefore highly vulnerable. The municipal disaster risk reduction program and the municipal disaster protection plan (recently updated), are the key local planning instruments for disaster risk protection and reduction.

The CLIMAAX project bridges the climate risks knowledge and management gap by introducing a harmonized, forward-looking framework for climate risk assessment, effectively situating Pomorie's local challenges within broader regional, national, and European contexts. The Municipality of Pomorie is exposed to an array of climate hazards that impact critical sectors, including agriculture, tourism, water management, infrastructure and urban development, environment and biodiversity, public health and social services.

Agriculture

- Significance: Agriculture is a crucial economic sector driven by fertile soils, vineyards, and sunflower cultivation.
- Climate risks such as prolonged droughts, increased temperatures, and irregular precipitation negatively impact crop yields, with documented reductions of 10-15% during drought years. Depleted soil moisture and irrigation limits drive economic instability.
- Extreme weather: Severe windstorms and hail have destroyed over 1,500 hectares of vineyards, causing multimillion-euro losses.

Tourism

- Significance: a major economic pillar centered on the Black Sea coast and Pomorie lagoon.
- Risks: heatwaves, storms, and flooding damage infrastructure and shorten visitor seasons.
- Coastal threats: sea-level rise and storm surges erode beaches and threaten coastal facilities.
- Impact on health: Extreme heat poses health risks, lowering the region's overall appeal.

Water resources & management

- Supply scarcity: Rising temperatures and dropping rainfall threaten public supplies and the lagoon's ecosystem.
- Infrastructure risks: Torrential rains and sea surges cause flash flooding, requiring updated, resilient flood defenses.

Infrastructure & urban development

- Vulnerability: Roads, bridges, and buildings are exposed to floods, strong winds, and extreme temperatures.
- Adaptation: Urban planning must integrate climate-proofing to prevent service disruptions and structural damage.

Environment and biodiversity

- Ecosystems: The Pomorie Lagoon, wetlands, and forests face altered salinity, drying, and increased wildfires.
- Implications: Disrupted biodiversity weakens vital ecosystem services that support local agriculture and tourism.

Public health and social services

- Health risks: Frequent heatwaves and cold spells threaten vulnerable populations (e.g., the elderly, about 27 % of the population according to NSI, 2025).
- Grid strain: Extreme heat spikes energy demand, leading to blackouts.
- Emergency response: disaster preparedness services, including emergency response to floods and storms, are critical to protect populations.

Examples of the adaptation challenges for the municipality include impact on public health and population: vulnerable groups, especially elderly residents, are at risk of severe stress during heatwaves; tourism resilience: coastal erosion and the loss of beach areas threaten the attractiveness and competitiveness of the resort sector; water resources and salt production: changes in precipitation regimes and amounts, and sea level could alter the salinity and water balance of Lake Pomorie.

The current CRA, conducted within Pomorie's existing governance and policy environment, encompasses national climate adaptation strategy, disaster risk management protocols, and local municipal development plans. Ultimately, this assessment is designed to fortify the evidence base for future adaptation initiatives, fostering a stronger alignment between Pomorie's stakeholders awareness of climate risks and the overarching policy objectives across all levels of government.

2.1.3. Participation and risk ownership

The responsibility for the identification, assessment, and mitigation of specific climate risks is not normatively provided in the climate law (Climate Change Mitigation Act, 2014, as amended). The main regulation of the roles and responsibilities in this area is in the Disaster Protection Act, 2006, as amended. Art. 6 a of this Act states that the disaster risk reduction planning is carried out at national, regional and municipal levels and it covers the development and updating of national disaster risk reduction strategy; national disaster risk reduction program; sectoral and regional programs related to disaster risk reduction; regional disaster risk reduction programs and municipal disaster risk reduction programs. Based on this multi-level governance structure, the municipalities are the lowest institutional tier with limited competences.

The mayor of Pomorie municipality is responsible for organization and management of disaster protection on the territory of the municipality; for organization, coordination and implementation of preventive measures to prevent or reduce the consequences of disasters; for organization for early warning of disasters and planning of financial resources for disaster protection in the draft municipal budget. The mayor is supported in the implementation of these activities by a municipal council for disaster risk reduction.

The two key local planning instruments for disaster risk protection and reduction are the municipal disaster risk reduction program and the municipal disaster protection plan. In the case of Pomorie, the municipality has recently adopted a new Disaster protection plan of Pomorie 2025 (the Plan). The Plan defines, among others, the objectives and relationship of the Plan with the National Strategy for Disaster Risk Reduction 2018 - 2030; the hazards and risks of disasters on the territory of the municipality of Pomorie; measures to prevent or reduce the risk of disasters; measures to protect the population and the distribution of roles and duties for implementation of the measures.

The Plan defines vulnerable groups as individuals requiring prioritized care, specifically pregnant women, elderly people, sick individuals, and people with disabilities, particularly those located in isolated or cut-off areas. The key institutional representatives responsible for their support are: Directorate for Social Assistance – Pomorie. This directorate is explicitly included as an essential entity holding a copy of the plan. It is responsible for providing basic necessities, medicines, and drinking water, as well as distributing humanitarian aid to the affected populations. Municipal organization of the Bulgarian Red Cross – Pomorie within the response system collects and distributes local and international aid, provides psychological and psychosocial support to victims and rescue teams, and coordinates emergency shelter provisions (tanks, tents, and prefabricated homes). The Regional Health Inspection together with the mayor and the Social Assistance Directorate ensures that vulnerable populations receive medicines and essential health-related supplies.

When evaluating the severity of any given disaster risk, the plan assigns strict weights to different areas of impact that directly reveal what the municipality considers least acceptable:

- **Population/Social consequences (50% weight)** - highest priority. Risk to human life, severe injuries, illnesses, or mass displacements are treated with highest priority, as the most unacceptable outcomes, independent of how likely the disaster is to occur.
- **Infrastructure consequences (25% weight)** - rated as a secondary priority, focusing heavily on protecting vital services and critical public infrastructure necessary for social care.
- **Economic losses (15% weight)** - given a lower weight because the plan notes that economic damage primarily impacts urbanized structures rather than immediate human survival, making it more tolerable in relative terms.
- **Environmental consequences (10% weight)** - treated as the most tolerable within this specific plan, as environmental damage is heavily deferred to other sector-specific institutional regulations.

2.1.4. Application of principles

Built on the core principles of the CLIMAAX framework, the Phase 2 Climate Risk Assessment integrated social justice, equity, and inclusivity by considering the vulnerable populations and varying exposure levels across urban areas. The assessment ensures quality, rigor, and transparency through harmonized datasets from EU to local level, clearly documented assumptions, and traceable sources. Additionally, it has adopted a precautionary approach, using scenario-based analysis to navigate uncertainty and explore plausible future climate outcomes. In addition, the analysis provides recommendations which will inform the future planning documents that could employ this principle better.

2.1.5. Stakeholder engagement

The municipality and the project team engaged the stakeholders and communicated actively the project goals/intermediate results within three main channels: the second workshop, a widely distributed survey and media publications. The workshop to discuss the second CRA report was held on June 29, 2026. 15 participants from the municipal administration, health services, the visitor center of Pomorie Lake, agricultural directorate, academia and citizens took part in it.

The stakeholder engagement was further expanded by a structured survey conducted in April- May 2026 to successfully operationalize the CLIMAAX framework's participatory process principle. Out of the total 52 respondents, 28 individuals (53.8%) identified themselves as representatives of local or regional government institutions. The citizens without institutional affiliation represent the second largest category, accounting for 11 respondents (21.2%). The educational sector is represented by 7 respondents (13.5%), while significantly smaller shares correspond to representatives of tourism, agriculture, healthcare, non-governmental organizations, and other professional categories (See Figure 2.1.4.1).

The response distribution indicates that more than half of all participants are directly involved in institutional governance and public-sector activities. At the same time, nearly half of the sample originates from non-administrative stakeholder groups, suggesting a relatively diverse participation structure.

An important feature of the survey is the inclusion of respondents connected to sectors that are particularly sensitive to environmental and climatic conditions, including tourism, agriculture, and education. Although these groups are numerically smaller, their participation broadens the range of local perspectives represented in the survey.

The overall stakeholder structure therefore reflects a combination of:

- institutional perspectives;
- citizen-based perceptions;
- sectoral viewpoints;
- professional experience from climate-sensitive activities.

Figure 2.1.5.1. Distribution of respondents by stakeholder group and institutional affiliation

The response distribution demonstrates that the survey is heavily dominated by economically active and professionally engaged population groups (more than 88 %). The overwhelming prevalence of respondents between 30 and 60 years of age indicates that the survey primarily reflects the perceptions of individuals actively involved in professional activities; institutional processes; local governance; economic activities and everyday municipal life. See Figure 2.1.4.2.

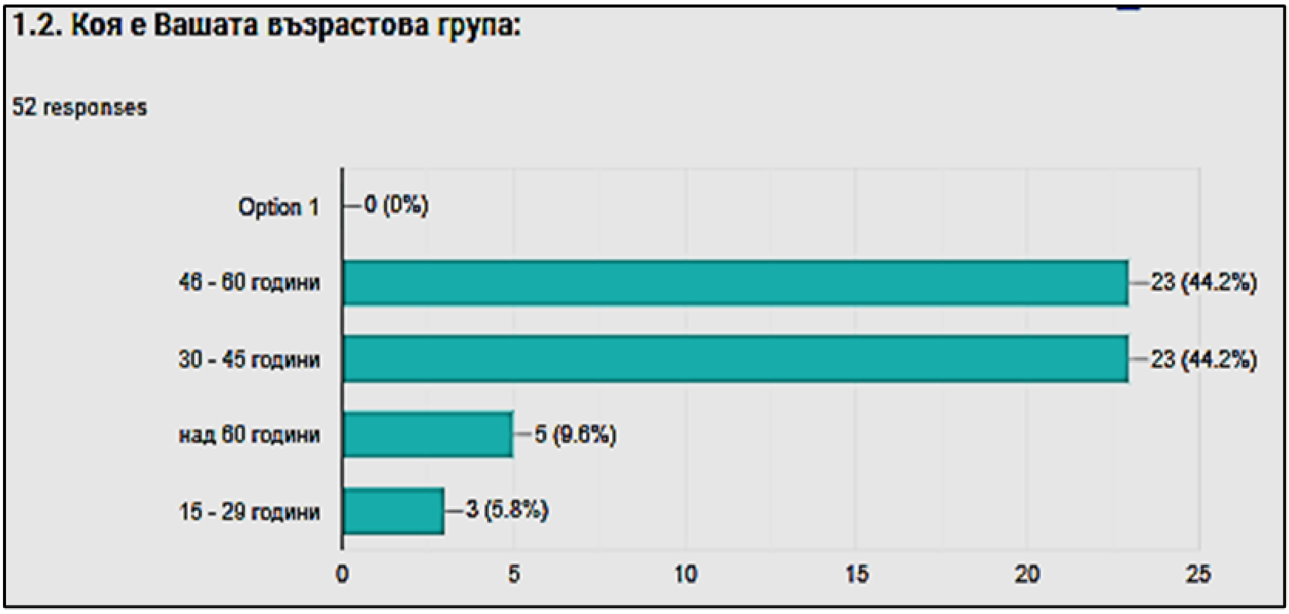

Figure 2.1.5.2. Distribution of respondents by age group

The feedback from the survey highlighted the following findings:

Primary hazards: very strong winds are overwhelmingly perceived as the most frequent (82.7%), significant, and severe climate hazard, as well as the most dangerous for professional activities (45.8%). **Health and biocomfort:** strong winds and high humidity/fog were equally identified (63.3%)

as having the greatest negative impact on everyday human health and physical comfort. **Vulnerable sectors:** tourism (23.4%) and agriculture (22.8%) are perceived as the economic sectors most threatened by climate-related disruptions. **Preferred adaptation measures:** respondents strongly favor practical, physical adaptations, prioritizing infrastructural improvements (78.4%), early warning systems (68.6%), and afforestation/green areas (66.7%). **Attitudes and concerns:** while 73.1% of respondents demonstrated a generally positive attitude toward participating in climate initiatives, there is significant concern regarding extreme weather (74.5%) and water scarcity (66.7%).

The survey also indicated that stakeholders would be most motivated to increase their personal engagement if they see "visible results from efforts" (28.2%) and receive "better understanding and information" (18.2%). One clearly highlighted problem pertains to vulnerabilities within the community itself—specifically, severe gaps in public awareness. E.g., 48.2% of respondents reported being entirely "Not informed" about flood evacuation plans, and 12.5% were entirely unaware of their existence. On a broader scale, the CRA could help the municipal and regional authorities design evidence-based adaptation policies and update risk management plans.

2.2. Risk Exploration

Risk exploration constitutes a critical step in the climate risk assessment process, providing the analytical bridge between the preliminary risk screening undertaken in Deliverable 1 (D1) and the more detailed risk characterisation, prioritisation and adaptation planning developed in the subsequent phases of the CLIMAAX assessment framework. Building upon the initial identification of priority climate-related hazards in Pomorie Municipality, this phase expands the evidence base and deepens the understanding of the interactions between hazards, exposed elements and vulnerability factors that shape current and future climate risks.

The risk exploration process was designed to move beyond a hazard-centred perspective and towards a more comprehensive risk-based approach. In accordance with the CLIMAAX framework, the assessment considered not only the occurrence and evolution of climate-related hazards, but also the characteristics of the populations, economic sectors, ecosystems and assets exposed to them, as well as the vulnerability factors influencing their susceptibility to adverse impacts. Particular attention was paid to the interactions between climatic drivers and local socio-economic and territorial conditions, recognizing that climate risks emerge from the combination of hazards, exposure and vulnerability rather than from climatic phenomena alone.

The analysis integrated multiple complementary sources of information and knowledge. First, hazard-specific CLIMAAX workflows and associated notebook outputs provided a harmonised European-scale framework for assessing the spatial distribution and potential evolution of selected climate hazards. Second, these outputs were complemented and contextualised through the analysis of local climatic observations and historical records, allowing a more detailed understanding of recent trends and locally specific manifestations of climate change. Third, local knowledge and risk perception were incorporated through a stakeholder survey involving members of the local community and representatives of municipal and institutional stakeholders. Although the survey was conducted anonymously, its distribution through municipal channels and broader public networks enabled the collection of diverse perspectives regarding the perceived significance, severity and urgency of climate-related risks in Pomorie Municipality.

The risk exploration process focused on the interrelationships between climate hazards, exposed elements and vulnerability factors relevant to the municipality (Table 2.2.1). The assessment considered the exposure of permanent residents, seasonal populations associated with tourism activities, critical infrastructure, economic assets, agricultural land and coastal areas. Vulnerability was examined through demographic characteristics, economic dependencies, territorial configuration and environmental conditions that may amplify climate impacts. Particular relevance was attributed to the municipality's strong dependence on tourism, the importance of agricultural activities in the surrounding hinterland, the concentration of assets in low-lying coastal zones and the presence of population groups potentially sensitive to heat-related impacts.

Table 2.2.1. Main hazards, exposed elements and vulnerability factors considered in the risk exploration process. Source: Authors' elaboration based on CLIMAAX workflow outputs, local climate analyses, stakeholder survey results and municipal context.

Climate hazard	Main exposed elements	Key vulnerability factors
Coastal flooding	Coastal infrastructure, tourism facilities, transport infrastructure, urban coastal areas, beaches	Low-lying coastal terrain, concentration of assets near the shoreline, exposure to sea-level rise and storm surges
Heavy rainfall/ extreme precipitation	Urban areas, transport networks, drainage systems, public infrastructure	Local drainage limitations, concentration of population and services in urban areas, exposure of critical infrastructure
Drought	Agricultural land, water resources, ecosystems, local agricultural producers	Dependence on climatic conditions, increasing water demand, soil moisture deficits, interaction with wildfire risk
Heatwaves	Permanent residents, elderly population, seasonal tourists, outdoor workers, public services	Ageing population, increased summer population, high seasonal concentration of visitors during the warmest period of the year, prolonged outdoor exposure, frequent occurrence of tropical nights and heat-stress conditions during summer, limited heat-adaptation measures
Windstorms	Buildings, transport infrastructure, utility networks, urban vegetation, tourism facilities	Exposure to strong wind gusts, vulnerability of infrastructure and vegetation, seasonal concentration of visitors and activities

An important outcome of the risk exploration phase was the recognition that climate hazards should not be considered in isolation. The analyses revealed multiple interactions and reinforcing mechanisms among hazards and impacts. heatwaves and droughts were found to be closely interconnected through their influence on water availability, ecosystem functioning and wildfire susceptibility. Extreme precipitation events were associated with localised flooding and disruptions to infrastructure and mobility. Coastal flooding risks were influenced by the combined effects of sea-level rise, storm conditions and the concentration of exposed assets in coastal areas. These interdependencies highlight the importance of adopting a multi-hazard perspective in subsequent stages of the assessment.

The integration of scientific evidence, local observations and stakeholder knowledge contributed to a more robust understanding of both current and emerging climate risks affecting Pomorie Municipality. The outcomes of this risk exploration phase provide the basis for refining the selection of priority hazards, evaluating future climate and socio-economic scenarios, and supporting the subsequent prioritisation of climate risks and adaptation needs (Figure 2.2.2). *The figure illustrates the integration of CLIMAAX workflow outputs, local climate observations and stakeholder knowledge within the risk exploration process, leading to an enhanced understanding of hazard, exposure and vulnerability interactions and supporting subsequent risk prioritisation.*

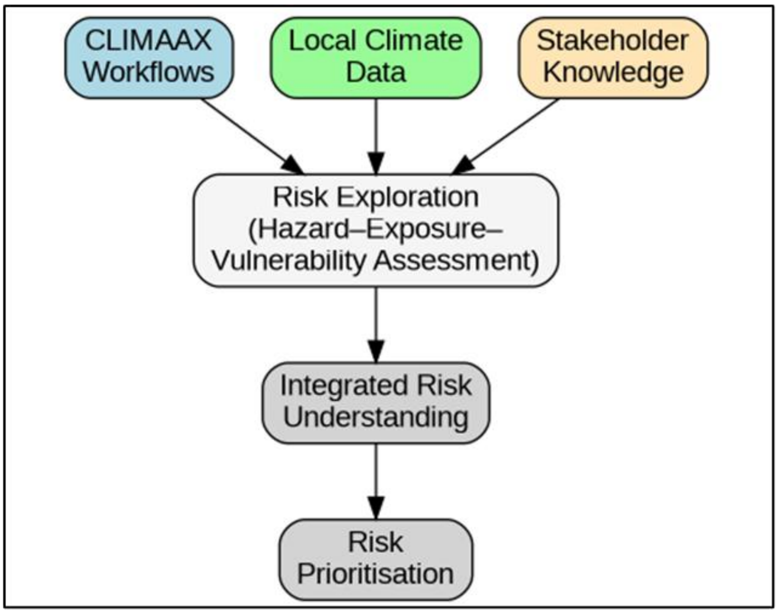

Figure 2.2.2. Integrated Risk Exploration Framework Applied in Pomorie Municipality

2.2.1. Screen risks (selection of main hazards)

The risk screening conducted in Deliverable 1 identified five priority climate-related hazards for Pomorie Municipality: heatwaves, droughts, coastal flooding, extreme precipitation and wind storms. The analyses undertaken during the present phase confirmed the continued relevance of these hazards and provided a more detailed understanding of their associated risks, exposed elements and vulnerability factors. The assessment integrated evidence from CLIMAAX workflow outputs, local climate observations, stakeholder consultation and regional climate information, thereby strengthening the analytical basis for risk characterisation and prioritisation.

The selected hazards are associated with a broad range of potential impacts affecting population, infrastructure, economic activities and environmental resources within the municipality (Table 2.2.2.1). While heatwaves and droughts represent municipality-wide hazards with implications for public health, water resources, agriculture and ecosystem functioning, coastal flooding primarily threatens low-lying coastal zones and tourism-related assets. Extreme precipitation and wind storms constitute additional sources of disruption, capable of affecting transport systems, public services, infrastructure and economic activities.

Table 2.2.2.1. Climate-related hazards and associated risks in Pomorie Municipality

Climate hazard	Main associated risks
Coastal flooding	Inundation of low-lying coastal areas, damage to tourism facilities and coastal infrastructure, economic losses, disruption of coastal activities
Heavy rainfall/extreme precipitation	Urban and pluvial flooding, disruption of transport and public services, damage to infrastructure and property, increased runoff and erosion
Droughts	Water scarcity, reduced agricultural productivity, ecosystem degradation, increased irrigation demand, elevated wildfire susceptibility
Heatwaves	Heat stress, increased heat-related morbidity and mortality, reduced thermal comfort, increased pressure on health services, impacts on tourism and outdoor activities
Windstorms	Damage to buildings and infrastructure, disruption of utility services, impacts on vegetation and agriculture, risks to tourism facilities and public safety

The current manifestation of the selected hazards demonstrates important differences in their spatial distribution and impact mechanisms. heatwaves and droughts affect the municipality as a whole, whereas coastal flooding is concentrated in low-lying coastal sectors characterised by a high concentration of economic assets and tourism infrastructure. Extreme precipitation and wind storms may affect both urban and coastal environments, generating localised but potentially significant impacts. The principal characteristics of the current hazard situation, affected areas and exposed sectors are summarised in Table 2.2.2.2.

Table 2.2.2.2. Current manifestation, spatial distribution and affected elements of climate hazards in Pomorie Municipality

Climate hazard	Current manifestation	Main affected areas	Main affected sectors and population groups
Coastal flooding	Exposure of low-lying coastal areas to marine flooding and sea-level rise impacts	Coastal zones, waterfront areas, beaches and tourism infrastructure, tourism facilities, coastal	Tourism sector, coastal businesses, transport infrastructure, residents and visitors in coastal areas

		businesses and recreational assets	
Heavy rainfall/extreme precipitation	Occurrence of short-duration high-intensity rainfall events causing local flooding and drainage overload	Urbanised areas, transport corridors, densely developed zones	Residents, transport services, municipal infrastructure, businesses and public services
Drought	Recurrent dry periods, increasing soil moisture deficits and pressure on water resources	Entire municipality, particularly agricultural areas and natural ecosystems	Agriculture, water resource management, ecosystems, local producers, rural communities
Heatwaves	Increasing air temperatures, growing occurrence of tropical nights and heat-stress conditions, and increasing duration of warm periods.	Entire municipality, including urban areas, coastal zones and tourist destinations, seasonal visitors and tourism-dependent businesses	Permanent residents, elderly population, seasonal visitors, outdoor workers, tourism sector, public health services
Windstorms	Episodic occurrence of strong wind events and damaging gusts	Entire municipality, particularly exposed coastal and open areas	Buildings, utility networks, vegetation, tourism facilities, transport infrastructure and the general population

The combined evidence from CLIMAAX workflows, local climate analyses and regional climate information indicates a consistent pattern of increasing climate-related pressures affecting Pomorie Municipality. The strongest signals are associated with rising temperatures, increasing heat extremes and growing drought risk. Additional evidence suggests increasing precipitation intensity, growing exposure to coastal flooding and continued vulnerability to damaging wind events. The observed and projected evolution of the assessed hazards is summarised in Table 2.2.2.3.

Table 2.2.2.3. Observed and expected evolution of climate hazards in Pomorie Municipality

Climate hazard	Observed evidence	Expected evolution
Coastal flooding	Existing exposure of low-lying coastal areas and tourism infrastructure to marine flooding and storm-related impacts	Increasing coastal flood risk associated with sea-level rise, higher exposure of coastal assets and growing potential for economic losses and infrastructure disruption
Heavy rainfall/extreme precipitation	Increasing concentration of rainfall in fewer but more intense events; occurrence of short-duration heavy precipitation episodes	Increased likelihood of high-intensity rainfall events, greater pluvial flood potential, higher pressure on drainage systems and urban infrastructure

Drought	Recurrent dry spells, increasing soil moisture deficits, pressure on water resources and agricultural production	More frequent and prolonged drought episodes, increased water stress, higher irrigation demand, greater pressure on ecosystems and elevated wildfire susceptibility
Heatwaves	Increasing air temperatures, more frequent and prolonged hot periods, increasing number of tropical nights and heat-stress conditions	Further increase in the occurrence of tropical nights, prolonged warm periods and heat-stress conditions, resulting in stronger thermal stress and growing health-related impacts, particularly during the summer tourist season
Windstorms	Occasional occurrence of strong wind events and damaging gusts affecting infrastructure, vegetation and economic activities	Continued occurrence of damaging wind events, although future trends remain more uncertain and less pronounced than for temperature-, drought- and precipitation-related hazards

Findings from the Copernicus Climate Atlas broadly confirm the hazard patterns identified through the CLIMAAX workflows and local climate analyses. Regional projections for southeastern Europe indicate increasing temperatures, more frequent and intense heat extremes, growing drought risk, increasing precipitation variability and intensification of heavy rainfall events, together with increasing pressures on coastal systems associated with sea-level rise. The consistency between regional projections and local evidence provides additional confidence in the robustness of the identified hazard patterns and associated risks.

The selection of heatwaves, droughts, coastal flooding, extreme precipitation and wind storms is supported by multiple and mutually reinforcing lines of evidence, including observed climatic trends, CLIMAAX workflow outputs, regional climate projections and stakeholder perceptions. Collectively, these hazards represent the principal pathways through which climate change may affect the municipality's population, economy, infrastructure and environmental resources. The principal arguments supporting their inclusion are summarised in Table 2.2.2.4.

Table 2.2.2.4. Justification for the selection of climate hazards in Pomorie Municipality

Climate hazard	Key justification for inclusion
Coastal flooding	Exposure of low-lying coastal areas, concentration of tourism infrastructure and economic assets, projected sea-level rise impacts
Heavy rainfall/extreme precipitation	Increasing rainfall intensity, local flood potential, risks to infrastructure, transport and public services
Drought	Increasing water stress, impacts on agriculture and ecosystems, elevated wildfire susceptibility, strong future climate signal

Heatwaves	Strong observed warming trends, increasing occurrence of tropical nights and heat-stress conditions, growing thermal stress, and high relevance for public health and tourism.
Wind storms	Historical occurrence of damaging events, exposure of infrastructure and coastal areas, continued relevance despite higher uncertainty in future projections

The assessment benefited from a diverse evidence base comprising CLIMAAX workflow outputs, local climate analyses, stakeholder knowledge and regional climate information. Nevertheless, several information gaps remain, particularly regarding local-scale vulnerability patterns, water-resource dynamics, coastal asset exposure, sub-daily precipitation characteristics and long-term wind extremes. Addressing these gaps would further strengthen future climate risk assessments and adaptation planning efforts. The available knowledge base and the principal remaining information needs are summarised in Table 2.2.2.5.

Table 2.2.2.5. Available knowledge and remaining information needs

Climate hazard	Available knowledge and evidence	Remaining information needs
Coastal flooding	CLIMAAX coastal flood assessments; sea-level rise scenarios; local coastal observations; regional coastal projections	High-resolution topographic datasets; detailed coastal asset inventories; locally refined sea-level rise scenarios; infrastructure vulnerability assessments
Heavy rainfall/ extreme precipitation	CLIMAAX precipitation workflow outputs; local rainfall analyses; regional climate projections	Long-term sub-daily precipitation records; flash-flood information; drainage system performance data
Drought	Agricultural and relative drought assessments; local climate analyses; regional drought projections	Groundwater monitoring data; irrigation demand assessments; long-term water availability information; ecosystem response analyses
Heatwaves	CLIMAAX heat-wave workflow outputs; local temperature records; stakeholder perceptions; regional climate projections	High-resolution urban heat information; microclimate analyses; heat-related health impact data; vulnerability mapping
Windstorms	Wind storm workflow outputs; historical observations; stakeholder knowledge; local records of damaging events	Long-term extreme wind datasets; detailed storm impact records; vulnerability assessments of exposed infrastructure

The final selection was further confirmed by the CLIMAAX hazard-specific workflows, which consistently identified increasing future risks associated with heatwaves, drought conditions, extreme precipitation and coastal flooding, while wind-related hazards remain relevant due to their recurrent impacts on infrastructure, agriculture and coastal areas.

2.2.2. Choose Scenario

Future Climate Conditions

The scenario selection process was guided by the CLIMAAX Framework and built upon the risk screening results presented in Deliverable 1. While the first assessment primarily focused on identifying the most relevant climate-related hazards affecting Pomorie Municipality, the present phase expands the analytical basis through the integration of CLIMAAX workflow outputs, local climate analyses, stakeholder consultation results, regional climate information from the Copernicus Climate Atlas and the strategic development priorities outlined in the Municipal Integrated Development Plan (MIDP) of Pomorie Municipality. This integrated approach enabled the development of future scenarios that consider both evolving climatic conditions and anticipated socio-economic developments, thereby providing a more comprehensive basis for climate risk assessment.

Future climate conditions considered in the assessment are derived from the combined evidence provided by the CLIMAAX workflows, local observational analyses and regional climate projections. The adopted climate scenarios are based on the assumption that the hazard trends identified during the screening stage will continue and, in most cases, intensify under future climate conditions. As summarised in Table 2.2.2.3 and confirmed by the hazard-specific analyses, the strongest climate signals are associated with increasing temperatures, growing occurrence of tropical nights and heat-stress conditions, increasing drought frequency and severity, greater precipitation variability and a higher likelihood of short-duration extreme rainfall events. Additional evidence indicates increasing exposure to coastal flooding associated with sea-level rise, while wind-related hazards are expected to remain relevant despite comparatively weaker and more uncertain future trends.

The consistency between local observations, CLIMAAX workflow outputs and Copernicus Climate Atlas projections provides a robust basis for considering these trends as the principal climate drivers shaping future risk conditions in Pomorie Municipality. Consequently, the future climate scenarios adopted in this assessment assume a progressive intensification of climate-related pressures affecting human health, water resources, agriculture, ecosystems, infrastructure and coastal assets throughout the municipality.

These climate conditions were selected because they represent the most plausible and evidence-based pathways through which climate change is expected to influence future hazard occurrence, exposure patterns and vulnerability levels within Pomorie Municipality.

Future Socio-Economic Developments

The assessment of future risk conditions considered not only projected climatic changes but also the socio-economic developments that may influence future exposure and vulnerability within Pomorie Municipality. In contrast to Deliverable 1, which primarily focused on hazard identification and preliminary risk screening, the present assessment incorporates additional evidence from the Municipal Integrated Development Plan (MIDP), thereby providing a more comprehensive understanding of the municipality's anticipated development trajectory and its implications for climate risk.

The selected socio-economic assumptions reflect the strategic priorities and development objectives defined by the municipality, including the continued expansion of tourism activities, further development of the blue economy, support for agricultural production, modernisation of infrastructure and enhancement of environmental sustainability. These priorities indicate that substantial economic activity, population presence and critical assets are expected to remain concentrated within coastal and urban areas that are potentially exposed to multiple climate-related hazards.

Particular importance was assigned to the expected continuation of tourism as a leading economic sector. The strategic vision outlined in the MIDP envisages the further development and diversification of tourism, including coastal, health, cultural, wine and eco-tourism. This development pathway is likely to increase seasonal population fluctuations and reinforce the concentration of economic assets and services within areas exposed to heatwaves, coastal flooding and extreme weather events.

The assessment also considered the continued significance of agriculture within the municipal economy. Future agricultural development, combined with projected climatic changes, may increase sensitivity to drought conditions, water scarcity and extreme weather events, particularly during the growing season. Consequently, future risks associated with water availability and agricultural productivity remain important components of the overall risk profile.

Demographic trends were also taken into account. Although the municipality has demonstrated comparatively favourable demographic dynamics relative to broader regional trends, challenges associated with population ageing remain relevant. An increasing proportion of elderly residents may contribute to higher vulnerability to heat stress and other climate-sensitive impacts, particularly during prolonged extreme weather events.

At the same time, the municipality's strategic objectives include continued investments in transport, water supply, wastewater, environmental and public infrastructure. These developments may contribute to strengthening adaptive capacity and reducing vulnerability in certain sectors, although the effectiveness of such measures will depend on their implementation and their ability to keep pace with the evolving climate risks.

The principal socio-economic developments considered in the assessment and their relevance for future climate risk are summarised in Table 2.2.3.1.

Table 2.2.3.1. Socio-economic developments considered in the assessment

Development trend	Relevance for risk assessment
Continued tourism development	Increased seasonal exposure
Continued coastal concentration of assets	Increased flood exposure
Modernisation of infrastructure	Potential reduction of vulnerability
Continued importance of agriculture	Continued drought sensitivity
Population ageing	Increased heat-wave vulnerability

Pressure on water resources	Increased drought risk

Integration of Climate and Socio-Economic Scenarios

The future risk scenarios developed for Pomorie Municipality were based on the combined consideration of projected climatic changes and anticipated socio-economic developments. This approach reflects the fundamental principle of climate risk assessment that future risk is determined not only by the evolution of climate hazards but also by changes in exposure, vulnerability and adaptive capacity.

The scenario framework assumes that the climate-related hazards identified in the assessment—heatwaves, droughts, extreme precipitation, coastal flooding and wind storms—will continue to affect the municipality under future climate conditions, with most hazards expected to increase in frequency, intensity or spatial extent. At the same time, the socio-economic development pathway outlined in the Municipal Integrated Development Plan indicates the continued importance of tourism, agriculture, coastal economic activities and infrastructure development, all of which influence future patterns of exposure and vulnerability.

The integration of these two dimensions implies that future climate risks may increase not only because climatic hazards become more severe, but also because valuable assets, economic activities and population groups remain concentrated in potentially exposed areas. In particular, the continued development of tourism and associated infrastructure may increase seasonal exposure to heatwaves, coastal flooding and extreme weather events. Similarly, the ongoing importance of agriculture and water-dependent activities may reinforce sensitivity to drought conditions and water scarcity.

At the same time, the assessment recognises that socio-economic development may also enhance adaptive capacity. Planned investments in transport, water management, environmental protection and public infrastructure have the potential to reduce vulnerability and improve resilience to climate-related impacts. Consequently, the future risk scenarios should not be interpreted as projections of unavoidable losses, but rather as plausible pathways describing how climate hazards and socio-economic development may interact under different future conditions.

The adopted scenario framework therefore assumes a dynamic interaction between changing climatic pressures and evolving socio-economic systems. This integrated perspective enables a more realistic assessment of future climate risks and provides a stronger basis for subsequent risk prioritisation and adaptation planning. The conceptual relationships between future climate conditions, socio-economic developments and future risk pathways are illustrated in Figure 2.2.3.2.

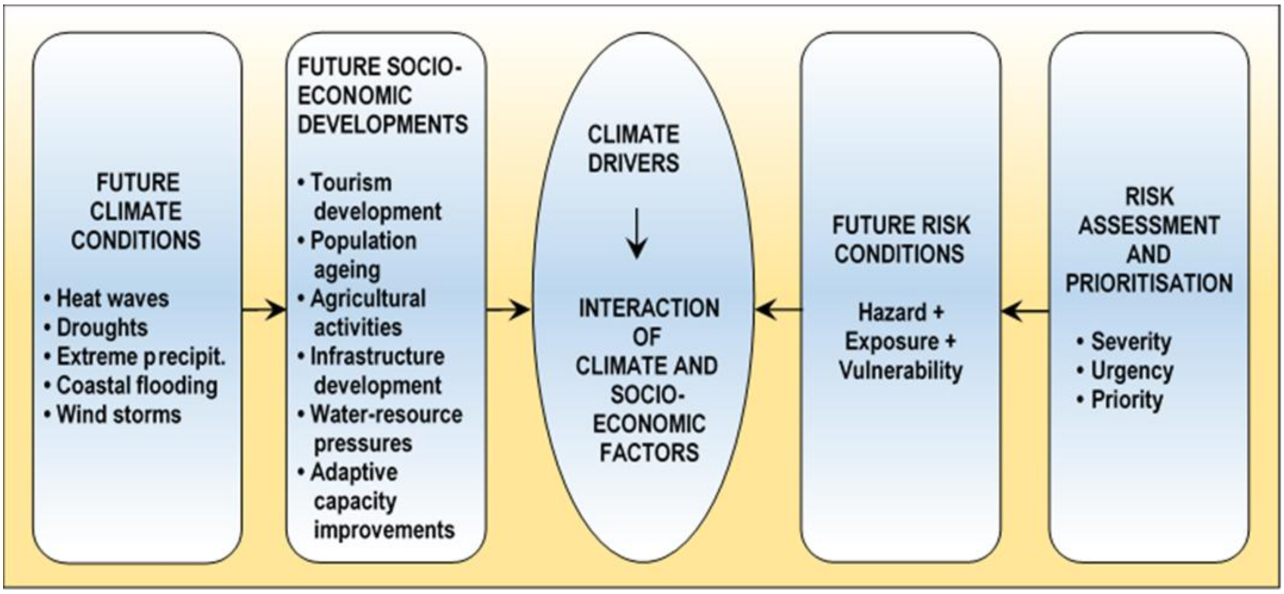

Figure 2.2.3.2. Conceptual framework linking future climate conditions and socio-economic developments in the climate risk assessment of Pomorie Municipality

Time Horizons and Scenario Assumptions

The assessment considered multiple temporal horizons in order to capture both current and future climate risk conditions and to support adaptation planning across different decision-making timescales. Current and historical conditions were used as the baseline for understanding existing hazard patterns, exposure characteristics and vulnerability factors. The baseline assessment was informed by local climate observations, stakeholder consultation, CLIMAAX workflow outputs and available municipal information.

The future-oriented analyses incorporated several time horizons, reflecting the specific requirements of the CLIMAAX workflows applied for the different hazards. For heavy rainfall, projections focused on the period 2041–2070 under the RCP8.5 scenario. Coastal flooding analyses compared present-day conditions with projections for approximately 2050 under RCP8.5. Heatwave assessments considered both near-future (2016–2045) and mid-century (2046–2075) conditions under RCP4.5 and RCP8.5. Drought assessments incorporated multiple future horizons, including 2031–2060 and 2071–2100, using SSP1-2.6, SSP3-7.0 and SSP5-8.5 scenarios. Additional agricultural drought analyses examined selected future conditions around 2046–2050. Although the individual hazard assessments employ different scenarios and time horizons, all analyses consistently indicate increasing climate-related pressures associated with warming temperatures, drought development, heat stress, precipitation extremes and coastal flood exposure.

The use of multiple climate scenarios allows the assessment to capture a range of plausible future climatic developments, from moderate to high greenhouse-gas emission pathways. Despite methodological differences among the individual CLIMAAX workflows, the results consistently indicate increasing climate pressures associated with higher temperatures, more frequent heat-related conditions, increasing drought risk, greater precipitation variability and growing coastal flood exposure.

Future socio-economic conditions were assessed qualitatively and were informed primarily by the strategic development priorities of Pomorie Municipality. The adopted assumptions are broadly consistent with a development pathway characterised by continued tourism activity, sustained agricultural production, ongoing infrastructure modernisation and gradual strengthening of adaptive capacity. At the same time, demographic ageing, increasing pressure on water resources and the continued concentration of economic activities and assets in coastal areas may contribute to increasing future exposure and vulnerability.

The adopted scenario framework therefore combines progressive climate change with continued socio-economic development and adaptation efforts. This integrated perspective provides a coherent basis for evaluating future climate risks and supports the subsequent assessment of risk severity, urgency and prioritisation.

2.3. Regionalised Risk Analysis

The Phase 2 regionalised risk analysis builds on the Phase 1 assessment and provides a more locally grounded interpretation of climate hazard, exposure, vulnerability and potential impacts for Pomorie Municipality. The analysis covers five priority climate risks: coastal flooding, heavy rainfall/extreme precipitation, drought, heatwaves and windstorms.

The detailed technical analysis, including workflow descriptions, local expert assessments, notebook figures, extended tables and supporting visualisations, is presented in **Annex 1 – Regionalised Risk Analysis for Pomorie Municipality**. The present section summarises the main findings for the deliverable body and focuses on the conclusions relevant for municipal risk understanding, adaptation planning and the preparation of Phase 3 activities.

The regionalisation followed a common approach across hazards. First, relevant CLIMAAX workflows were applied to the Pomorie area of interest or to the appropriate regional scale. Second, the workflow outputs were interpreted against local territorial conditions, exposed assets and vulnerable groups. Third, where available, local high-resolution observations were used to validate or contextualise the modelled outputs. Fourth, limitations were identified in order to distinguish between strategic screening results and the need for more detailed local modelling or data collection.

Figure 2.3-1. Summary of the regionalised risk analysis approach for Pomorie Municipality

Source: Authors' elaboration based on CLIMAAX workflows, local observations, national/regional reference data and local interpretation.

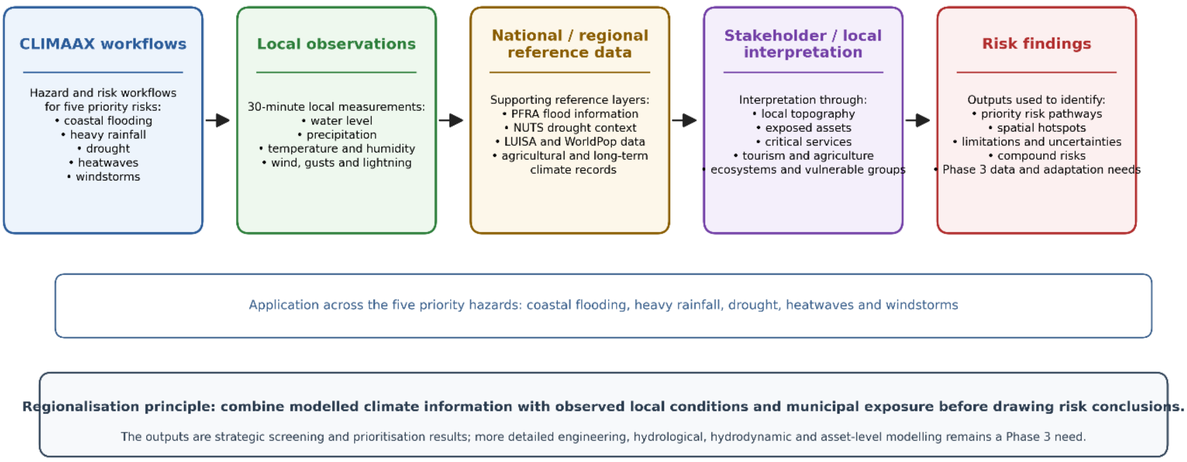

Figure 2.3. Summary of the regionalised risk analysis approach for Pomorie Municipality. *Source: Authors' elaboration based on CLIMAAX workflows, local observations, national/regional reference data and local interpretation*

Table 2.3. Summary of datasets and outputs used in the regionalised risk analysis

Climate risk	Main CLIMAAX / model-based data	Local and reference data	Main risk outputs and interpretation
Coastal flooding	Deltares Global Flood Maps for present-day and 2050 RCP8.5 conditions; water-level and sea-level-rise workflow outputs; LUISA land-use exposure and JRC depth-damage curves.	Obscape Level water-level observations for Pomorie, 04.10.2024–05.05.2026; local topographic interpretation; PFRA information for the Black Sea Basin District.	Coastal flood potential and indicative damage are concentrated in low-lying coastal sectors where elevated water levels overlap with tourism, residential, transport, ecological and public-service assets. Local water-level observations show that high-water events are episodic and strongly influenced by low pressure and NE/E onshore winds.
Heavy rainfall / Extreme precipitation	EURO-CORDEX precipitation data at approximately 12 km resolution; historical period 1976–2005; future period 2041–2070 under RCP8.5; annual maximum 3-hour and 24-hour precipitation; threshold-based risk workflow.	Local 30-minute precipitation observations for Pomorie, 04.10.2024–12.06.2026; long-term annual precipitation series for Pomorie/Burgas, 1894–2023.	The 50 mm / 24 h threshold associated with a current 5-year return period is projected to become more frequent under future climate conditions. Local observations show that even without events above 50 mm / 24 h, short-duration rainfall can be concentrated within a few hours and may overload drainage systems.

Drought	Relative drought workflow using NUTS3 precipitation-deficit indicators; agricultural drought workflow using climate data, crop parameters, evapotranspiration and irrigation availability; crop yield and revenue-loss outputs.	Local dry-spell analysis from Pomorie 30-minute precipitation observations converted to daily totals; 2024 Burgas agricultural report; wildfire and vegetation-fire records for Pomorie Municipality, 2021–2025.	Long dry periods are a significant local signal. The longest dry spell lasted 51 consecutive days during summer 2025. Drought risk is relevant for rainfed crops, irrigation demand, vineyards, orchards, vegetables, pasture, urban green areas, tourism landscaping and sensitive ecosystems. Wildfire is treated as a secondary drought-related risk.
Heatwaves	EuroHEAT heatwave occurrence data from EURO-CORDEX under RCP4.5 and RCP8.5; Xclim heatwave indicators using user-defined temperature thresholds; regional heatwave risk workflow using WorldPop vulnerable population data.	Long-term temperature series for Pomorie/Burgas, 1894–2023; local 30-minute meteorological observations, 04.10.2024–14.06.2026; local heat-discomfort indicators.	Future heatwave occurrence is expected to increase, especially under RCP8.5. Locally, Pomorie's coastal station recorded no classical ≥30°C heatwaves, but recorded 78 tropical nights and several heat–humidity episodes. Heat risk is therefore driven strongly by warm nights, humidity, persistence and vulnerable population exposure.
Windstorms	Windstorm selection helper using historical European storm tracks; selected storm footprint for storm ID 1293; maximum 3-second wind gust hazard layer; structural damage workflow using LUISA exposure and wind vulnerability curves.	Long-term wind and thunderstorm records from Burgas, 1965–2023; local 30-minute wind and gust observations in Pomorie, 04.10.2024–14.06.2026; lightning observations.	The selected CLIMAAX storm produced low indicative structural damage, but this should be interpreted as an event-based stress test. Local observations show that Pomorie's wind hazard is driven mainly by short-duration gusts, with maximum gusts up to 30.0 m/s and severe gusts concentrated mainly from NE and NW directions.

2.3.1. Hazard #1 - Coastal Flooding - fine-tuning to local context

Table 2.3.1. Data overview workflow #1

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Deltares Global Flood Maps accessed through the Microsoft Planetary Computer. The dataset provides coastal flood-depth rasters for present-day climate, represented by ca. 2018, and future	JRC depth-damage curves for land-use damage classes, including residential, commercial, industrial, agricultural, transport and road/infrastructure categories. The LUISA	JRC LUISA land-use data for Europe, 2018, at 100 m resolution, clipped to the Pomorie area of interest. Land-use classes include urban areas, commercial and industrial land,	Flood-depth maps and flood-extent maps for selected scenarios and return periods; indicative damage maps; estimated potential economic damage by land-use class;

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
climate in 2050 under RCP8.5. Available return periods include 2, 5, 10, 25, 50, 100 and 250 years. For the Pomorie workflow, the data were clipped to the municipality area of interest and reprojected to EPSG:3035.	damage information file was adapted using Bulgaria-specific GDP/capita input to support indicative economic damage estimation.	agricultural land, natural areas, infrastructure and water bodies.	identification of coastal flood-risk hotspots.
Copernicus Climate Data Store / GTSMv3.0-based water-level time series and statistics, including modelled extreme water levels for the 5-year and 100-year return periods.	National PFRA criteria and thresholds for evaluating significant adverse flood consequences across human health, economic activity, environment and cultural heritage. These were used as a qualitative cross-check, not as a direct replacement of the CLIMAAX risk workflow.	Local contextual exposure: Pomorie Old Town waterfront, northern beach area, Sunset Resort coastal sector, low-lying isthmus, road access to the peninsula, coastal promenades, port and tourist infrastructure, salinas, Pomorie Lake and adjacent lagoon/wetland areas.	Local interpretation of likely exposed assets and functions; qualitative assessment of indirect impacts, including disruption of access, public services, tourism, emergency response, water/wastewater systems and ecosystem services.
Local Obscape Level monitoring station in Pomorie, providing 30-minute water-level and atmospheric-pressure observations for the period 04 October 2024 – 05 May 2026, complemented by wind speed, wind gust and wind-direction observations from a nearby automatic weather station.	Local vulnerability factors: low elevation, micro-topographic variability, concentration of tourism and public infrastructure in coastal zones, exposure of vulnerable groups and seasonal visitor population, dependence of local economy on beach and coastal assets.	Local topographic interpretation based on digital elevation information and supplementary Google Earth review. Several coastal sectors are approximately 0–1 m above sea level, while central urban areas are generally around 2–4 m above sea level.	Additional local hazard indicators: high water-level threshold ≥0.30 m, very high water-level threshold ≥0.50 m, number of high-water observations and affected days, maximum observed water level, relationship with low atmospheric pressure and NE/E wind directions.

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
Future climate condition: 2050 coastal flood maps under RCP8.5 and sea-level-rise contribution included in the global flood maps. Sea-level rise is also assessed through IPCC AR6 / NASA sea-level projection tools.	Future vulnerability condition: no detailed local dynamic vulnerability model was available for 2050. Vulnerability was therefore interpreted using present-day damage functions and local knowledge of exposed sectors.	Future socio-economic condition: no high-resolution local future population, building, cadastral or land-use projection was applied in this iteration. Current land use and existing critical assets were used as the baseline exposure layer, with qualitative consideration of continued coastal tourism and infrastructure concentration.	Future risk output: comparison of present-day and 2050 flood potential; identification of areas where current exposure could translate into increasing future risk under sea-level rise and more frequent/intense coastal storms.

2.3.1.1. Hazard assessment summary

Coastal flooding remains one of the most important climate risks for Pomorie Municipality because of the settlement's coastal configuration and the concentration of exposed assets in low-lying areas. Pomorie town is located on a narrow peninsula connected to the mainland by a low-lying isthmus and bordered by the Black Sea, Pomorie Lake and lagoon/wetland systems. This setting increases sensitivity to elevated sea levels, storm surge, low atmospheric pressure and persistent onshore winds.

The CLIMAAX coastal-flooding workflow was used to assess present-day and future coastal flood potential. Global coastal flood maps were clipped and reprojected to the Pomorie area of interest. The results indicate that flood potential is concentrated mainly in the lowest coastal sectors, including the Old Town waterfront, the low-lying isthmus, the northern beach area, the coastal zone near large tourist facilities, Pomorie Lake and the salinas.

The local Obscape Level monitoring data provide an important additional layer for interpreting this hazard. High water-level conditions, defined as observations equal to or above 0.30 m relative to the local reference level, represented approximately 0.99% of all observations and occurred on 46 days. Very high water-level conditions, defined as observations equal to or above 0.50 m, represented approximately 0.37% of observations and occurred on 17 days. The maximum observed water-level anomaly reached 1.728 m. These findings show that elevated water levels are episodic but potentially significant when they occur.

The local analysis also identified the main meteorological drivers. Elevated water levels were associated with low atmospheric pressure and, especially, with northeasterly and easterly wind directions. More than 40% of high-water observations occurred under NE/E wind conditions. This confirms that wind direction, not only wind speed, is a key local factor for coastal-flooding hazard in Pomorie.

2.3.1.2. Risk assessment summary

The flood-risk assessment combines flood hazard layers with exposure and vulnerability data. The CLIMAAX workflow uses LUISA land-use data and JRC depth-damage curves to estimate indicative economic damage. The results show that risk is not determined only by water depth, but by the overlap between inundation and exposed assets such as residential areas, hotels, waterfront businesses, transport links, public infrastructure, tourism facilities and sensitive ecosystems.

The most important risk zones are the Pomorie peninsula and waterfront, the low-lying isthmus and access roads, the northern beach sector, coastal tourism areas, Pomorie Lake and the salinas. These areas are exposed not only to direct physical damage, but also to access disruption, emergency-response constraints, temporary loss of tourism revenue, interruption of public services and possible disturbance of protected lagoon and wetland ecosystems.

The national PFRA framework for the Black Sea Basin District confirms that the wider coastal section including Pomorie is relevant for several categories of flood consequence, including human health, economic activity, environment and cultural heritage. This supports the interpretation of coastal flooding as a multi-sector municipal risk rather than only an economic damage issue.

The main limitation is that the current analysis remains a strategic screening assessment. It does not include detailed local hydrodynamic modelling, high-resolution elevation data, complete cadastral/building information, drainage-system data, local defence structures or asset-level replacement costs. Phase 3 should therefore prioritise high-resolution elevation and exposure datasets, detailed coastal and drainage modelling, validation against official flood hazard and risk maps, and integration of coastal flooding into spatial, tourism and emergency planning.

2.3.2. Hazard #2 - Heavy Rainfall/Extreme Precipitation - finetuning to local context

Table 2.3.2 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
EURO-CORDEX precipitation flux data at approximately 12 km spatial resolution, accessed through the Climate Data Store and processed through the CLIMAAX Heavy Rainfall workflow. The analysis used the historical period 1976–2005 and the future period 2041–2070. The model chain used in the uploaded workflow was ICHEC-EC-EARTH / KNMI-RACMO22E under RCP8.5.	Critical impact-based rainfall threshold used in the risk workflow: 50 mm / 24 h associated with a 5-year return period. This threshold was used to assess how the magnitude and frequency of potentially impactful rainfall may change under future climate conditions.	Pomorie Municipality area of interest, defined through the workflow bounding box. The exposure context includes the urban area of Pomorie, the Old Town peninsula, low-lying coastal and lake-adjacent areas, roads, stormwater drainage infrastructure, tourist facilities, agricultural land, Pomorie Lake and the salinas.	Annual maximum precipitation series for 3-hour and 24-hour durations; return-period estimates for selected rainfall durations; future return period for the current critical threshold; future precipitation magnitude if the current return period is maintained; raster outputs showing current return period, return-period shift and precipitation factor.
Annual maximum precipitation datasets generated for 3-hour and	Local vulnerability factors: limited drainage capacity in	Current socio-economic exposure was used as the baseline. No	For the 2041–2070 period, the 50 mm / 24 h threshold currently associated with a

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
24-hour durations for the historical and future periods. Extreme-value analysis was applied to estimate expected precipitation amounts for selected return periods.	urbanized areas, sealed surfaces, road and access-route sensitivity, erosion-prone areas, agricultural fields vulnerable to waterlogging, and possible exposure of vulnerable population groups during sudden local flooding.	detailed future land-use, population or asset-distribution projection was applied in this iteration. Future exposure was interpreted qualitatively, assuming continued concentration of tourism, services and infrastructure in coastal and urbanized areas.	5-year return period is projected to require approximately 39% higher precipitation to maintain the same frequency. If the rainfall magnitude remains fixed at 50 mm / 24 h, the return period changes from 5 years to approximately 3 years, indicating increased frequency.
Local automatic meteorological station data from Pomorie, collected with high-resolution Obscape sensors at 30-minute intervals for the period 04 October 2024 – 12 June 2026. Daily precipitation totals and moving 30-minute, 1-hour, 3-hour and 6-hour accumulations were calculated.	Local observational indicators used for contextual vulnerability interpretation: number of wet days, heavy-rainfall days, rainfall-event duration, maximum short-duration intensity and concentration of rainfall within a limited number of events.	Site-specific local exposure: the monitoring station is located in the urban area of Pomorie, at the tip of the Old Town peninsula, at the land-sea interface. Its observations are therefore particularly relevant for the urban coastal setting, but not fully representative of the entire municipality.	Local impact-relevant indicators: highest daily precipitation total, monthly totals, number of days ≥20 mm and ≥30 mm, maximum 30-minute, 1-hour, 3-hour and 6-hour precipitation totals, top rainfall events by accumulated precipitation and by mean intensity.
Long-term annual precipitation series for Pomorie/Burgas covering 1894–2023, used to assess background precipitation variability and long-term tendencies.	Long-term vulnerability interpretation: high natural variability of precipitation, absence of a strong trend in annual totals, but possible increasing relevance of intra-seasonal variability, short-duration intense events and dry spells.	Wider municipal exposure: settlements, transport links, agricultural land, tourism areas, lake and lagoon ecosystems, and disaster-response systems.	Long-term trend indicator: weak positive trend in annual precipitation totals, approximately 0.7 mm/year, with very low explanatory power, indicating that natural interannual variability remains dominant.

2.3.2.1. Hazard assessment summary

Heavy rainfall was assessed as a separate hazard because its impact pathways differ from coastal flooding, even though both may contribute to local inundation and may interact under compound-event conditions. In Pomorie, heavy rainfall is particularly relevant for urban drainage, road access, low-lying neighbourhoods, tourist areas, agricultural land, Pomorie Lake and the salinas.

The CLIMAAX heavy-rainfall workflow used EURO-CORDEX precipitation data at approximately 12 km resolution. The historical period was 1976–2005 and the future period was 2041–2070 under RCP8.5. Annual maximum precipitation series were generated for 3-hour and 24-hour durations, and extreme-value analysis was applied to estimate return-period rainfall amounts.

Local observations were used to regionalise the modelled results. The Pomorie automatic station recorded precipitation at 30-minute intervals for the period 04 October 2024 – 12 June 2026. During this period, no rainfall event above 50 mm / 24 h was recorded. The highest daily total was 34.357 mm on 2 June 2026, followed by 32.725 mm on 17 May 2026. Only five days reached or exceeded 20 mm, and only two days reached or exceeded 30 mm.

However, the local data show that rainfall can be highly concentrated within short periods. On 2 June 2026, maximum accumulations reached approximately 19.5 mm in 30 minutes, 28.7 mm in 1 hour, 34.3 mm in 3 hours and 34.4 mm in 6 hours. A second intense event occurred on 4 June 2026, when 21.7 mm fell within approximately 2.5 hours. These results show that the hazard should not be assessed only through daily or monthly totals. Short-duration intensity is essential for understanding runoff and drainage stress.

The long-term annual precipitation record for Pomorie/Burgas for 1894–2023 shows a weak positive trend, but with very low explanatory power. Natural variability remains dominant. Therefore, the most relevant local concern is not a strong increase in annual totals, but the combination of short-duration rainfall intensity, dry intervals, high intra-seasonal variability and future shifts in the frequency of critical rainfall thresholds.

2.3.2.2. Risk assessment summary

The heavy-rainfall risk workflow was implemented as a threshold-based climate risk assessment. Unlike the coastal-flooding workflow, it does not estimate direct economic damage. Instead, it evaluates how a critical rainfall threshold changes under future climate conditions.

The selected threshold was 50 mm / 24 h, associated with a 5-year return period. For 2041–2070 under RCP8.5, the workflow indicates that maintaining the same 5-year frequency would require approximately 39% higher rainfall. Conversely, if the threshold remains fixed at 50 mm / 24 h, its return period decreases from 5 years to approximately 3 years. This means that rainfall conditions currently treated as a 5-year threshold event may become more frequent in the future.

The main exposed systems are stormwater drainage infrastructure, roads and access routes, low-lying urban areas, waterfront zones, public buildings, tourist facilities, agricultural fields, Pomorie Lake and the salinas. Short-duration rainfall may cause rapid runoff, drainage overload, local flooding, road disruption, erosion, contamination of surface waters and pressure on emergency-response institutions.

Heavy rainfall also has a clear compound-risk pathway with coastal flooding. If intense rainfall coincides with elevated sea levels, storm surge or restricted drainage outflow, water accumulation may increase in the Old Town peninsula, the isthmus, coastal tourist zones and areas close to Pomorie Lake. Phase 3 should therefore link rainfall thresholds, drainage-capacity assessment and coastal-flooding response planning.

The main limitation is the absence of detailed local drainage capacity, sewer-network information, cadastral/building data, road underpass inventories, historical damage records and hydraulic modelling. Phase 3 should focus on identifying runoff hotspots, assessing stormwater drainage capacity under short-duration rainfall intensities, integrating rainfall thresholds into early warning and strengthening coordination between heavy-rainfall and coastal-flooding preparedness.

2.3.3. Hazard #3 - Drought - finetuning to local context

Table 2.3.3. Data overview workflow #3

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
Relative drought workflow: monthly total precipitation for NUTS3 regions in Bulgaria. The workflow uses pre-processed ISIMIP 3b bias-adjusted atmospheric climate input data, based on the ensemble average of five CMIP6 global climate models. The historical period is 1981–2015. Future periods include 2031–2060 and 2071–2100 under SSP1-2.6, SSP3-7.0 and SSP5-8.5.	...Relative drought vulnerability indicators: GDP per capita and rural population share, used as generic proxies for economic and social vulnerability to drought.	NUTS3-level exposure indicators: cropland, livestock density, population and water-stress indicators. These represent exposure to agricultural activity, animal husbandry, human water demand and competition for water resources.	Drought hazard index based on WASP/ precipitation-deficit metrics; relative drought exposure; relative drought vulnerability; relative drought risk score and relative risk category at NUTS3 level.
Agricultural drought hazard workflow: EURO-CORDEX daily climate data for precipitation flux, maximum and minimum temperature, relative humidity, wind speed and solar radiation at approximately 12 km resolution. The uploaded workflow used the NUTS2 region BG34 / Yugoiztochen and a future example period 2046–2050 under RCP2.6, with the CNRM-CERFACS-CM5 / KNMI-RACMO22E model chain selected in the workflow.	Agricultural vulnerability proxy: irrigation availability. Areas with lower irrigation availability are interpreted as more vulnerable to precipitation scarcity and soil-water deficits.	Agricultural exposure data: crop production from MapSPAM 2020, crop value from GAEZ for staple crops, and crop-specific EUROSTAT prices for non-staple crops. The crop list included wheat, barley, rapeseed, sunflower, temperate fruits and tomatoes.	Potential crop yield loss under rainfed-only conditions; potential revenue loss from lack of irrigation, expressed as lost opportunity cost; spatial maps showing yield/revenue loss and irrigation availability.
Local Pomorie dry-spell analysis based on 30-minute precipitation records from the Obscape station in Pomorie, converted to daily totals. The station is located in the Old Town peninsula area at the land-sea interface. The analysed period is 04 October 2024 – 12 June 2026. A dry day	Local vulnerability factors: rainfed agricultural production, seasonal irrigation demand, limited soil-water storage, high summer evaporation, exposed crops during sensitive growth stages, dependence of urban green systems and	Local exposure: arable land, vineyards, orchards, vegetable production, pasture, livestock systems, Pomorie Lake, salinas, urban green areas, tourism infrastructure and water users. Additional agricultural context was taken from	Maximum consecutive dry days; number of dry days by month; identification of completely rain-free periods versus climatologically dry periods with micro-rainfall; qualitative risk interpretation for agriculture,

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
was defined as daily precipitation below 1 mm.	tourism landscapes on water availability, and sensitivity of wetlands and lake ecosystems to water balance changes.	the 2024 Burgas agricultural report.	ecosystems, water management and urban/tourism functions.
Future socio-economic condition: the relative drought workflow includes future cropland, population, GDP and water-stress-related exposure/vulnerability proxies. The agricultural drought workflow uses current production/value and irrigation datasets as baseline exposure and vulnerability layers, without detailed local future crop-structure projections.	Future vulnerability interpretation: continued pressure on water resources, potential increase in irrigation demand, possible changes in crop suitability, and increased sensitivity of rainfed production during longer dry periods.	Future exposure interpretation: current agricultural and socio-economic exposure was used as the main baseline. No municipality-level future crop, irrigation-network or land-use scenario was available in this phase.	Future risk interpretation: strategic indication of areas and sectors where drought hazard, exposure and vulnerability may become more relevant; basis for prioritising irrigation efficiency, drought monitoring, crop adaptation and water-resource planning.

2.3.3.1. Hazard assessment summary

Drought was assessed as a separate hazard because it affects agriculture, water resources, soil moisture, ecosystems, vegetation, urban green systems, tourism landscapes and wider socio-economic resilience. Unlike flooding hazards, drought develops over longer time scales and may not produce immediate visible damage, but its impacts may accumulate over weeks or months.

The assessment combined three layers: the CLIMAAX relative drought workflow, the agricultural drought workflow and a local dry-spell analysis. The relative drought workflow provides a NUTS3-level regional screening layer for Burgas Province, using precipitation-deficit indicators. The agricultural drought workflow assesses crop-water deficits and potential yield losses under rainfed-only conditions. The local dry-spell analysis uses high-resolution Pomorie precipitation observations.

The local dry-spell analysis defined a dry day as a day with less than 1 mm of precipitation. Dry conditions occupied a large share of the observation period. Several months had more than 80–90% dry days, and July, September and December 2025 were entirely dry according to this threshold.

The most important local drought indicator is the 51-day rain-free period from 29 June to 18 August 2025. This dry spell occurred during the warm season, when evapotranspiration demand is high and precipitation deficits can rapidly translate into soil moisture stress and agricultural impacts. Other substantial dry spells included 39 days from 29 November 2025 to 6 January 2026, 31 days from 1 September to 1 October 2025 and 29 days from 13 October to 10 November 2024.

The local analysis also distinguishes between completely rain-free periods and climatologically dry periods with only micro-rainfall below 1 mm. This distinction is important because very small precipitation amounts may not meaningfully replenish soil moisture or reduce agricultural drought stress.

2.3.3.2. Risk assessment summary

Drought risk was assessed through both relative regional drought risk and agricultural drought risk. The relative drought workflow combines hazard, exposure and vulnerability indicators to produce comparative NUTS3 risk categories. These categories are useful for regional screening but should not be interpreted as absolute loss estimates.

The agricultural drought workflow is more directly relevant to Pomorie's economic structure because it links crop-water deficit to potential yield loss and potential revenue loss. Exposure is represented by crop production and crop value, while irrigation availability is used as a vulnerability proxy. This is relevant for cereals, oilseeds, fruits, vegetables, vineyards, orchards and pasture systems.

Local agricultural evidence supports the importance of drought as an impact pathway. The 2024 Burgas agricultural report linked low maize yields to drought during the vegetation period, and sunflower also recorded low average yields. This confirms that drought is not only a climatic condition but can translate into measurable agricultural impacts.

The most exposed sectors in Pomorie include rainfed agricultural land, irrigated crops dependent on reliable water supply, vineyards, orchards, vegetable fields, pasture and livestock-related systems, urban green areas, tourism landscaping, Pomorie Lake, the salinas and other sensitive ecosystems. Drought risk may be amplified when long dry spells coincide with heatwaves, high evapotranspiration, peak tourism water demand or critical crop-growth stages.

Wildfire is treated as a secondary drought-related risk. Ten significant wildfire and vegetation-fire events were recorded in Pomorie Municipality during 2021–2025, affecting approximately 3,550 dka of forest, shrub, pasture and agricultural land. Although wildfire is not considered one of the dominant climate hazards for Pomorie, prolonged dry periods and high temperatures may increase vegetation flammability and make this risk more relevant in the future.

The main limitations are the absence of detailed local irrigation-network data, farm-level crop distribution, soil-moisture monitoring, actual irrigated-area information, groundwater abstraction data, reservoir and water-supply data, and historical drought-damage records. Phase 3 should therefore prioritise improved drought monitoring, soil-moisture tracking where feasible, mapping of irrigated and rainfed agricultural areas, collection of crop-loss data and integration of drought indicators into water-resource, agricultural and ecosystem-management planning.

2.3.4. Hazard #4 - Heatwaves - finetuning to local context

Table 2.3.4. Data overview workflow #4

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
EuroHEAT heatwave occurrence data from Copernicus Climate Data Store, based on EURO-CORDEX climate projections at approximately 12 km resolution. The health-related EU-wide definition identifies	Vulnerable population groups from WorldPop, focusing on age groups particularly sensitive to heat, including young children and	Regional exposure: Burgas district / Pomorie Municipality within the selected administrative region. Local exposure includes	Projected heatwave occurrence per year; trend in heatwave occurrence under RCP4.5 and RCP8.5; relative change in heatwave occurrence for near

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
heatwave days during June–August when maximum apparent temperature and minimum temperature exceed their monthly 90th percentile thresholds for at least two days. Data are available for 1986–2085 under RCP4.5 and RCP8.5. For Pomorie, the manual point used was approximately 42.55°N, 27.65°E, with the nearest grid-cell centre at approximately 42.50°N, 27.70°E.	older people. The Burgas district workflow uses both male and female population layers for age 1–5 and older-age groups such as 65, 70, 75 and 80.	the Old Town peninsula, densely built-up residential areas, tourist accommodation areas, public spaces, transport stops, health and social-care facilities, beaches, urban green spaces and outdoor workplaces.	future and further future; regional heatwave-risk classes for vulnerable population groups using a 10x10 risk matrix.
Xclim heatwave hazard workflow based on daily maximum and minimum 2 m air temperature from EURO-CORDEX climate-model data at 12 km resolution. The workflow allows the use of user-defined thresholds for maximum temperature, minimum temperature and minimum event duration. The Pomorie bounding box was defined as approximately 27.399243–27.680081°E and 42.538932–42.90717°N, with a manual point near 42.56°N, 27.64°E.	Threshold-based vulnerability interpretation: heat-health risk depends not only on daytime maxima, but also on warm nights, persistence, humidity, ventilation, age, health status, housing quality, access to cooling, outdoor work and visitor exposure.	Current socio-economic exposure was used as the baseline. No detailed future land-use, tourism-population or building-level exposure scenario was applied in this iteration.	Heatwave index, heatwave frequency and heatwave total length; annual values for selected scenarios; comparison between RCP4.5 and RCP8.5; identification of increasing heatwave hazard under future climate conditions.
Regional heatwave risk workflow for Burgas district, combining EuroHEAT hazard data with WorldPop vulnerable population data. The workflow compares future periods 2016–2045 and 2046–2075 against the reference period 1976–2015.	Vulnerability classes derived from the concentration of vulnerable population groups. These classes are relative within the selected region and should not be interpreted as absolute vulnerability levels.	Administrative-region exposure for Burgas district. The workflow is suitable for regional-scale comparison, but not for detailed street-level urban heat-island assessment.	Relative change in heatwave occurrence; classified magnitude of projected hazard change; combined heatwave-risk class for vulnerable population groups. The uploaded Burgas workflow shows lower relative change classes for the near future and much higher classes for 2046–2075, especially under RCP8.5.
Local observation-based temperature analysis for Pomorie. Long-term monthly mean air temperature series for Pomorie/Burgas, 1894–	Local vulnerability interpretation based on tropical nights, very warm nights,	Local exposure: coastal urban areas, inland built-up sectors,	Long-term warming trend; annual, January and July temperature trends; absolute

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
2023, and high-resolution local meteorological data for 04 October 2024 – 14 June 2026. The local station is located on the Old Town peninsula, directly exposed to the marine environment.	heat–humidity episodes and compound heat-discomfort conditions. Vulnerable groups include older people, young children, people with chronic illness, outdoor workers, tourists, socially isolated persons and people in poorly ventilated buildings.	accommodation facilities, outdoor public spaces, beaches, markets, transport stops, social and health facilities, schools/kindergartens, and areas with limited shade or ventilation.	maximum and minimum temperatures; number of hot days, tropical nights and heat–humidity episodes; compound heat-discomfort indicators combining temperature, humidity, wind speed and solar radiation.
Satellite-derived heat exposure methodology based on Landsat 8 land surface temperature at 30 m resolution and WorldPop vulnerable population at 100 m resolution.	Vulnerability represented by density of vulnerable population groups. The method can be improved with local census, health, social-care and critical-facility datasets.	Local surface exposure: built-up areas, paved surfaces, low-vegetation zones, public spaces and potentially overheated surfaces.	Local heat-risk map based on risk = heat exposure x vulnerable population density. This is a methodological layer for future refinement because it requires suitable cloud-free satellite scenes and local validation.

2.3.4.1. Hazard assessment summary

Heatwaves were assessed as a separate hazard because of their direct relevance for human health, tourism, urban comfort, energy demand, labour productivity, agriculture, ecosystems and water demand. In Pomorie, heat risk has a specific coastal character. The Black Sea moderates daytime temperature extremes but may also contribute to warmer nights and higher humidity, reducing physiological recovery during the night.

The CLIMAAX EuroHEAT workflow was used to assess future heatwave occurrence based on EURO-CORDEX data. The EuroHEAT definition considers both maximum apparent temperature and minimum temperature, making it relevant for health-related heat stress. The Xclim workflow provided a flexible methodological layer for calculating heatwave indicators using user-defined thresholds for maximum and minimum temperature.

The model-based outputs indicate that future heatwave occurrence is expected to increase, particularly under high-emission conditions and in the further future. The regional Burgas workflow shows higher projected heatwave-occurrence change for 2046–2075, especially under RCP8.5.

The local observation-based analysis adds a crucial interpretation layer. The long-term temperature series for Pomorie/Burgas for 1894–2023 shows a persistent warming trend, with July warming more strongly than the annual average. This confirms that the warm-season background climate is becoming progressively warmer.

At the coastal monitoring station, however, no classical hot days and no heatwave events were recorded during 04 October 2024 – 14 June 2026 using the threshold of maximum air temperature ≥30°C. The maximum recorded air temperature was 28.8°C. This reflects the strong maritime moderation of daytime temperatures at the station location.

The nocturnal signal is much stronger. The station recorded 78 tropical nights, 42 very warm nights and one hot night. In addition, three persistent heat–humidity episodes were identified in July 2025, lasting 4, 5 and 3 days. These findings show that Pomorie's heat hazard cannot be assessed only through maximum daytime temperature. Warm nights, humidity, wind speed, solar radiation and persistence are essential indicators for local heat-risk planning.

2.3.4.2. Risk assessment summary

Heatwave risk focuses mainly on human-health and social vulnerability, but also affects tourism, labour productivity, public spaces, infrastructure, ecosystems, water demand and agriculture. The main risk pathway is the overlap between increasing heatwave occurrence, warm nights, heat–humidity episodes and vulnerable population groups.

The regional heatwave risk workflow for Burgas district combines EuroHEAT hazard change with WorldPop vulnerable-population data. Vulnerable groups include young children and older people. Projected heatwave-occurrence change and vulnerable-population concentration are reclassified and combined through a 10×10 risk matrix. The resulting classes are relative within the selected Burgas district analysis and should not be interpreted as absolute European-level risk rankings.

For Pomorie Municipality, key exposed groups include older residents, young children, people with chronic illnesses, socially isolated people, outdoor workers, tourism-sector workers, beach users and visitors who may not be acclimatised to local conditions. Tourists are particularly relevant because peak tourism overlaps with the warmest months and with the period of frequent tropical nights.

The local observations suggest that heat risk in Pomorie may be driven less by extreme daytime maxima and more by warm nights, humidity and persistence. Tropical nights may reduce night-time recovery, especially in poorly ventilated dwellings, accommodation facilities without adequate cooling and densely built-up areas. Heat–humidity episodes may also reduce comfort and safety in beaches, promenades, public spaces and outdoor workplaces.

Urban morphology may further modify risk. The coastal station may underrepresent daytime heat exposure in more inland and densely built-up sectors with weaker ventilation and higher surface temperatures. For this reason, the satellite-based heat-risk workflow is relevant for Phase 3. Combining Landsat-derived land surface temperature at 30 m resolution with vulnerable-population data at 100 m resolution can help identify overheated surfaces and priority areas for shading, tree planting, cool surfaces, water points and targeted heat-health measures.

The main limitations are the 12 km resolution of EuroHEAT/Xclim hazard data, the use of modelled WorldPop population data, the absence of seasonal tourism-population data and the lack of detailed local information on housing quality, social isolation, access to cooling and institutional populations. Phase 3 should focus on locally adapted heat-warning indicators, monitoring of tropical nights and compound heat–humidity conditions, satellite-based urban heat mapping and targeted heat-health planning for vulnerable groups and tourism areas.

2.3.5. Hazard #5 - Windstorms - finetuning to local context

Table 2.3.5. Data overview workflow #5

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Windstorm tracks and footprints derived from reanalysis over Europe from 1940 to present, accessed through the Copernicus Climate Data Store. The selection helper used the Hodges tracking algorithm and identified storm events by distance to a selected point near the study area.	Vulnerability curves for different building/construction classes, adapted from published wind-damage functions. The curves relate 3-second wind gust speed to percentage of structural damage.	Pomorie area of interest defined by a bounding box. Exposure was represented through LUISA land-cover data clipped to the municipality area.	List of historical storms closest to the selected location; storm tracks; selected storm-event footprint; spatial map of maximum 3-second wind gusts.
Selected historical storm footprint: storm ID 1293, with the CDS date configuration corresponding to 27 December 1999. The hazard variable is a maximum 3-second wind gust.	LUISA land-use classes were linked to maximum structural damage values and to vulnerability curves according to the assumed building/asset composition of each land-use class.	LUISA land-cover classes, including urban fabric, industrial/commercial units, transport infrastructure, port areas, agricultural land, forests, wetlands, beaches, lagoons and water bodies.	Event-based structural damage map; damage by land-cover class; total estimated damage for the selected event.
Optional workflow functionality: relocation of historical storm footprints to test the effect of storms occurring in a different location. This can be used as a sensitivity test but should not be interpreted as a direct future projection unless supported by additional climate evidence.	Local vulnerability factors: exposed coastal infrastructure, roofs and lightweight structures, port and tourism facilities, outdoor commercial areas, street trees, electricity and communication lines, agricultural installations, greenhouses and temporary beach infrastructure.	Local exposure context: Pomorie Old Town peninsula, coastal promenades, port and waterfront areas, tourist accommodation zones, road access, beaches, agricultural land, vineyards, orchards, salinas and Pomorie Lake surroundings.	Qualitative identification of sectors and assets requiring attention during strong wind and gust events.
Local long-term wind and thunderstorm records from the Burgas meteorological station, 1965–2023, used as a regional proxy for the Pomorie area.	Local vulnerability interpretation based on long-term wind regime, thunderstorm occurrence and exposure of coastal systems.	Regional context: Burgas/Pomorie coastal area, with similar physical-geographical coastal characteristics.	Long-term mean wind speed, annual thunderstorm days, weak long-term trends, interannual variability.

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Local automatic weather-station observations from Pomorie, 04 October 2024 – 14 June 2026, at 30-minute resolution. The station is located on an exposed coastal promontory.	Threshold-based local vulnerability interpretation: windstorm day defined as at least one 30-minute observation with mean wind speed ≥10 m/s; severe windstorm day defined as gust speed ≥20 m/s.	Immediate coastal exposure around the monitoring station and wider municipal interpretation for coastal infrastructure, tourism, transport, urban and agricultural assets.	Number of windstorm days and episodes; number of severe windstorm days and episodes; maximum sustained wind speed; maximum gust speed; directional distribution of strong winds and severe gusts; lightning and compound wind–lightning indicators.
Future climate and future socio-economic conditions: no fully probabilistic local future windstorm scenario was applied in this iteration. Future conditions are addressed qualitatively through exposure sensitivity and through the workflow's ability to test relocated historical storm footprints.	Future vulnerability may increase if coastal development, tourism infrastructure, temporary structures, ageing buildings or dependence on overhead networks increase without corresponding strengthening and maintenance.	Current exposure was used as the baseline. No detailed future building, infrastructure, tourism or land-use scenario was available for this phase.	Strategic indication of present-day vulnerable assets and sectors; basis for future detailed stress-testing with stronger or differently located storm footprints.

2.3.5.1. Hazard assessment summary

Windstorms were assessed as a separate hazard because of their relevance for coastal infrastructure, transport, tourism, agriculture, electricity and communication networks, buildings, trees and outdoor public spaces. In Pomorie, the hazard has a coastal character because several exposed assets are located directly along the Black Sea coast, where open marine exposure and pressure gradients can generate strong winds and damaging gusts.

The CLIMAAX windstorm workflow is event-based. The windstorm selection helper identified historical storm events passing close to the selected location. Storm ID 1293, with a CDS date configuration corresponding to 27 December 1999, was selected for the hazard and structural damage workflows. The windstorm hazard layer is a footprint of maximum 3-second wind gusts.

This workflow is useful for stress testing, but it does not provide a full probabilistic windstorm climatology or future projection for Pomorie. Therefore, local wind observations were used to provide a more operational interpretation of the hazard.

Long-term regional data from Burgas for 1965–2023 show a mean annual wind speed of approximately 3.9 m/s and an average of around 33 thunderstorm days per year. Both wind speed and thunderstorm occurrence show weak positive linear trends, but with very low explanatory power. This means that interannual variability remains the dominant feature of the long-term record.

Local 30-minute observations from Pomorie for 04 October 2024 – 14 June 2026 show a generally persistent but moderate coastal wind regime. Monthly mean wind speeds ranged from 3.5 to 5.0 m/s. The maximum sustained wind speed was 16.0 m/s, while maximum gusts reached 30.0 m/s. This confirms that the key wind hazard in Pomorie is short-duration gust intensity rather than sustained high mean wind speed.

Using a threshold of mean wind speed ≥10 m/s, 70 windstorm days and 42 windstorm episodes were identified. Using a severe-gust threshold of ≥20 m/s, 11 severe windstorm days and eight severe windstorm episodes were identified. Severe gusts were concentrated mainly from the northeast and northwest. Northeastern winds are relevant because of the long marine fetch over the Black Sea, while northwestern winds are often linked to frontal and post-frontal pressure-gradient situations.

Lightning was also analysed because thunderstorms can interact with wind hazards. The station recorded 7,799 lightning strikes and 68 lightning days, but compound wind–lightning events were relatively rare. Only one day combined lightning with gusts above 20 m/s, and no days combined lightning with gusts above 25 m/s. This suggests that windstorm and thunderstorm hazards should be treated as related but not identical pathways.

2.3.5.2. Risk assessment summary

The windstorm risk assessment combines the selected storm footprint with land-cover exposure and vulnerability curves. The structural damage workflow uses maximum 3-second wind gust as the hazard variable, LUISA land-cover classes as exposure and wind vulnerability curves as the vulnerability component. DamageScanner was used to estimate potential structural damage for the selected storm event.

The calculated damage for the selected event was low: approximately €0.077 million for the analysed Pomorie region. The damage was concentrated mainly in non-irrigated arable land and pastures, while many urban and infrastructure classes showed zero estimated damage for this specific event. This result should be interpreted carefully. It does not mean that urban assets in Pomorie are not vulnerable to windstorms. It means that, under the selected historical storm footprint and the applied model assumptions, damaging wind speeds did not overlap strongly with high-value urban asset classes.

From a local risk perspective, the event-based damage estimate should be treated as an illustrative stress test rather than a complete assessment of windstorm risk. Local observations provide stronger evidence for operational risk understanding. Gusts up to 30.0 m/s may affect temporary structures, roofs, trees, signage, street furniture, beach facilities, port and marina infrastructure, overhead electricity and communication lines, agricultural structures and exposed tourism facilities.

The most exposed systems include the Old Town peninsula, waterfront and promenade areas, port and coastal infrastructure, beaches and beach-service installations, tourist facilities, open public spaces, roads exposed to crosswinds, orchards, vineyards, greenhouses, electricity and communication networks and urban trees. Risk may increase during the tourist season when outdoor exposure and use of temporary structures are higher.

Windstorms may also interact with coastal flooding when strong onshore winds coincide with elevated sea levels, and with heavy rainfall or thunderstorms when frontal or convective systems produce multiple hazards. The directional findings are therefore important for early warning and preparedness: NE and NW storm situations should receive particular attention.

The main limitations are the use of one selected historical storm footprint, generalized land-cover exposure, generalized maximum damage values and vulnerability curves, and the lack of local building footprints, roof-type information, tree inventories, overhead-network data, port and beach facility inventories, insurance claims and observed wind-damage records. Phase 3 should prioritise continued wind and gust monitoring, collection of wind-damage records, mapping of exposed lightweight structures and overhead networks, use of gust-based warning thresholds and integration of windstorm preparedness with coastal-flooding, thunderstorm and emergency-response planning.

2.3.6. Integrated findings for Phase 3

Across all five hazards, the Phase 2 regionalised analysis confirms that Pomorie Municipality faces a multi-hazard climate-risk profile shaped by its coastal location, tourism economy, low-lying urban and ecological assets, agricultural exposure and dependence on infrastructure systems that may be affected by extreme weather.

The most important cross-hazard findings are:

- coastal flooding and heavy rainfall should be treated as connected flood-risk pathways, especially where intense rainfall coincides with elevated sea levels or restricted drainage outflow;
- drought and heatwaves should be considered together because long dry spells, warm nights, high evapotranspiration and tourism-season water demand can reinforce each other;
- windstorms can interact with coastal flooding, thunderstorms and infrastructure disruption, particularly under NE/E onshore or NW frontal conditions;
- local observations are essential for Pomorie because regional climate-model outputs alone cannot capture micro-topography, coastal exposure, short-duration rainfall, tropical nights, gust direction or local dry spells;
- most workflow outputs are strategic screening results and should not be interpreted as detailed engineering, hydrological, hydrodynamic or asset-level damage models.

The Phase 3 assessment should therefore focus on transforming the Phase 2 screening results into operational adaptation priorities. The main data and planning needs include high-resolution elevation and drainage data, local cadastral/building and infrastructure datasets, monitoring of rainfall, water level, wind gusts and tropical nights, soil-moisture and irrigation information, satellite-based heat mapping, local damage/loss records and stronger integration of climate-risk indicators into municipal emergency, spatial, tourism, water-resource and ecosystem-management planning.

2.4. Key Risk Assessment Findings

2.4.1. Mode of engagement for participation

The mode of engagement for participation of the relevant stakeholders, experts and priority groups has been diverse. A structured survey involved 52 respondents, the second workshop attracted 14 participants from the local administration, health authorities, NGOs and academia. The media publications reached out to the local and regional general public, in addition to contacts with specialized authorities and experts.

Two aspects from the survey results should be emphasised in the context of engagement and participation process because they bear significance for the overall CRA.

Perceived Frequency of Climate Hazards

The overall response distribution demonstrates several notable characteristics (Figure 2.4.1.1.). First, there is a very **strong dominance of wind-related hazards** compared to all other climatic phenomena. The difference between very strong winds (82.7%) and the second-ranked hazard — extreme precipitation (40.4%) — exceeds 40 percentage points, indicating a particularly strong perception of wind-related climatic disturbances within the municipality.

Second, the survey responses reveal a predominance of hazards associated with the warm half of the year. **Heatwaves, droughts, extreme precipitation, windstorms, flooding, and fires** all received substantially higher frequencies than winter-related phenomena such as severe cold, icy conditions, and snowdrifts.

Third, the response distribution demonstrates that respondents perceive **multiple climate hazards simultaneously** rather than concentrating exclusively on a single dominant threat. Even hazards occupying middle positions within the ranking — such as droughts, floods, storms, and fires — are still identified by approximately one quarter of the survey participants.

Overall, the results indicate that local stakeholders primarily associate climate-related disturbances in Pomorie Municipality with **strong winds, extreme precipitation, heat-related hazards, and hydro-meteorological extremes, while winter-related climatic hazards occupy a clearly secondary position within local risk perception**.

Figure 2.4.1.1. Perceived frequency of climate hazards affecting Pomorie Municipality

Perceived significance and priority of climate hazards

The responses reveal a differentiated perception regarding the significance and priority of climate hazards affecting Pomorie Municipality. The normalized distribution of responses demonstrates substantial variation in how individual hazards are evaluated by stakeholders, particularly with regard to the balance between low and high significance assessments.

The highest perceived significance is clearly associated with *very strong winds*. Nearly half of all respondents evaluating this hazard (48.9%) classified it within the "High" significance category, while an additional 23.4% assigned it to the "Extremely high" category. Combined, 72.3% of all valid responses for this hazard fall within the two highest significance classes. At the same time, only 2.1% evaluated very strong winds as a low-significance hazard. This makes strong winds the most strongly prioritized climate hazard within the survey.

A similarly pronounced concentration within the higher significance classes is observed for *heatwaves*. A total of 44.4% of respondents classified heatwaves as a "High" significance hazard, while 19.4% evaluated them as "Extremely high". Together, the two highest categories account for 63.8% of all responses related to this hazard. Only 11.1% of respondents assigned heatwaves to the "Low" category.

Extreme precipitation also demonstrates a strong concentration in the upper significance classes. A total of 41.7% of respondents evaluated this hazard as "High", while 5.6% classified it as "Extremely high". Combined, nearly half of all responses (47.3%) place extreme precipitation within the two highest significance categories.

A moderately high level of perceived significance is also observed for *droughts*. Approximately 37.5% of respondents assigned droughts to the "High" category and an additional 12.5% to the "Extremely high" category. Together, exactly half of all responses associated droughts with elevated significance levels.

The response distribution for *storms* is more concentrated within the intermediate significance category. More than half of all respondents (55.9%) evaluated storms as having "Moderate" significance, while only 17.6% classified them as "High" and 14.7% as "Extremely high". This indicates a more balanced perception of storm-related hazards compared to the sharply dominant perception associated with very strong winds.

A similarly moderate-centered distribution is observed for *fog*, where exactly half of all respondents (50.0%) assigned the hazard to the "Moderate" category. Only 5.3% classified fog as "Extremely high" in significance.

The perception structure for *floods* appears considerably more polarized. While 45.2% of respondents evaluated floods as a "Low" significance hazard, a combined 25.9% nevertheless assigned floods to the "High" or "Extremely high" categories. This indicates the coexistence of differing perceptions regarding the relative importance of flood-related hazards within the municipality.

Several hazards are characterized predominantly by lower significance evaluations. For example, *snowdrifts* received the highest concentration of "Low" significance assessments among all hazards, accounting for 67.9% of responses. Only 3.6% classified snowdrifts as "High" significance, while 10.7% assigned them to the "Extremely high" category.

Similarly, *icy conditions*, *severe cold*, *frosts*, and *hailstorms* are largely concentrated within the "Low" and "Moderate" significance classes. For icy conditions, 83.9% of responses fall within the two lower categories, while for severe cold the combined share reaches 75.9%.

Overall, the response distribution demonstrates that local stakeholders assign the highest climate-hazard significance primarily to: very strong winds; heatwaves; extreme precipitation and droughts. By contrast, winter-related hazards consistently occupy lower positions within the significance hierarchy. The results additionally reveal important variations in perception structure between hazards characterized by broad consensus (e.g., very strong winds) and hazards associated with more differentiated or polarized evaluations (e.g., floods and storms).

2.4.2. Gather output from Risk Analysis step

The risk evaluation for the Pomorie Municipality is based upon a comprehensive set of outputs produced during the Risk Analysis phase, in adherence to the CLIMAAX Common Methodology Framework and the Key Risk Assessment Protocol. These outputs serve as the analytical basis for assessing risk severity, urgency, and local resilience capacity in the subsequent evaluation stages. The Risk Analysis integrates findings from the multi-hazard screening (p.2.2.) and the regionalized risk assessment (p.2.3.). Collectively, these results facilitate a consistent, transparent comparison of risks across different hazards and provide the evidence base required for effective prioritization.

Hazard characterization outputs: The Risk Analysis produced specific indicators for the five priority hazards—**coastal flooding, heavy rainfall, droughts, heatwaves, and windstorms**—which describe their intensity, frequency, spatial extent, and future evolution. Key hazard-specific outputs for Pomorie include:

- **Coastal Flooding:** Utilization of Deltares Global Flood Maps and Copernicus GTSMv3.0 water-level statistics to identify flood-depth potential for return periods up to 250 years. This was refined using local Obscape Level monitoring station data (period 04 Oct 2024 – 05 May 2026) to establish high-water thresholds (≥0.30 m) and interpret impacts of NE/E onshore winds.
- **Heavy Rainfall:** Analysis of EURO-CORDEX precipitation flux data (period 2041–2070, RCP8.5) coupled with 30-minute high-resolution precipitation records from the local Obscape sensor (04 Oct 2024 – 12 Jun 2026) to evaluate short-duration intensity and drainage-overload risk.
- **Droughts:** Assessment using the CLIMAAX relative drought workflow (NUTS3 level) and an agricultural drought workflow (NUTS2 level), complemented by a local dry-spell analysis identifying consecutive rain-free periods (including a 51-day period in 2025) to evaluate soil moisture and irrigation stress.
- **Heatwaves:** Integration of EuroHEAT and Xclim hazard workflows with long-term temperature records (1894–2023) and recent local observations. This output highlights the local hazard profile, specifically the prevalence of tropical nights and heat-humidity episodes over classical daytime heatwave thresholds.
- **Windstorms:** Event-based structural damage assessment utilizing historical tracks from the Copernicus Climate Data Store (e.g., storm ID 1293) and local 30-minute wind observations (04 Oct 2024 – 14 Jun 2026) to determine hazard thresholds based on maximum 3-second gust speeds (≥20 m/s) rather than mean wind speed.

Exposure assessment outputs: Spatial data and mapping identifying the location and extent of municipal assets, population centers, economic activities, and infrastructure exposed to the selected hazards.

Vulnerability assessment outputs: Analysis identifying key sectors, social groups, and infrastructural elements that are most susceptible to the identified hazards, accounting for both physical and socio-economic vulnerability factors.

Integrated risk outputs: Combined assessments that link hazard, exposure, and vulnerability to illustrate the potential impact of climate risks on the municipality.

Use of stakeholder perception data: The results from the structured survey with 52 respondents have been used as additional evidence on perceived severity and frequency of hazards, sectoral impacts on health, infrastructure, and economic activities, and levels of awareness and preparedness. These perception-based outputs were not applied as standalone risk indicators but have been used to contextualise and validate analytical findings, in line with the participatory principles of the CLIMAAX framework.

Role of outputs in risk evaluation: These synthesized outputs serve as the primary input for the CLIMAAX Evaluation Dashboard, providing the data necessary to assess the severity, urgency, and resilience capacity for each hazard, thereby enabling a transparent and participatory risk prioritization process.

2.4.3. Assess Severity

Severity Assessment Framework

The assessment of risk severity constitutes a central component of the CLIMAAX Key Risk Assessment Protocol, providing a structured evaluation of the magnitude and significance of climate-related risks affecting Pomorie Municipality. Severity reflects not only the frequency and intensity of climate hazards, but also the scale of their impacts on population, infrastructure, economic activities and environmental resources, as well as their potential to generate irreversible consequences and cascading effects across interconnected systems.

In accordance with the CLIMAAX methodology, the severity assessment was conducted for both current and future risk conditions using a four-level classification framework comprising the categories Limited, Moderate, Substantial and Critical (Table 2.4.3.1). The evaluation was informed by multiple complementary sources of evidence, including CLIMAAX workflow outputs, local climate analyses, Copernicus Climate Atlas information, stakeholder survey results and relevant municipal planning documents. This integrated approach enabled the assessment to combine scientific evidence with local knowledge and institutional perspectives, thereby strengthening the robustness and contextual relevance of the results.

Particular attention was given to the observed and projected evolution of the five priority climate hazards previously identified through the risk exploration process, namely heatwaves, droughts, coastal flooding, extreme precipitation and wind storms. The assessment considered both the current manifestation of these hazards and their expected future evolution under changing climatic conditions. In addition to the direct impacts associated with each hazard, the analysis examined their implications for human health, economic activities, critical infrastructure, water resources, ecosystems and municipal services.

Severity was evaluated using four principal criteria derived from the CLIMAAX Key Risk Assessment Protocol: (i) magnitude and frequency of impacts; (ii) consequences for exposed populations, economic sectors and infrastructure systems; (iii) potential for irreversible damage or long-term degradation of environmental and socio-economic assets; and (iv) capacity to generate cascading effects extending beyond the initially affected sector or area. The resulting classification framework is presented in Table 2.4.3.1.

Table 2.4.3.1. Severity Classification Framework Applied in the Assessment of Climate Risks in Pomorie Municipality. Source: Adapted from the CLIMAAX Key Risk Assessment Protocol and applied to the climate risk assessment of Pomorie Municipality.

Severity Category	General Interpretation
Limited	Localised impacts with limited spatial extent, manageable consequences and low disruption of socio-economic activities, infrastructure or environmental systems.
Moderate	Noticeable impacts affecting specific sectors, population groups or municipal functions, generating measurable but generally manageable consequences under existing capacities.
Substantial	Significant impacts affecting multiple sectors, larger population groups and critical functions, resulting in considerable economic losses, operational disruptions and increased pressure on municipal resources.
Critical	Severe and potentially irreversible impacts with major socio-economic consequences, extensive spatial extent, significant disruption of critical infrastructure and services, and strong cascading effects across interconnected systems.

Comparative Severity Assessment of the Identified Climate Risks

The comparative assessment of severity was undertaken for the five priority climate risks identified through the risk exploration and screening process, namely droughts, heatwaves, coastal flooding, extreme precipitation and windstorms. The evaluation considered both current and future risk conditions and was based on the combined analysis of hazard characteristics, exposure patterns, vulnerability factors, stakeholder perceptions and projected climate developments. Particular attention was given to the magnitude and frequency of impacts, the potential for irreversible environmental and socio-economic consequences, and the likelihood of cascading effects affecting multiple sectors simultaneously.

The results indicate that not all risks exhibit the same severity profile. Some hazards are characterised by frequent occurrence and widespread impacts, while others are associated with lower occurrence probability but potentially substantial long-term consequences. Furthermore, the future evolution of the identified risks suggests an overall increase in climate-related pressures, although the magnitude of change differs among hazard types. The comparative severity assessment therefore reflects both current conditions and the expected evolution of climate risks under projected future climatic and socio-economic conditions.

The severity assessment was further supported by the hazard-specific analyses undertaken within the CLIMAAX framework. These analyses consistently identified increasing future pressures associated with drought development, heat-stress conditions, sea-level-rise-related coastal exposure and the growing intensity of short-duration rainfall events. Together, these findings provide additional evidence supporting the comparative severity classification of the identified climate risks.

Table 2.4.3.2 summarises the comparative severity assessment of the identified climate risks and provides the basis for the subsequent analysis of urgency and risk prioritisation.

Table 2.4.3.2. Comparative Severity Assessment of the Identified Climate Risks. Source: Authors' assessment based on CLIMAAX workflow outputs, stakeholder survey results, local climate analyses and municipal planning documents.

Risk	Current Severity	Future Severity	Key Drivers of Severity
Coastal flooding	Moderate	Substantial	Coastal assets, tourism infrastructure, sea-level rise, irreversible losses
Heavy rain/extreme precipitation	Moderate	Substantial	High-intensity rainfall events, urban flooding, infrastructure disruption
Drought	Substantial	Critical	Water scarcity, agricultural losses, ecosystem degradation, cascading effects
Heatwaves	Substantial	Substantial–Critical	Human health impacts, tropical nights, thermal stress, tourism exposure
Windstorms	Substantial	Moderate–Substantial	Infrastructure damage, economic disruption, high stakeholder concern

Interpretation of Severity Assessment Results

Coastal flooding, extreme precipitation and windstorms constitute a second group of significant climate risks characterised by different impact mechanisms and temporal dynamics. Coastal flooding is currently assessed as a moderate risk but is expected to reach substantial severity under future conditions. Although its spatial extent is more limited than that of droughts or heatwaves, the risk is associated with potentially irreversible consequences, including coastal erosion, degradation of coastal ecosystems, loss of valuable land and damage to tourism-related infrastructure. Given the economic importance of coastal resources for Pomorie Municipality, even relatively infrequent flood events may generate considerable long-term impacts.

Heavy rainfall/extreme precipitation is likewise expected to increase in severity, primarily due to the projected concentration of rainfall into fewer but more intense events. While total annual precipitation does not show a consistent increasing trend, the growing likelihood of high-intensity rainfall episodes increases the potential for pluvial flooding, drainage-system overload and local infrastructure disruption. These impacts may affect urban areas, transport networks and public services, particularly during short-duration extreme rainfall events. Consequently, the future severity of extreme precipitation is assessed as substantial despite the relatively limited irreversibility of its direct impacts.

The severity assessment highlights important differences in both the current and projected future significance of the identified climate risks. Among the assessed hazards, **droughts** emerge as the most severe long-term risk for Pomorie Municipality. While currently classified as substantial, their future severity is assessed as critical due to the combined effects of increasing water scarcity, growing pressure on agricultural production, ecosystem degradation and the potential for cascading impacts extending to water supply, biodiversity and wildfire susceptibility. The long duration of drought episodes and their capacity to affect multiple sectors simultaneously further contribute to their elevated severity profile. This conclusion is reinforced by the consistency of the drought-related analyses, which indicate increasing pressure on water resources, agricultural production and ecosystems under multiple future climate scenarios and assessment horizons.

Heatwaves also represent a major climate risk for the municipality. Their severity is currently assessed as substantial and is expected to increase further in the future, approaching critical levels under continued warming trends. Particular concern arises from the projected increase in the frequency and duration of heatwaves, as well as from the growing occurrence of tropical nights, which reduce opportunities for physiological recovery and amplify health-related risks, especially among vulnerable population groups. In addition to direct health impacts, prolonged heat stress may affect tourism activities, energy demand and water resource management.

Windstorms remain an important climate risk for Pomorie Municipality due to their documented impacts on infrastructure, economic activities and public safety, as well as their prominent position in stakeholder perceptions and reported damage experience. Their current severity is assessed as substantial. This assessment reflects documented damage experience, infrastructure exposure and stakeholder concern rather than evidence of a strong increasing climatic trend. However, unlike droughts, heatwaves and extreme precipitation, the available evidence does not indicate a comparable increase in severity under future climate conditions. Climate projections and local analyses suggest a less pronounced or more uncertain future trend for wind-related hazards, supporting the conclusion that their future severity is expected to remain within the moderate-to-substantial range rather than increase substantially over the assessment period.

Stakeholder and institutional perspectives on Risk Severity

Particular consideration was also given to the perspectives of vulnerable population groups, including elderly residents, individuals with chronic health conditions and sectors directly dependent on climate-sensitive resources.

The severity assessment is further supported by the results of the stakeholder consultation conducted within the CLIMAAX framework. Survey participants identified heatwaves, droughts, extreme precipitation and windstorms among the most significant climate-related hazards affecting Pomorie Municipality, largely confirming the priority risks identified through the scientific and technical assessment. Respondents also reported direct experience with damages associated with strong winds, floods, droughts and other extreme weather events, highlighting the tangible impacts already being experienced at the local level.

Stakeholder responses further indicated concerns regarding the potential impacts of climate change on tourism, agriculture, water resources and the urban environment, all of which represent sectors of strategic importance for the municipality. These findings reinforce the conclusion that the most severe future risks are those capable of affecting multiple sectors simultaneously and generating cascading socio-economic consequences. At the same time, the consultation results suggest a generally positive level of awareness among local institutions and decision-makers regarding climate-related challenges. The existence of strategic planning documents, ongoing participation in climate adaptation initiatives and the relatively positive assessment of municipal preparedness reported by survey respondents indicate an increasing institutional understanding of climate risks, although continued capacity-building and adaptation planning remain necessary.

Overall, the severity assessment demonstrates that climate risks in Pomorie Municipality are expected to intensify over time, although the magnitude and nature of these changes differ among hazard types. Droughts emerge as the most severe long-term risk due to their extensive impacts, potential irreversibility and strong cascading effects across environmental, economic and social systems. heatwaves, coastal flooding and extreme precipitation also exhibit increasing severity under future conditions, while windstorms remain an important but comparatively more stable risk. These findings provide a robust basis for the subsequent urgency assessment, which examines not only the magnitude of climate risks but also the timescales over which their impacts may materialise and the extent to which immediate adaptation measures are required.

2.4.4. Assess Urgency

Urgency Assessment Framework

The assessment of risk urgency complements the severity assessment by evaluating the timescale within which adaptation and risk reduction measures should be implemented in order to minimise future impacts. While severity focuses on the magnitude and consequences of climate-related risks, urgency considers the need for action, taking into account the expected evolution of risks, the timing of potential impacts and the available window of opportunity for effective intervention. Consequently, risks with similar severity levels may differ substantially in urgency depending on how rapidly they are expected to develop and how quickly adaptation measures need to be introduced.

In accordance with the CLIMAAX Key Risk Assessment Protocol, the urgency assessment was conducted for both current and future risk conditions using a four-level classification framework comprising the categories No Action Needed, Watching Brief, More Action Needed and Immediate Action Needed (Table 2.4.4.1). The assessment was informed by the results of the climate hazard analyses, the severity assessment, stakeholder consultation outcomes, local climate observations, municipal planning documents and expert judgement. This integrated approach enabled the evaluation to reflect both scientific evidence and local perceptions regarding the timing and significance of climate risks.

Particular attention was given to the five priority climate risks identified for Pomorie Municipality: droughts, heatwaves, coastal flooding, extreme precipitation and windstorms. The assessment considered not only the current manifestation of these risks but also their projected future evolution under changing climatic and socio-economic conditions. In addition, the analysis examined whether the identified hazards are associated primarily with sudden-onset events, such as intense rainfall and windstorms, or with slower and cumulative processes, such as droughts, heat stress and sea-level rise, as these characteristics strongly influence the urgency of adaptation responses.

Urgency was evaluated using five principal criteria derived from the CLIMAAX methodology and the objectives of the assessment: (i) the extent to which risk severity is expected to increase in the future; (ii) the timeframe within which major impacts are likely to occur; (iii) the likelihood of significant deterioration under future climate conditions; (iv) the sudden or gradual nature of hazard occurrence; and (v) the persistence and long-term accumulation of impacts. Together, these criteria provide a structured basis for determining the urgency with which adaptation and risk reduction measures should be prioritised and implemented. The resulting classification framework is presented in Table 2.4.4.1.

Table 2.4.4.1. Urgency Classification Framework Applied in the Assessment of Climate Risks in Pomorie Municipality

Urgency Category	General Interpretation
No action needed	Current and projected conditions do not require additional adaptation measures beyond existing practices.
Watching brief	The risk should be monitored and periodically reviewed, but no immediate additional intervention is currently required.
More action needed	Additional adaptation measures, preparedness actions and risk reduction efforts should be progressively implemented in the near term.
Immediate action needed	Immediate adaptation and risk reduction measures are required due to the high likelihood of significant impacts, increasing risk severity or limited time available to prevent damages.

Comparative Urgency Assessment of the Identified Climate Risks

The comparative assessment of urgency was undertaken for the five priority climate risks identified through the risk exploration, screening and severity assessment process, namely droughts, heatwaves, coastal flooding, extreme precipitation and windstorms. While the severity assessment examines the magnitude and consequences of these risks, the urgency assessment focuses on the timeframe within which adaptation measures are required and the extent to which delayed action may increase future damages and reduce adaptation effectiveness.

The assessment considered both current and future risk conditions and evaluated how rapidly each climate risk is expected to evolve, whether major impacts are already being experienced, and how much time remains available for effective intervention. Particular attention was given to differences between sudden-onset hazards, such as extreme precipitation and windstorms, and slower but persistent processes, such as droughts, heat stress and coastal flooding. These different hazard characteristics influence not only the timing of impacts but also the urgency with which adaptation and preparedness measures need to be implemented.

The results indicate that all identified climate risks require continued attention and adaptation efforts, although the degree of urgency differs among hazard types. Some risks already require immediate action due to their potential for sudden and highly disruptive impacts, while others are characterised by progressively increasing urgency driven by long-term climatic trends and cumulative effects. In several cases, the implementation of timely adaptation measures during the current period may substantially reduce future damages and help prevent further escalation of climate-related risks.

The urgency assessment was further supported by the hazard-specific analyses conducted within the CLIMAAX framework. These analyses indicate increasing future pressures associated with drought development, heat-stress conditions, coastal flood exposure and the increasing intensity of short-duration rainfall events. The results also highlight important differences in the temporal behaviour of hazards, ranging from rapidly occurring and difficult-to-predict precipitation events to gradual but persistent processes such as droughts and sea-level rise, which require early adaptation planning despite their slower manifestation.

Table 2.4.4.2 summarises the comparative urgency assessment of the identified climate risks and provides the basis for the subsequent interpretation of urgency patterns and adaptation priorities. The resulting urgency profile is further illustrated in Table 2.4.4.2.

Table 2.4.4.2. Comparative Urgency Assessment of the Identified Climate Risks

Risk	Current Urgency	Future Urgency	Main Drivers of Urgency
Coastal flooding	More action needed	Immediate action needed	Sea-level rise, irreversible coastal impacts, long planning and infrastructure adaptation requirements
Extreme precipitation	Immediate action needed	Immediate action needed	Sudden-onset events, low predictability, potential for severe damage, increasing rainfall intensity and concentration
Drought	More action needed	Immediate action needed	Increasing water stress, persistence, cross-sectoral impacts, long-term resource pressures
Heatwaves	More action needed	Immediate action needed	Increasing temperatures, growing frequency of tropical nights, health impacts, long adaptation lead times
Windstorms	More action needed	More action needed	Infrastructure damage, economic disruption, stakeholder concern, uncertain future trend

Table 2.4.4.3. Current and Future Urgency Profile of the Identified Climate Risks in Pomorie Municipality

Risk	Current	Future
Coastal flooding		
Heavy rainfall/Extreme precipitation		
Drought		
Heatwaves		
Windstorms		

More action needed Immediate action needed

Interpretation of Urgency Assessment Results

The urgency assessment reveals important differences in the timing, evolution and management requirements of the identified climate risks. Although all five risks require continued monitoring and adaptation efforts, their urgency levels vary according to the speed at which impacts may occur, the persistence of underlying hazard processes and the available timeframe for effective intervention. The assessment indicates that both rapidly occurring hazards and slowly developing climate processes may require high levels of urgency, albeit for different reasons. While sudden-onset events demand immediate preparedness and response capacity, gradual climate changes often require early action because delayed intervention may significantly increase future damages and adaptation costs.

Coastal flooding exhibits a different urgency profile, reflecting its association with gradual but persistent processes such as sea-level rise, coastal erosion and the long-term degradation of coastal assets. Under current conditions, the urgency is assessed as More Action Needed, as adaptation planning, spatial planning measures and investments in coastal resilience can still be implemented proactively. However, the urgency increases to Immediate Action Needed under future conditions due to the cumulative nature of coastal processes and the potentially irreversible consequences associated with land loss, ecosystem degradation and damage to tourism-related infrastructure. The long lead times required for planning and implementing coastal adaptation measures further reinforce the need for timely action before impacts become more difficult and costly to address.

Among the identified risks, **droughts** emerge as one of the most important long-term adaptation challenges for Pomorie Municipality. Their urgency increases from More Action Needed under current conditions to Immediate Action Needed under future conditions. This reflects the progressive nature of drought development, the increasing pressure on water resources and the strong interconnections between water availability, agriculture, ecosystems and local economic activities. Although drought impacts typically accumulate over extended periods, delayed implementation of adaptation measures may substantially reduce future response options and increase the likelihood of severe cascading effects across multiple sectors.

Heatwaves are also expected to become increasingly urgent over time. Under current conditions, the urgency is assessed as More Action Needed, reflecting the need for continued adaptation planning and preparedness measures. While local observations indicate relatively moderate daytime temperature extremes compared with inland regions of Bulgaria, the growing occurrence of tropical nights and the associated accumulation of nocturnal heat stress already represent an emerging concern for vulnerable population groups. Future warming is expected to further increase health-related risks and place additional pressure on public services, urban environments and energy demand. Consequently, the urgency classification increases to Immediate Action Needed under future conditions, reflecting the need to strengthen adaptation measures before heat-related impacts become more pronounced.

Extreme precipitation represents one of the most urgent climate risks for Pomorie Municipality under both current and future conditions. Unlike many gradual climate processes, extreme rainfall events may occur suddenly, often with limited warning time, while generating substantial impacts on urban areas, transport infrastructure and public services. Recent flood events along the Bulgarian Black Sea coast have further increased public awareness of the potentially severe consequences associated with high-intensity rainfall. This perception is consistent with the local climate analyses, which indicate a tendency towards increasing rainfall intensity and concentration despite the absence of a clear increase in total annual precipitation amounts. The urgency classification therefore remains Immediate Action Needed for both current and future conditions. Under present conditions, this reflects the need to strengthen preparedness, emergency response capacity and drainage infrastructure in order to reduce vulnerability to sudden flood events. Under future conditions, urgency remains equally high due to the projected tendency towards increasing rainfall intensity and precipitation concentration, which may further increase the likelihood of local flooding and infrastructure disruption. At the same time, early implementation of robust adaptation measures has the potential to substantially reduce future damages and improve long-term resilience despite the expected intensification of extreme rainfall events.

Windstorms display a comparatively stable urgency profile. Their urgency is assessed as More Action Needed under both current and future conditions, reflecting the existence of documented impacts on infrastructure, economic activities and public safety, as well as the need for continued preparedness and maintenance of protective measures. However, unlike droughts, heatwaves, coastal flooding and extreme precipitation, the available evidence does not indicate a similarly pronounced increase in future hazard intensity or frequency. Consequently, while adaptation and preparedness efforts remain necessary, the urgency of additional measures is not expected to increase substantially over the assessment period. Continued monitoring of future trends nevertheless remains important given the inherent uncertainty associated with wind-related hazards and their potential to generate localised but significant damage.

Stakeholder and Institutional Perspectives on Risk Urgency

Particular consideration was given to the perspectives of stakeholders, vulnerable population groups and local institutions when assessing the urgency of climate risks in Pomorie Municipality. Stakeholder consultation results indicate a high level of awareness regarding the potential impacts of climate change, particularly in relation to droughts, heatwaves, extreme precipitation, coastal flooding and wind-related hazards. Respondents identified several of these risks among the most important climate challenges facing the municipality and reported direct experience with weather-related damages and disruptions, reinforcing the perception that climate impacts are no longer limited to future scenarios but are already affecting local communities and economic activities.

The consultation results further highlight concerns regarding the vulnerability of key sectors, including tourism, agriculture, water resources and municipal infrastructure. These sectors play a central role in the local economy and are directly exposed to both gradual climate changes and sudden extreme events. Stakeholder responses suggest that the urgency of adaptation measures is particularly high for risks capable of producing widespread socio-economic consequences or affecting essential services and livelihoods.

The perspectives of vulnerable groups also contribute to the urgency assessment. Elderly residents, individuals with chronic health conditions and people whose livelihoods depend on climate-sensitive sectors may experience disproportionately high impacts from heat stress, water scarcity, flooding and other climate-related hazards. The increasing occurrence of tropical nights, the potential disruption of water resources during drought periods and the impacts of sudden extreme rainfall events further emphasise the need for timely adaptation measures that address both current and future vulnerabilities.

From an institutional perspective, the municipality has already demonstrated growing awareness of climate-related challenges through participation in climate adaptation initiatives, strategic planning processes and local development frameworks. Nevertheless, the urgency assessment indicates that continued efforts are required to strengthen preparedness, improve adaptive capacity and ensure that adaptation measures are implemented sufficiently early to reduce future risks and avoid escalating damages. The integration of scientific evidence, local knowledge and stakeholder perspectives therefore provides an important foundation for prioritising adaptation actions and supporting climate-resilient development within Pomorie Municipality.

Overall, the urgency assessment demonstrates that climate risks in Pomorie Municipality differ not only in their severity but also in the timeframe within which adaptation measures need to be implemented. The assessment highlights that both sudden-onset hazards and slowly evolving climate processes may require early intervention, although for different reasons. extreme precipitation emerges as the most immediately urgent risk due to its low predictability, sudden occurrence and potential to cause substantial damage within a very short period of time. Droughts, heatwaves and coastal flooding exhibit progressively increasing urgency under future conditions, reflecting the cumulative nature of climate change impacts and the importance of timely adaptation planning. Windstorms remain an important risk requiring continued preparedness and risk reduction measures, although their urgency is not expected to increase substantially over the assessment period.

The results further indicate that delaying adaptation actions may significantly increase future damages, reduce the effectiveness of available response options and limit the capacity of the municipality to cope with escalating climate pressures. Consequently, the urgency assessment provides an important foundation for determining climate risk priorities and identifying those risks that require the earliest and most comprehensive adaptation responses. These findings are therefore used in the subsequent prioritisation stage to support the identification of key climate risks requiring strategic attention within Pomorie Municipality.

2.4.5. Understand Resilience Capacity

According to the CLIMAAX Key Risk Assessment Protocol, the resilience capacity describes the financial, social, human, physical, and natural resources of Pomorie Municipality required to tackle climate-related risks. The capacity assessment encompassed existing and already implemented measures, while also taking into account formally planned interventions where relevant. The existing resilience capacity is evaluated on a four-level qualitative scale (Low, Medium, Substantial, High). Risks combining high severity with low or medium resilience capacity require the highest level of attention in future adaptation planning.

The assessment has been informed by desktop research of municipal documentation, survey results, observed response performance during past events, and outputs of the risk analysis.

Existing Climate Risk Management Measures

The current climate risk management capacity in Pomorie Municipality is shaped by the disaster response strategic framework, though it exhibits significant limitations across multiple dimensions when dealing with escalating climate risks.

Financial capacity: Municipal budgets currently allow for emergency response and routine maintenance. The municipality lacks comprehensive financial capacity, as the local budget cannot support large-scale preventive or adaptive investments without external funding.

Human capacity: Emergency services and municipal departments have practical operational experience in disaster response. There are identified gaps in climate-specific risk understanding, particularly regarding heatwaves and compound risks, which indicates a need for strengthened training. Public awareness of precise high-risk flood locations is limited, with 52.7% of surveyed individuals having only a general idea.

Social capacity: Public awareness of general flooding risks is relatively high. Preparedness and knowledge of response actions remain highly uneven, with 48.2% of surveyed respondents reporting they are not informed about flood evacuation plans. Existing social inclusion mechanisms are not currently fully leveraged for climate risk reduction.

Physical capacity: Forecasting and warning systems exist at the national level and are accessible locally. Local-level integration for short-duration rainfall and heat stress is limited, and the municipality lacks the physical capacity to forecast and warn about rapid-onset events independently. Physical capacity is heavily constrained by ageing and undersized drainage infrastructure.

Natural capacity: The municipality has limited natural buffering capacity due to extensive sealed surfaces. There is insufficient green-blue infrastructure, which reduces the local ability to absorb extreme heat and heavy rainfall.

Sufficiency of capacity and weaknesses

Pomorie Municipality does not currently possess sufficient capacity to comprehensively address its escalating climate risks. While existing systems provide a functional baseline for managing episodic events, local capacities are increasingly strained by systemic risks related to extreme precipitation and heat.

Weaknesses:

Infrastructure deficits: Ageing and undersized drainage infrastructure, combined with high impervious surface coverage, severely limits the physical ability to handle heavy rainfall.

Procedural awareness: A critical lack of detailed public knowledge regarding evacuation routes and emergency procedures restricts effective disaster response.

Early warning systems: The absence of localized forecasting and warning systems limits the municipality's ability to prepare for sudden, rapid-onset climate events.

Implemented and planned interventions

The municipality relies on a mix of foundational protective measures and forward-looking adaptive planning.

Implemented Interventions:

- Establishment of emergency response systems and winter maintenance services.
- Construction of flood protection structures.
- Development of sectoral plans aligned with national disaster risk management frameworks.
- Installation of a rainwater runoff cistern, which has proven effective in draining recent intensive rains.
- Adoption of a new Disaster Protection Plan in 2025.

Planned interventions:

- Upgrades to urban drainage systems.
- Development of green infrastructure and heat risk management initiatives.
- Adoption of a new municipal disaster risk reduction program for the 2025–2030 period.
- Implementation of educational campaigns and localized early warning systems, heavily supported by surveyed stakeholders.

Resilience capacity assessment is summarized in Table 2.4.5.1.

Table 2.4.5.1. Resilience capacity assessment summary

Climate Hazard	Resilience capacity	Existing measures and gaps
Coastal flooding	Medium	A functional baseline for episodic events exists, supported by strict spatial planning regulations in high-risk zones and existing protective coastal infrastructure. However, systems are strained by escalating risks, with continuous wave destruction and storm surges threatening natural beach surfaces and the heavily tourism-dependent local economy.
Heavy rainfall/ extreme precipitation	Low–Medium	Existing capacity includes stormwater drainage systems and emergency response coordinated by the Municipal administration. Physical capacity is constrained by ageing infrastructure, with over 60% of third-class and municipal roads in poor condition, and a distinct lack of sewage networks in rural settlements. Preventive measures include regular cleaning of the Aheloy and Hadzhiyska riverbeds and dam monitoring, but comprehensive adaptive capacity remains insufficient.
Drought	Medium	Functional baseline exists but requires enhanced adaptive planning. Prolonged dry spells threaten vital local economic sectors like agriculture (viticulture) and strain water supply networks during peak tourist seasons. Furthermore, droughts significantly exacerbate the risk of field and forest fires across the municipality's forested territories (25.1% of the area).
Heatwaves	Medium	Basic operational capacity is well-established, supported by local healthcare infrastructure, including the local hospital of Pomorie and specialized rehabilitation hospitals. Though public understanding of compound risks requires improvement, physiological vulnerability is heightened by an aging demographic structure, particularly in rural inland villages.
Windstorms	Substantial	Systems provide a functional baseline for managing these episodic events, with active Volunteer Formations and the Unified Rescue System effectively coordinating to clear debris and restore critical infrastructure. However, gaps remain, particularly the exposure of above-ground power and telecommunications lines in rural areas to high winds.

2.4.6. Decide on Risk Priority

Methodological approach

The final prioritisation of the selected climate risks was carried out following the methodological framework of the CLIMAAX Handbook. The prioritisation was based on an integrated expert assessment combining the results of the previously completed evaluations of **risk severity**, **urgency**, and **resilience capacity**. Rather than applying a mathematical aggregation of individual scores, the assessment considered the interactions among these three dimensions together with the specific local context of Pomorie Municipality.

The prioritisation process synthesised multiple sources of evidence, including the outputs of the CLIMAAX analytical notebooks, local observational datasets, municipal planning and risk-management documents, expert judgement supported by the quantitative and qualitative evidence collected throughout the assessment process, and the stakeholder consultation conducted during the Climate Risk Assessment process, including the questionnaire survey carried out among representatives of the local community and relevant stakeholders. This integrated approach allowed the final priority ranking to reflect not only the magnitude of the identified climate risks but also the municipality's capacity to respond to them, the perceived importance of individual hazards at the local level, and the urgency of implementing adaptation measures.

Accordingly, the overall priority assigned to each climate hazard represents an expert synthesis of the available quantitative and qualitative evidence and provides a strategic basis for identifying the climate risks requiring the highest attention during the subsequent phases of adaptation planning. The resulting integrated priority assessment is presented in Table 2.4.6.1.a and Table 2.4.6.1.b

Table 2.4.6.1.a. Risk Assessment Evaluation Dashboard

Risk Workflow	Severity (C)	Severity (F)	Urgency	Resilience capacity	Risk Priority
Coastal flooding	Moderate	Substantial	More action needed	Medium	HIGH
Heavy Rainfall	Moderate	Substantial	Immediate action needed	Medium	HIGH
Drought	Substantial	Critical	More action needed	Medium	VERY HIGH
Heatwaves	Substantial	Substantial-Critical	More action needed	Medium	VERY HIGH
Windstorms	Substantial	Moderate-Substantial	More action needed	Substantial	MODERATE
		Severity	Urgency	Resilience Capacity	Risk Ranking
		Critical	Immediate action needed	High	VERY HIGH
		Substantial	More action needed	Substantial	HIGH
		Moderate	Watching brief	Medium	MODERATE
		Limited	No action needed	Low	LOW

Table 2.4.6.1.b Risk Assessment Evaluation Dashboard explained

Climate hazard	Severity	Urgency	Resilience Capacity	Overall Priority	Interpretation
Drought	Substantial → Critical	More action needed → Immediate action needed	Medium	Very High Priority	Future severity projected to become critical; increasing pressure on water resources, agriculture and ecosystems; contributes to wildfire susceptibility.

Heatwaves	Substantial → Substantial–Critical	More action needed → Immediate action needed	Substantial	Very High Priority	Increasing frequency of prolonged hot periods and tropical nights; significant impacts on human health, tourism and energy demand; daytime heat partly moderated by the maritime climate.
Coastal flooding	Moderate → Substantial	More action needed → Immediate action needed	Medium	High Priority	Low-lying coastal areas; observed high water-level events; exposure of tourism infrastructure; projected sea-level rise.
Heavy rainfall/ Extreme precipitation	Moderate → Substantial	mmediate tion needed → Immediate action needed	Low–Medium	High Priority	Immediate adaptation needs; limited resilience capacity; potential for local flooding, urban drainage overload and infrastructure disruption.
Windstorms	Substantial → Moderate–Substantial	More action needed → More action needed	Substantial	Moderate Priority	Highest perceived risk in the stakeholder survey; comparatively high municipal resilience; projected impacts increase less markedly than those of droughts, heatwaves and coastal flooding.

Integrated priority assessment

The integrated assessment indicates that **droughts and heatwaves** emerge as the highest-priority climate hazards for Pomorie Municipality, although they differ in their dominant impact mechanisms. Droughts received the highest priority because of their projected increase in severity from *Substantial* to *Critical*, their growing implications for water resources, agriculture, natural ecosystems, and their contribution to increased wildfire susceptibility. Heatwaves were also assigned a very high priority due to their significant impacts on human health, tourism, and energy demand, together with the projected increase in the frequency and duration of prolonged hot periods. In the specific climatic conditions of Pomorie, however, daytime heat stress is partially moderated by the cooling influence of the Black Sea and the regular sea-breeze circulation. Consequently, the local heat-related risk is associated primarily with the increasing occurrence of tropical nights and prolonged periods of elevated night-time temperatures, which reduce physiological recovery and increase health risks for vulnerable population groups.

Coastal flooding and **heavy rainfall** were classified as high-priority hazards. Although their severity assessments are generally lower than those of droughts and heatwaves, both hazards require timely adaptation measures because of their potentially severe impacts on critical infrastructure, tourism, economic activities, and public safety. The priority assigned to coastal flooding reflects the low-lying coastal topography of Pomorie, the observed high water-level events documented in the local monitoring data, and the projected increase in sea-level rise under future climate scenarios. Extreme precipitation was assigned a similarly high priority because it is the only hazard requiring *Immediate action needed* under both present and future conditions, while the municipality currently exhibits comparatively limited resilience capacity for managing such events.

Windstorms were assigned a moderate overall priority despite being identified by the stakeholder questionnaire as the climate hazard of greatest concern among local respondents. This apparent discrepancy reflects the difference between perceived and integrated climate risk. Strong wind events are highly visible, frequently affect daily life, transport, coastal activities, and electricity supply, and therefore occupy a prominent place in public perception. However, the integrated assessment additionally considers hazard severity, urgency, resilience capacity, projected future climate trends, and the broader evidence base developed throughout the Climate Risk Assessment. The relatively high resilience capacity of the municipality, together with the absence of a substantial increase in projected impacts compared with other climate hazards, results in a lower overall priority despite the high level of public concern.

Implications for adaptation planning

Overall, the final prioritisation reflects a balanced integration of quantitative analyses, local observational evidence, stakeholder perceptions, expert judgement, and the methodological framework of the CLIMAAX Handbook. It provides a strategic basis for directing future adaptation planning and resource allocation towards the climate hazards expected to have the greatest long-term consequences for Pomorie Municipality.

The adopted priority ranking should therefore be interpreted as a strategic framework for adaptation planning rather than a simple ordinal classification of climate hazards. Climate risks assigned to the same priority category may require different adaptation approaches depending on their impact mechanisms, spatial distribution, affected sectors, and future evolution under climate change.

As new monitoring data, climate information, and adaptation measures become available, the priority ranking should be periodically reviewed and updated to ensure that future adaptation planning remains evidence-based, locally relevant, and responsive to evolving climate risks.

2.5. Monitoring and Evaluation

Phase 2 of the CRA provided Pomorie Municipality with a more insightful, evidence-based and locally contextualised assessment of the climate risks, building on and expanding the results of Phase 1. The learning process followed the CLIMAAX Common Methodology Framework and demonstrated the value of combining scientific analysis, analyzing local data and stakeholder engagement.

Key lessons learned and challenges

The assessment successfully expanded beyond coastal flooding to a comprehensive multi-risk assessment perspective, incl. heatwaves, droughts, heavy rainfall, windstorms. A critical takeaway was how the European datasets and local datasets could be employed for more contextualized CRA and scenario-based predictive modeling.

At the same time, the project revealed clear limitations in local institutional capacity, particularly in relation to advanced data analysis and modelling and explaining the complex CRA outputs to the stakeholders. The analytical team faced operational bottlenecks primarily due to a scarcity of high-resolution local data, a lack of historical damage records, and inconsistent stakeholder participation across sectors outside of municipal administration.

Role of stakeholders in assessment and monitoring

The stakeholders have been crucial for providing insights into the attitudes of local administration, citizens and other stakeholders towards climate risks and their impacts. Their participation—via a dedicated workshop and a **52**-respondent survey—provided essential institutional, citizen, and sectoral perspectives (e.g., tourism, agriculture) will be a valuable guide for future adaptation policies.

The stakeholders overwhelmingly perceive strong winds as the most frequent and severe hazard (**82.7%**). They expressed significant concern over extreme weather and water scarcity. Notably, the survey revealed a severe gap in public awareness, with **48.2%** of respondents entirely uninformed about flood evacuation plans. To address these risks, stakeholders strongly favored practical adaptations like infrastructural improvements and early warning systems.

Learning processes and continuity

The learning process along the CRA has been ensured through the methodological integration of harmonized CLIMAAX workflows with empirical local data and stakeholder knowledge. Workshops were actively used to inform and involve the stakeholders. This approach ensures that findings are contextualized and fed directly into updates for local disaster risk management plans and municipal development strategies.

Further learning and monitoring will be supported throughout the next phase by involvement of the stakeholders in the project activities like the discussions on the revision of municipal strategic documents and in the final conference. The communication and outreach activities will include enhanced presence in local and regional media.

Data availability and future needs

The CRA at this phase applied new datasets, e.g. high-resolution observations from the newly utilized local Obscape Level monitoring station (October 2024 – June 2026) provided vital **30**-minute interval data on water levels, precipitation, dry spells, and wind gusts. To move past generic exposure models, the municipality will need, among others long-term local extreme wind datasets, high-resolution urban heat mapping, groundwater monitoring data, detailed coastal asset inventories, and localized drainage capacity assessments.

Communication of results

The project outcomes are communicated through active stakeholder engagement channels, including workshops, surveys, and local and regional media publications. The project has utilized public municipal portals (e.g., the Pomorie municipality website) for project events communication, ensuring that results reach the municipal administration, social/health services, key economic sectors like the harbour and agriculture, and the broader public.

Monitoring systems and institutional embedding

While disaster response is currently guided by the updated Municipal Disaster Protection Plan (2025), the CRA phase successfully integrated real-time data from a local Obscape Level monitoring station. This station tracks atmospheric pressure, wind, and water levels, forming the foundational layer of a local, risk-specific monitoring system, though broader systemic integration across all hazards is still developing. New effective monitoring measures could be embedded in the upcoming municipal Disaster Risk Reduction Program and the integrated development plan.

What Worked Well:

- the project increased the awareness of stakeholders of the value of climate assessment for adaptation planning;
- the CLIMAAX risk prioritisation protocol has been applied successfully;
- the stakeholder perspectives were integrated in the CRA through expert inputs and structured survey;
- the municipal administration has been involved and supportive throughout the process;
- trust and cooperation between municipal experts and external experts have been established;
- the threshold-based observational analysis using the local Obscape station worked exceptionally well to ground global models in local reality. For example, it successfully identified that elevated coastal water levels in Pomorie are strongly tied to specific northeasterly onshore winds.

What Did Not:

- the involvement of regional and national-level stakeholders was limited;
- the estimation of economic damage using generalized European depth-damage curves and **12** km resolution climate grids (EURO-CORDEX) lacked the precision needed for street-level or building-specific assessments.
- the short observational record (2024–2026) limited the calculation of robust long-term return periods.

Efficiency and overall impact

Overall, the resources were used efficiently by combining the municipality's internal scientific, environmental, and policy experts with procured external technical support. The involvement of prof. Zoya Mateeva from Climate, Atmosphere and Water Research Institute, Bulgarian Academy of Science added additional scientific and legitimacy value to the assessments. To bypass the high costs and time required to generate primary local climate models from scratch, the team successfully downscaled freely available harmonized European datasets. The CRA process has had a clear positive impact on: institutional understanding of climate risks; stakeholder awareness and engagement and the readiness to apply science-based evidence in local climate planning.

The CRA has profoundly impacted Pomorie by shifting the institutional focus from retrospective, reactive emergency management to a forward-looking, scenario-based understanding of climate risk. It exposed critical gaps in public awareness (such as evacuation protocols) and clarified the true nature of local hazards. This scientifically backed evidence base is now positioned to drive urban planning, justify targeted adaptation investments, and secure funding to build long-term climate resilience.

2.6. Work plan Phase 3

The final phase aims to transfer the accumulated data and knowledge from the CRA into the policy-making processes of Pomorie Municipality. Phase 3 will aim to bridge the gap between climate risk knowledge and municipal governance by embedding the assessment results into local strategic frameworks.

Main Activities

Review and propose updates to municipal strategic documents: The team will revise core instruments, specifically the **Municipal Plan for Integrated Development** and the **Municipal Disaster Risk Reduction Program (2026–2030)**. This ensures that climate adaptation is not treated as a peripheral issue but is formally integrated into the municipality's primary planning and budgetary processes. One direction for updates to the strategic documents will be the framework for the Disaster Risk Reduction Program. The CRA categorized droughts and heatwaves as *Very High Priority*, while coastal flooding and heavy rainfall are defined as *High Priority*. The program should reflect these explicit priorities in planning and resource allocation and interaction with institutions, business and civil society.

Drafting a Climate Adaptation Strategy: This will be a dedicated document designed to provide a cohesive long-term vision for Pomorie. It will focus on actionable, evidence-based measures to address the hazards identified as "Very High" and "High" priority, such as droughts, heatwaves, coastal flooding, and heavy rainfall.

Final Conference and Presentation: This event will serve as a platform to disseminate project results to policymakers, the public, and relevant stakeholders, ensuring institutional uptake and community awareness.

Limitations

Phase 3 will focus exclusively on developing adaptation measures for the highest-priority risks based on hazard modelling or regionalised risk analysis undertaken in Phase 1 and 2. This focused scope will ensure efficient use of resources and allow the project to concentrate on climate adaptation policies for the most significant risks.

Further stakeholder involvement

The stakeholders, experts, and priority groups will be actively engaged also during Phase 3, particularly in the review of the municipal disaster risk reduction programme and, where relevant, other municipal strategic documents. The survey will be open for new respondents at the municipal website. Stakeholders will also be involved during the final project conference to establish further ownership, legitimacy, and policy relevance of the outcomes.

3. Conclusions Phase 2- Climate risk assessment

The primary objective of Phase 2 has been to advance Pomorie's Climate Risk Assessment (CRA) from a standalone Phase 1 coastal flooding focus into an integrated, forward-looking multi-hazard framework. This phase synthesizes localized empirical data, Copernicus/C3S climate projections, and stakeholder risk perceptions to establish an actionable baseline for municipal adaptation planning.

Challenges successfully addressed

Transition to Multi-Hazard Scope: Successfully expanded the municipal risk profile beyond coastal flooding to evaluate four additional interacting hazards: heavy rainfall, droughts, heatwaves, and windstorms.

Empirical Grounding of Global Models: Leveraged a local Obscape Level monitoring station (October 2024 – June 2026) to clip, reproject, and qualitatively validate coarse European-scale datasets against 30-minute real-time coastal observations.

Sectoral Integration: Contextualized climate impacts across Pomorie's highly sensitive economic pillars: recreational tourism, viticulture/agriculture, and the balneotherapy/salt production ecosystems of Lake Pomorie.

Challenges not fully addressed

The Direct economic damage estimation remains indicative; it relies on 12 km grid spacing (EURO-CORDEX) and generalized European depth-damage curves rather than localized building footprints or asset-level cadastral replacement costs. The 2024–2026 local station timeline is insufficient to calculate robust, long-term return periods for extreme weather anomalies. While general risk awareness is present, a critical breakdown in procedural preparedness exists—48.2% of surveyed stakeholders reported being entirely uninformed about municipal flood evacuation protocols.

Pomorie's capacity profile exhibits distinct strengths and systemic weak spots:

Financial Capacity: Constrained; municipal budgets effectively fund post-disaster response and routine maintenance but cannot support large-scale preventive climate-proofing without external funding streams (e.g., Horizon Europe, local and national budget).

Physical & Infrastructural Capacity: Strained by ageing, undersized stormwater drainage infrastructure and a lack of sewage networks in rural inland settlements. Over 60% of municipal and third-class roads remain in poor condition.

Human & Operational Capacity: Well-established reactive systems via the Unified Rescue System and active Volunteer Formations. However, a clear gap remains in integrating predictive, scenario-based forecasting into spatial urban planning.

Main findings

Drought and heatwaves have been identified as the highest priority climate risks for Pomorie Municipality. Both hazards combine substantial to critical severity, more action needed urgency, and only medium resilience capacity, indicating a strong need for near-term adaptation action. Coastal flooding and heavy rainfall represent a high-priority risk, characterised by moderate to substantial severity, widespread exposure, and, medium resilience capacity. Windstorms remain relevant with substantial severity and more actions needed but have been assessed as moderate level of risk priority due to relatively stronger existing capacity.

Heatwaves were also assigned a very high priority due to their significant impacts on human health, tourism, and energy and water demand, together with the projected increase in the frequency and duration of prolonged hot periods. Droughts received the highest priority due to their growing implications for water resources, agriculture, natural ecosystems, and their contribution to increased wildfire susceptibility.

The evaluation of resilience capacity demonstrated that Pomorie Municipality does not currently possess sufficient capacity to comprehensively address its escalating climate risks. While existing systems provide a functional baseline for managing episodic events, local institutional, infrastructural, and social capacities are increasingly strained by systemic climate risks.

Stakeholder engagement confirmed the practical relevance of the analytical findings, while also revealing gaps between risk awareness and preparedness, particularly regarding response measures and evacuation procedures.

Overall assessment

Overall, Phase 2 has achieved its objective of delivering a clear and relevant climate risk assessment for Pomorie Municipality. The combination of scientific evidence, local data and expertise, and stakeholder input resulted in a growing understanding of climate risks as immediate local problems and challenges, rather than abstract or distant threats.

Phase 2 provides a solid foundation for Phase 3 which will focus on operational policy implementation and climate-proofing actions and implement strategic Policy Integration: Review and revise the *Municipal Plan for Integrated Development 2021-2027* and update the *Municipal Disaster Risk Reduction Program* to embed forward-looking climate risk assessment into local governance. By drafting a Climate Adaptation Strategy the municipality will formulate concrete structural, non-structural, and nature-based adaptation options tailored to the high-priority risks identified in Phase 2 (e.g., urban shading, beach preservation, and drainage upgrades).

4. Progress evaluation

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
Minimum 1 workflow successfully applied on Deliverable 1 – by the end of month 6	Report on Deliverable 1 submitted on 5.9.2025
1 climate multirisk assessment report published – by the end of month 16	Multirisk report submitted on 30.06.2026
15 stakeholders involved in the activities of the project – by the end of month 22	In progress Kick-off meeting, Workshop 1 and 2 completed and stakeholders involved
20 000 residents, key local and regional authorities and stakeholders reached through awareness campaigns – by the end of month 22	In progress, publications in local and regional media
1 awareness-raising campaign conducted – by the end of month 22	In progress, media publications on workshop 1 and 2
4 articles in regional media mentioning the project	In progress, articles in regional media and on the municipal website
2 local workshops, one final conference and meetings conducted for decision-makers and stakeholders – meeting by the end of month 2, workshop on the adaptation and application – by mid-month 6, workshop with stakeholders – by the end of month 15, final conference – by the end of month 22	In progress, Workshop 1 and 2 completed
2 international workshops for sharing of experience and best practices – by mid-2025 and end of 2026	In progress, the international workshop in Barcelona attended
Municipal strategic documents regarding risk reduction, disaster and accidents management being revised – by the end of month 21	In progress

Table 4-2 Overview milestones

Milestones	*Progress*
M1: Successful Kick-off Meeting and Press Conference (Activity 1.1 and 1.3) – by the end of month 2 and end of month 5	Activity 1.1. completed in Month 5, Activity 1.3. completed in Month 6
M2: Completion of Inventory of potential hazards and policy context (Activity 1.2) – by the end of month 5	Activity 1.2. completed in Month 5

Milestones	*Progress*
M3: Workshop on CLIMAAX Framework Application (Activity 1.4) – by mid-month 6	Activity 1.4. completed in Month 6
M4: Completion of CLIMAAX Framework Application Report (Activity 1.5) – by the end of month 6	Activity 1.5. completed in Month 6
M5: Completion of Data Collection and Research for Multi-Risk Assessment (Activity 2.1) – by the end of month 14	Activity 2.1. completed in Month 15
M6: Stakeholder Workshop on Multi-Risk Assessment (Activity 2.2) – by the end of month 15	Activity 2.2. completed in Month 16
M7: Attend the CLIMAAX workshop held in Barcelona – by mid2025	Activity completed
M8: Submission of Multi-Risk Assessment Report (Activity 2.3) – by the end of month 16	Activity completed in Month 16
M9: Review and update of municipal strategic documents on climate risk, environmental and disaster management (Activity 3.1) – by the end of month 20	In progress
M10: Draft Climate Adaptation Strategy (Activity 3.2) – by the end of month 21	In progress
M11: Final Conference and presentation of project results (Activity 3.3) – by the end of month 22	In progress
M12: Attend the CLIMAAX workshop held in Brussels – by the end of 2026	Pending

5. Supporting documentation

- Main Report (PDF)
- Visual Outputs (infographics, maps, charts)

Annex 1 – Regionalized Risk Analysis
Annex 2 – Archive with CLIMAAX Jupyter Notebooks

- Publicity about the project:
    - ✓ Public invitation to the workshop for Deliverable 2: https://www.pomorie.bg/pokana-za-utchastie-v-seminar-po-proekt-vklimatitchno-inteligentno-pomorie-kartirane-na-ustoytchivo-badeshtev/
    - ✓ News on regional media: https://burgasmedia.com/news/klimatichno-inteligentno-pomorie-seminar-za-ustoychivo-badeshte-na-29-yuni?lang=bg

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ANNEX 1 - REGIONALISED RISK ANALYSIS FOR POMORIE MUNICIPALITY

The Phase 2 regionalised risk analysis builds on the Phase 1 coastal-flooding assessment and extends it by introducing a more locally grounded interpretation of hazard, exposure, vulnerability and potential impacts. While Phase 1 demonstrated the applicability of the CLIMAAX coastal-flooding workflow for Pomorie Municipality, Phase 2 focuses on fine-tuning the outputs to the specific territorial, socio-economic and institutional context of the municipality.

The selected workflow was regionalised through four complementary steps. First, the global coastal flood hazard maps were clipped and reprojected to the Pomorie area of interest, allowing a spatially explicit comparison between present-day and future flood potential. Second, the hazard layers were combined with European land-use and vulnerability data to estimate potential economic damage across different land-use classes. Third, the results were interpreted against local coastal morphology, critical assets and locally observed water-level variability. Fourth, the outputs were compared with national flood-risk information from the Preliminary Flood Risk Assessment for the Black Sea Basin District, which provides an official reference framework for past and potential future flood consequences.

This combination of CLIMAAX workflow outputs, local monitoring data and national flood-risk information makes the assessment more relevant for municipal decision-making. It also clarifies the limitations of the analysis: the results should be interpreted as a strategic risk-screening and prioritisation tool, not as a detailed engineering design or hydrodynamic flood model. The main value of the assessment is to identify exposed areas, vulnerable functions, likely impact pathways and priorities for more detailed follow-up work in Phase 3.

Indirect impacts were considered qualitatively. These include disruption of access to the peninsula and waterfront areas, interruptions of public services, effects on tourism and local businesses, pressure on emergency response, potential damage to water and wastewater infrastructure, salinisation or degradation of sensitive coastal and lagoon ecosystems, and increased social vulnerability among residents and visitors located in low-lying areas.

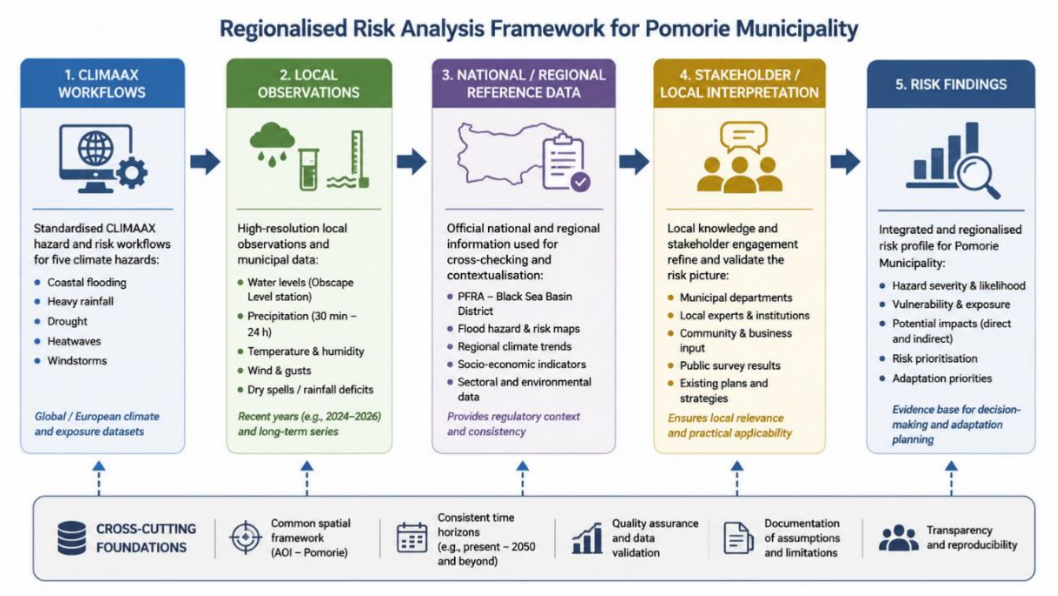


Figure A1. Regionalised Risk Analysis framework for Pomorie Municipality

1. Hazard #1 - Coastal Flooding - fine-tuning to local context

Coastal flooding was retained as one of the key climate hazards for Pomorie Municipality because of the municipality's geographical configuration and the concentration of population, tourism infrastructure, cultural assets and economic activity in low-lying coastal areas. Pomorie town is located on a narrow peninsula connected to the mainland by a low-lying isthmus and bordered by the Black Sea and Pomorie Lake. This makes the local risk profile different from inland flood-risk areas: even moderate sea-level anomalies, when combined with storm surge, low atmospheric pressure and persistent onshore winds, may affect waterfront zones, beaches, transport access, tourism facilities and sensitive lagoon environments.

The Phase 2 fine-tuning of the flood workflow therefore focused on moving from a general map of coastal flood potential to a more locally meaningful interpretation of how coastal water-level extremes interact with topography, land use, infrastructure and economic exposure. The hazard was assessed through global coastal flood maps and water-level statistics, while the local interpretation was strengthened through short-term high-resolution water-level observations from Pomorie and through the national PFRA framework for past and future flood consequences.

Figure A1-1. Pomorie coastal-flooding area of interest and main exposed coastal zones

Table A1-1. Data overview workflow #1

Hazard data	***Vulnerability data***	***Exposure data***	***Impact metrics/Risk output***
Deltares Global Flood Maps accessed through the Microsoft Planetary Computer. The dataset provides coastal flood-depth rasters for present-day climate, represented by ca. 2018, and future climate in 2050 under RCP8.5. Available return periods include 2, 5, 10, 25, 50, 100 and 250 years. For the Pomorie workflow, the data were clipped to the municipality area of interest and reprojected to EPSG:3035.	JRC depth-damage curves for land-use damage classes, including residential, commercial, industrial, agricultural, transport and road/infrastructure categories. The LUISA damage information file was adapted using Bulgaria-specific GDP/capita input to support indicative economic damage estimation.	JRC LUISA land-use data for Europe, 2018, at 100 m resolution, clipped to the Pomorie area of interest. Land-use classes include urban areas, commercial and industrial land, agricultural land, natural areas, infrastructure and water bodies.	Flood-depth maps and flood-extent maps for selected scenarios and return periods; indicative damage maps; estimated potential economic damage by land-use class; identification of coastal flood-risk hotspots.
Copernicus Climate Data Store / GTSMv3.0-based water-level time series and statistics, including modelled extreme water levels for the 5-year and 100-year return periods.	National PFRA criteria and thresholds for evaluating significant adverse flood consequences across human health, economic activity, environment and cultural heritage. These were used as a qualitative cross-check, not as a direct replacement of the CLIMAAX risk workflow.	Local contextual exposure: Pomorie Old Town waterfront, northern beach area, Sunset Resort coastal sector, low-lying isthmus, road access to the peninsula, coastal promenades, port and tourist infrastructure, salinas, Pomorie Lake and adjacent lagoon/wetland areas.	Local interpretation of likely exposed assets and functions; qualitative assessment of indirect impacts, including disruption of access, public services, tourism, emergency response, water/wastewater systems and ecosystem services.
Local Obscape Level monitoring station in Pomorie, providing 30-minute water-level and	Local vulnerability factors: low elevation, micro-topographic variability,	Local topographic interpretation based on digital elevation information and supplementary Google	Additional local hazard indicators: high water-level threshold ≥0.30 m, very high water-level threshold ≥0.50 m,

Hazard data	***Vulnerability data***	***Exposure data***	***Impact metrics/Risk output***
atmospheric-pressure observations for the period 04 October 2024 – 05 May 2026, complemented by wind speed, wind gust and wind-direction observations from a nearby automatic weather station.	concentration of tourism and public infrastructure in coastal zones, exposure of vulnerable groups and seasonal visitor population, dependence of local economy on beach and coastal assets.	Earth review. Several coastal sectors are approximately 0–1 m above sea level, while central urban areas are generally around 2–4 m above sea level.	number of high-water observations and affected days, maximum observed water level, relationship with low atmospheric pressure and NE/E wind directions.
Future climate condition: 2050 coastal flood maps under RCP8.5 and sea-level-rise contribution included in the global flood maps. Sea-level rise is also assessed through IPCC AR6 / NASA sea-level projection tools.	Future vulnerability condition: no detailed local dynamic vulnerability model was available for 2050. Vulnerability was therefore interpreted using present-day damage functions and local knowledge of exposed sectors.	Future socio-economic condition: no high-resolution local future population, building, cadastral or land-use projection was applied in this iteration. Current land use and existing critical assets were used as the baseline exposure layer, with qualitative consideration of continued coastal tourism and infrastructure concentration.	Future risk output: comparison of present-day and 2050 flood potential; identification of areas where current exposure could translate into increasing future risk under sea-level rise and more frequent/intense coastal storms.

1.1. Hazard assessment

The coastal-flooding hazard assessment was based on two complementary approaches: the CLIMAAX global coastal flood workflow and additional local water-level analysis.

The CLIMAAX workflow uses the Deltares Global Flood Maps dataset, which represents coastal flood potential under extreme sea-water levels. The dataset includes present-day flood maps and 2050 flood maps under a high-emission RCP8.5 scenario. The flood maps are based on global modelling of tides, storm surges and sea-level rise and provide water-depth estimates for different return periods. For Pomorie, the relevant raster layers were clipped to the local area of interest and reprojected to the European projected coordinate system in order to support spatial analysis and map production.

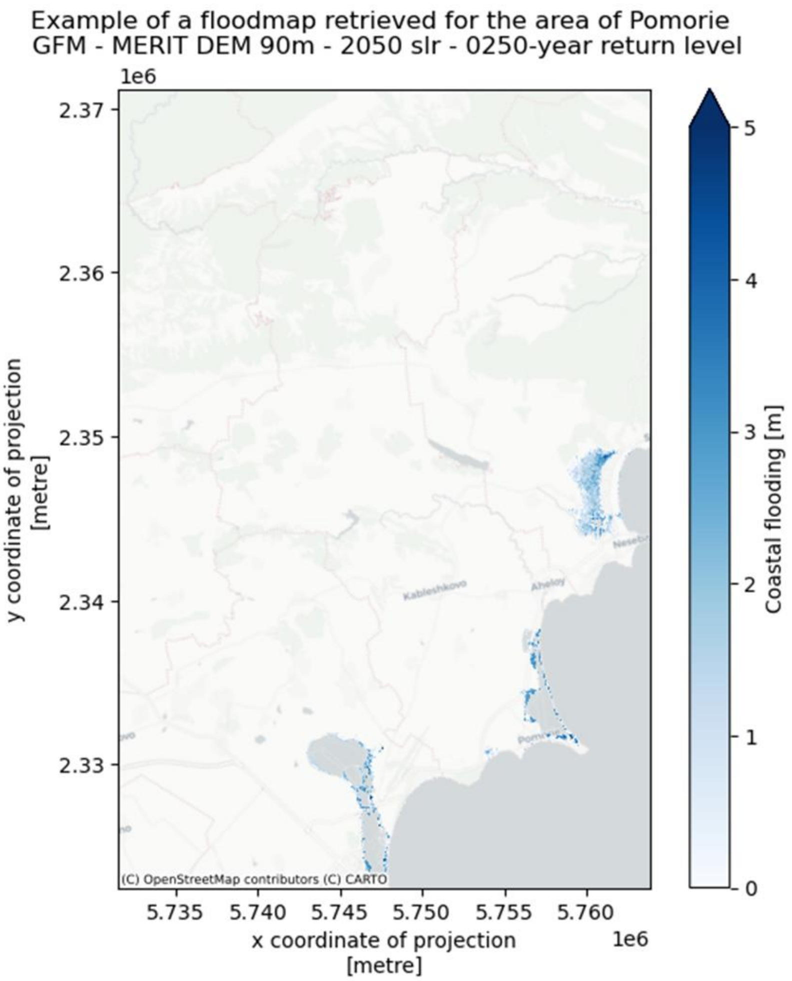


Figure A1-2. Coastal flood hazard map for Pomorie under present-day climate conditions
Source: CLIMAAX coastal flooding hazard workflow based on Deltares Global Flood Maps.

The global maps indicate that coastal flood potential is concentrated in the lowest coastal sectors and around areas where low elevation coincides with direct exposure to the sea, Pomorie Lake or the lagoon system. The main areas requiring attention are the Pomorie peninsula and waterfront, the low-lying isthmus connecting the town to the mainland, the northern beach sector, the coastal zone near large tourist complexes, the area around Pomorie Lake and the low-lying coastal and agricultural zones in the wider municipality. These areas are relevant not only because of possible water depth, but also because of the concentration of economic, transport, tourism and ecological assets.

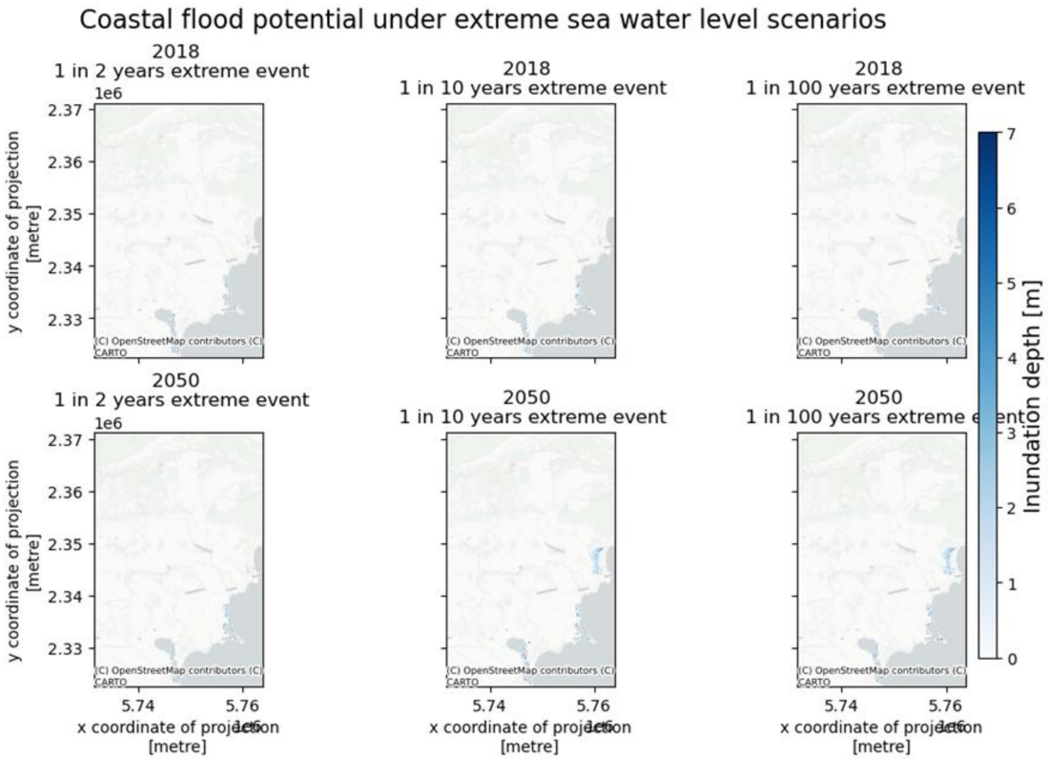
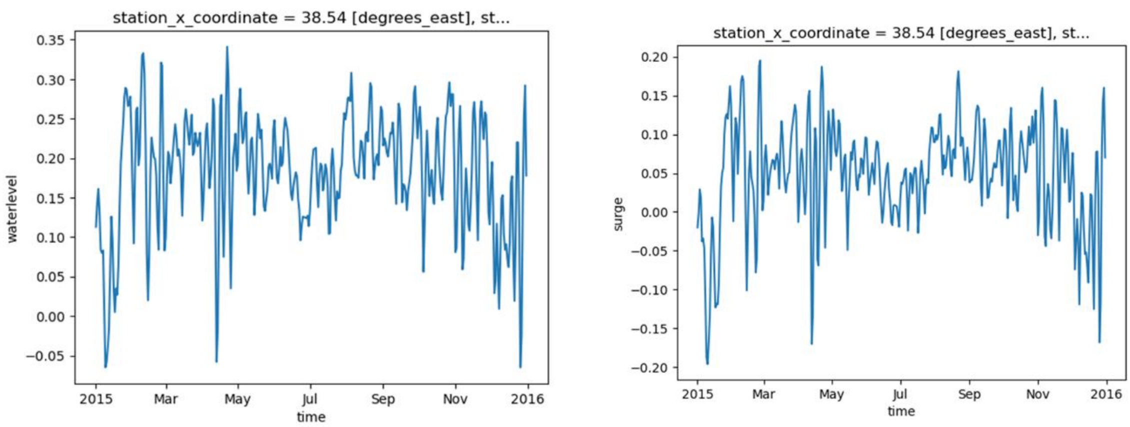


Figure A1-3. Comparison of modelled coastal flood potential in Pomorie for present-day and 2050 RCP8.5 conditions

Source: CLIMAAX coastal flooding hazard workflow based on Deltares Global Flood Maps.

The water-level and sea-level-rise notebook provided additional context for local coastal water levels. Based on modelled water-level statistics from the Copernicus Climate Data Store, extreme water levels for the 5-year return period are estimated at approximately 0.4 m above mean sea level, while the 100-year return period is estimated at approximately 0.5 m above mean sea level. These values should be interpreted cautiously, as the underlying global model has limited capacity to represent all local characteristics of the Pomorie coastal system, including the semi-enclosed configuration, local bathymetry, coastal structures and lagoon interactions.



Figures A1-4. Modelled daily maximum water levels and surge levels near Pomorie
Source: CLIMAAX coastal water-level and sea-level-rise workflow based on Copernicus Climate Data Store / GTSMv3.0 data.

The local Obscape Level monitoring analysis provides important regionalisation of the hazard assessment. Unlike temperature and precipitation hazards, long-term local coastal water-level records are not available for Pomorie. Therefore, the local analysis used high-resolution observations from the Obscape Level station for the period 04 October 2024 – 05 May 2026. The station records water level and atmospheric pressure at 30-minute intervals, while complementary wind observations were obtained from a nearby automatic station.

The local observations are expressed relative to a local reference level established during station installation, not relative to an absolute geodetic datum. For this reason, the results are used to assess relative water-level variability and short-term positive anomalies rather than absolute inundation depth. Within the analysed period, the water-level dataset included 26,223 observations. The mean water-level indicator was -0.079 m, the median was -0.084 m, and the maximum recorded value reached 1.728 m above the local reference level.

A threshold-based approach was applied to identify potentially hazardous water-level conditions. High water-level conditions were defined as observations equal to or exceeding 0.30 m, corresponding approximately to the upper 1% of the observed distribution. Very high water-level conditions were defined as observations equal to or exceeding 0.50 m. Using these thresholds, 260 high-water observations were identified, representing approximately 0.99% of all observations and occurring on 46 individual days. Very high water-level conditions were rarer: 96 observations exceeded 0.50 m, representing approximately 0.37% of the full record and occurring on 17 individual days. This confirms that extreme positive water-level anomalies are relatively rare but potentially significant when they occur.

Coastal Water-Level Variability and Flooding Potential in the Pomorie Area Based on Local Observations

Coastal flooding represents one of the most important climate-related hazards affecting low-lying coastal environments worldwide. Elevated sea levels associated with atmospheric depressions, storm surges and persistent onshore winds may cause temporary inundation of coastal areas, damage to infrastructure, disruption of economic activities and increased risks to public safety. The severity of coastal-flooding impacts depends not only on the magnitude of sea-level rise but also on local topography, shoreline configuration and exposure of vulnerable assets.

In the case of Pomorie, coastal-flooding hazard is of particular interest due to the municipality's unique geographical setting. The town is situated on a narrow peninsula extending into the Black Sea and connected to the mainland by a low-lying isthmus. In addition, substantial parts of the surrounding coastal zone are characterised by very low elevations and proximity to both the sea and Pomorie Lake (Figure 1). These conditions increase the potential sensitivity of the area to elevated water levels and storm-induced coastal inundation.

Unlike the analyses of precipitation and temperature-related hazards, long-term observational records of coastal water levels are not available for the study area. Consequently, the present assessment is based on high-resolution observations obtained from the Obscape Level monitoring station located in the immediate coastal zone of Pomorie. The station provides water-level and atmospheric-pressure measurements at 30-minute intervals for the period 04, October 2024 – 05, May 2026. Complementary meteorological observations, including wind speed, wind gusts and wind direction, were obtained from the nearby automatic weather station operating within the same monitoring network.

Water-level observations represent deviations from a predefined local reference level established during station installation. Consequently, both positive and negative values occur within the dataset, reflecting fluctuations above and below the selected reference datum rather than absolute elevations relative to mean sea level. For the purposes of hazard assessment, the analysis focuses on relative water-level variability and the occurrence of extreme positive water-level anomalies.

To ensure consistency with the analyses of other climate hazards presented in this study, the water-level record was analysed using a threshold-based approach. High water-level conditions were defined as observations equal to or exceeding 0.30 m, corresponding approximately to the upper 1% of the observed distribution. Very high water-level conditions were defined using a threshold of 0.50 m. A water-level episode was defined as a sequence of one or more consecutive 30-minute observations meeting or exceeding the selected threshold. Consecutive observations were merged into a single episode, allowing assessment of both event frequency and duration.

The analysis examines the statistical characteristics of the water-level record, the relationship between water levels and atmospheric pressure, the frequency and duration of high-water events, and the influence of wind speed and wind direction on the occurrence of elevated sea levels. Finally, the observed hazard characteristics are evaluated in relation to the local topographic setting in order to assess exposure and vulnerability to coastal flooding in the Pomorie area.

Water-Level Characteristics

The statistical characteristics and percentile distribution of the observed water-level series are presented in Tables 1 and 2. The analysed dataset covers the period from 4 October 2024 to 5 May 2026 and contains water-level observations recorded at 30-minute intervals by the Obscape Level monitoring station located within the coastal zone of Pomorie.

Table A1-2. Descriptive Statistics of Water Level

Statistic	Water Level Indicator (m)
Number of observations	26223
Mean	-0.079
Median	-0.084
Standard deviation	0.237
Minimum	-2.789
25th percentile	-0.147
75th percentile	-0.001
95th percentile	0.161
99th percentile	0.297
Maximum	1.728

Table A1-3. Water-Level Classes

Water Level Class (m)	Observations (number)
< -0.50	269
-0.50 to -0.25	932
-0.25 to 0.00	18511
0.00 to 0.25	6079
0.25 to 0.50	336
> 0.50	96

The observed water-level record exhibits substantial short-term variability around the local reference level used by the monitoring system. Both positive and negative values occur throughout the observation period, indicating fluctuations above and below the selected reference datum. Such behaviour is typical for coastal water-level records and reflects the combined influence of atmospheric pressure variations, wind forcing, wave setup and other meteorological and oceanographic processes affecting the nearshore environment.

The distribution of water-level values is strongly concentrated around the central part of the observed range, while extreme positive values occur relatively infrequently (Table 2). This pattern indicates that elevated water levels represent rare events rather than a persistent feature of the local hydrometeorological regime. The upper tail of the distribution is particularly important from a hazard-assessment perspective because it contains the events most likely to contribute to coastal flooding.

To identify potentially hazardous conditions, percentile-based thresholds were derived from the empirical distribution of observed water levels. The threshold of 0.30 m corresponds approximately to the upper 1% of all observations (Table 2) and was therefore adopted as the criterion for defining High Water Level conditions. A second threshold of 0.50 m was selected to identify Very High Water Level conditions representing substantially more extreme departures from normal water-level variability (Table 2).

The statistical analysis confirms that observations exceeding these thresholds constitute only a small fraction of the total record (Tables 1 and 2), highlighting the rarity of extreme water-level conditions in the analysed period. Nevertheless, the occurrence of such events demonstrates that substantial short-term increases in water level are possible within the coastal zone of Pomorie and therefore warrant further investigation of their frequency, duration and controlling meteorological factors.

The selected threshold-based approach provides a consistent framework for analysing coastal-flooding hazard and facilitates direct comparison with the methodology applied to other climate-related hazards examined in this study. In the following sections, the identified high-water events are analysed in relation to atmospheric pressure, wind conditions and local exposure characteristics in order to evaluate the potential for coastal flooding in the Pomorie area.

Atmospheric Pressure and Water Level

The relationship between atmospheric pressure and observed water-level conditions is summarized in Table 3. Atmospheric pressure is one of the primary meteorological factors influencing short-term sea-level variability through the inverse barometer effect, whereby reductions in atmospheric pressure are generally associated with increases in sea level.

The analysis reveals a clear tendency for elevated water levels to occur during periods of reduced atmospheric pressure. The highest mean water level was observed within the lowest pressure class (<1005 hPa), where the average water level reached 0.170 m. This category also exhibited the highest maximum recorded water level (1.727 m) and the highest 95th percentile value (1.629 m), substantially exceeding the corresponding values observed under higher-pressure conditions (Table 3).

Table A1-4. Relationship between Atmospheric Pressure and Water Level

Atmospheric Pressure (hPa)	Number of observations	Mean Water Level (m)	Maximum Water Level (m)	P95 Water Level (m)
<1005	700	**0.170**	**1.727**	**1.629**
1005–1010	1211	-0.012	1.650	0.222
1010–1015	3573	-0.139	1.183	0.146
1015–1020	5026	-0.094	0.777	0.148
>1020	11926	-0.068	0.639	0.154

In contrast, pressure classes above 1010 hPa were generally associated with negative mean water-level anomalies and considerably lower extreme values. Although occasional high-water observations were recorded under higher-pressure conditions, the magnitude and frequency of extreme water levels were noticeably reduced compared with low-pressure situations.

Interestingly, the overall linear correlation between atmospheric pressure and water level was found to be very weak. This apparent contradiction reflects the highly episodic nature of extreme water-level events. Most observations correspond to normal conditions characterized by relatively small fluctuations around the reference level, whereas the most important water-level extremes are concentrated within a comparatively small number of low-pressure situations. Consequently, pressure-related effects become most evident when examining the upper part of the water-level distribution rather than the complete observational record.

These results indicate that atmospheric depressions play an important role in the generation of elevated water levels in the Pomorie coastal zone. Although atmospheric pressure alone cannot fully explain observed water-level variability, periods of reduced pressure create favourable conditions for the occurrence of extreme water-level events and therefore represent an important contributing factor to coastal-flooding hazard.

High Water-Level Events

The frequency of high and very high water-level conditions is presented in Table 4. Using the threshold values established from the percentile analysis (Table 2), observations equal to or exceeding 0.30 m were classified as High Water Level events, while observations equal to or exceeding 0.50 m were classified as Very High Water Level events.

The results indicate that high water-level conditions were relatively uncommon during the analysed period. A total of 260 observations exceeded the 0.30 m threshold, representing approximately 0.99% of all available measurements. These observations were distributed across 46 individual days, demonstrating that elevated water levels occurred only occasionally despite the coastal location of the monitoring site (Table 4).

Table A1-5. Frequency of High and Very High Water-Level Events

Indicator	High Water Level (≥0.30 m)	Very High Water Level (≥0.50 m)
Number of observations	**260**	**96**
Percentage of all observations	**0.99%**	**0.37%**
Number of affected days	**46**	**17**
Maximum water level (m)	**1.728**	**1.728**
Mean water level during events (m)	**0.746**	**1.406**
95th percentile (m)	**1.650**	**1.695**

Very high water-level conditions were considerably rarer. Only 96 observations exceeded the 0.50 m threshold, corresponding to approximately 0.37% of the complete record. These observations occurred during 17 individual days, indicating that the most extreme water-level conditions were concentrated within a limited number of events (Table 4).

An important characteristic of both categories is the large difference between threshold values and observed maxima. The maximum recorded water level reached 1.728 m, greatly exceeding both threshold levels. Furthermore, the mean water level during High Water Level events reached 0.746 m, while the corresponding mean during Very High Water Level events reached 1.406 m. This finding indicates that once elevated water-level conditions develop, water levels frequently rise substantially above the minimum threshold used for event identification.

The rarity of observations exceeding 0.30 m and 0.50 m confirms that these thresholds successfully isolate the most significant positive water-level anomalies within the observational record. At the same time, the magnitude of the recorded extremes demonstrates that substantial short-term increases in coastal water level are possible in the Pomorie area. Such events, although infrequent, represent the water-level conditions most relevant to coastal-flooding hazard assessment.

Water-Level Episodes

While the frequency analysis presented in Table 4 provides information on the occurrence of elevated water levels, the duration and persistence of such events are equally important from a coastal-flooding perspective. Short-lived peaks may have limited practical consequences, whereas prolonged periods of elevated water level increase the likelihood of inundation, shoreline erosion and disruption of coastal activities. To address this aspect, consecutive observations exceeding the selected thresholds were merged into individual water-level episodes, and their duration characteristics were analysed (Table 5).

A total of 148 High Water Level episodes (≥0.30 m) were identified during the observation period (Table 5). Collectively, these episodes accounted for 130 hours of elevated water-level conditions and affected 46 individual days. The shortest episodes lasted a single 30-minute observation interval (0.5 h), while the longest persisted for 12 hours. The mean episode duration reached 0.88 hours, whereas the median duration remained 0.5 hours, indicating that most events were relatively short-lived and that the overall average was influenced by a limited number of longer-lasting episodes.

Table A1-6. Water-Level Episodes

Indicator	≥ 0.30 m	≥ 0.50 m
Number of episodes	**148**	**29**
Shortest duration (h)	**0.5**	**0.5**
Longest duration (h)	**12.0**	**12.0**
Mean duration (h)	**0.88**	**1.66**
Median duration (h)	**0.5**	**0.5**
Total duration (h)	**130.0**	**48.0**
Number of affected days	**46**	**17**

Episodes exceeding the higher threshold of 0.50 m were considerably less frequent. Only 29 Very High Water Level episodes were identified throughout the entire record, affecting 17 individual days and accounting for a cumulative duration of 48 hours (Table 5). As in the previous category, the shortest episode lasted 0.5 hours and the longest reached 12 hours. However, the mean duration increased to 1.66 hours, almost twice the value observed for the ≥0.30 m category.

The difference in mean duration between the two thresholds is particularly noteworthy. Although very high water-level conditions occurred much less frequently, they tended to persist longer once established. This suggests that the most extreme water-level events are not merely isolated short-term spikes but may represent more organised hydrometeorological situations capable of maintaining elevated sea levels over extended periods.

The predominance of short episodes is further reflected by the median duration of 0.5 hours for both threshold categories, indicating that more than half of all identified episodes consisted of only a single observation interval. Nevertheless, the occurrence of events lasting several hours and, in exceptional cases, up to 12 hours demonstrates that prolonged high-water conditions are possible in the Pomorie coastal zone. Such persistent episodes are likely to represent the greatest coastal-flooding concern because they allow elevated water levels to act over longer periods and may coincide with additional forcing factors such as low atmospheric pressure and onshore winds.

Overall, the episode analysis indicates that extreme water levels in Pomorie are characterised by a combination of rarity and episodic persistence. Most events are brief and localized in time, but a small number of longer-lasting episodes account for a disproportionate share of the total duration of elevated water-level conditions. These events therefore warrant particular attention in subsequent analyses of meteorological controls and coastal-flooding hazard.

Water Level and Wind Conditions

Wind forcing is widely recognised as one of the principal mechanisms controlling short-term coastal water-level variability. Depending on shoreline orientation and local coastal geometry, persistent winds may either promote the accumulation of water along the coast or facilitate offshore water transport. To evaluate the role of wind conditions in the generation of elevated water levels in Pomorie, water-level observations were analysed in relation to wind speed and wind direction (Tables 6–8).

The relationship between wind speed and water level is summarised in Table 6. Contrary to what might be expected, the highest observed water levels were not consistently associated with the strongest winds. Maximum water levels exceeding 1.7 m occurred predominantly during periods characterised by low to moderate wind speeds, while observations associated with wind speeds exceeding 10 m/s were comparatively rare. This finding suggests that wind speed alone cannot adequately explain the occurrence of extreme water-level events in the study area.

Table A1-7. Relationship between Wind Speed and Water Level

Wind Speed Class (m/s)	Number of Observations	Mean Water Level (m)
<5	17302	-0.08
5–10	8228	-0.09
10–15	451	-0.08
15–20	2	0.19
≥20	0	–

A more distinct pattern emerges when wind direction is considered (Table 7). Northeasterly and easterly winds were associated with the highest maximum water levels and with a substantial proportion of both High Water Level and Very High Water Level observations. The highest recorded water level of the entire observational period (1.727 m) occurred under northeasterly wind conditions, while easterly winds were associated with the highest number of Very High Water Level observations. These results are physically consistent with the geographical configuration of Pomorie, where winds blowing from the Black Sea toward the coast favour onshore water transport and coastal water accumulation.

The directional analysis also reveals notable contrasts between wind sectors. Southerly winds were associated with very few elevated water-level observations, whereas northeasterly and easterly winds contributed disproportionately to the occurrence of extreme water levels. This contrast indicates that the effectiveness of wind forcing depends strongly on wind orientation relative to the coastline rather than on wind speed alone.

Table A1-8. Relationship between Wind Direction and Water Level

Wind Direction	Number of Observations	Mean Water Level (m)	Maximum Water Level (m)	Number of Observations with High Water Levels (≥0.30 m)	Number of Observations with Very High Water Levels (≥0.50 m)
N	608	-0.030	1.718	16	14
NE	2791	**-0.004**	**1.727**	55	13
E	6104	-0.077	1.686	49	21

SE	1430	-0.130	1.728	7	5
S	693	-0.105	0.330	1	0
SW	1097	-0.141	1.649	8	5
W	7108	-0.126	1.653	32	19
NW	6380	-0.059	1.653	**92**	19

The combined analysis of high water levels, wind speed and wind direction further strengthens this interpretation (Table 8). Of the 260 High Water Level observations identified during the study period, 107 occurred under northeasterly or easterly winds, representing more than 40% of all high-water observations. In comparison, only 23 observations coincided with strong winds exceeding 10 m/s. A similar pattern was observed for Very High Water Level conditions, where nearly 40% of all observations occurred during northeasterly or easterly winds, whereas only a very small fraction was associated with strong winds.

Table A1-9. Coincidence of High Water Levels, Strong Winds and NE/E Wind Directions

Indicator	Number of Observations
High Water Levels (≥0.30 m)	**260**
High Water Levels + Strong Wind (≥10 m/s)	**23**
High Water Levels + NE Wind	**55**
High Water Levels + E Wind	**49**
High Water Levels + NE/E Wind	**107**
High Water Levels + Strong NE/E Wind	**21**
Very High Water Levels (≥0.50 m)	**96**
Very High Water Levels + Strong Wind (≥10 m/s)	**3**
Very High Water Levels + NE/E Wind	**38**
Very High Water Levels + Strong NE/E Wind	**3**

Particularly noteworthy is the fact that almost all High Water Level observations occurring during strong-wind conditions were associated with northeasterly or easterly airflow. This result indicates that wind direction acts as the primary controlling factor, while wind speed becomes important mainly when combined with a favourable onshore orientation. Consequently, the most hazardous coastal-flooding situations are likely to develop not simply during periods of strong wind, but during episodes when elevated water levels coincide with persistent winds from the northeastern and eastern sectors.

Taken together, the results demonstrate that wind direction exerts a stronger influence on extreme coastal water levels than wind speed alone. The observed dominance of northeasterly and easterly winds provides a physically plausible explanation for the occurrence of elevated water levels in the Pomorie coastal zone and highlights the importance of onshore wind forcing as a key mechanism contributing to coastal-flooding hazard.

Although the observation period remains relatively short, the consistency of the observed relationships provides strong evidence that onshore wind forcing represents an important driver of elevated water levels in the Pomorie coastal zone.

These findings provide the basis for evaluating the exposure and vulnerability of the municipality to coastal flooding under extreme meteorological conditions.

Exposure and Vulnerability of Pomorie to Coastal Flooding

The potential impacts of coastal flooding in Pomorie are strongly influenced by the physical-geographical characteristics of the municipality and, in particular, by the exceptionally low elevation of substantial parts of the coastal zone. Unlike many other sections of the Bulgarian Black Sea coast, Pomorie is situated on a narrow peninsula connected to the mainland by a low-lying isthmus and bordered by both the Black Sea and Pomorie Lake. This geographical setting increases the exposure of the municipality to elevated sea levels and storm-driven coastal water accumulation.

A review of local topographic conditions based on digital elevation data and supplementary assessment using Google Earth indicates that several coastal sectors are situated at elevations close to mean sea level. Along parts of the Old Town waterfront, the northern beach area and sections of the coastal zone near the Sunset Resort complex, elevations generally range between approximately 0 and 1 m above sea level, while locally depressed areas may even occur slightly below sea level. In contrast, elevations in the central urban area are generally between 2 and 4 m above sea level, reaching approximately 3 m around St. George Monastery. The local relief is characterised by pronounced micro-topographic variability, with slightly elevated coastal ridges alternating with lower inland depressions, resulting in a spatially heterogeneous pattern of potential flood susceptibility.

The analysis of observed water-level conditions demonstrates that the maximum recorded water level during the monitoring period reached 1.728 m above the local reference level. Furthermore, high water-level events were shown to occur preferentially during periods of low atmospheric pressure and under easterly and northeasterly winds, which promote onshore water accumulation along the exposed coastal sector. Although most high-water events were relatively short-lived, individual episodes persisted for up to 12 hours, increasing the potential for local inundation in particularly vulnerable low-lying areas.

The comparison between observed water-level extremes and local topographic conditions suggests that several coastal sectors may be exposed to temporary flooding during extreme meteorological and oceanographic conditions. The highest exposure is expected along low-lying coastal areas, beaches, waterfront promenades, and sectors adjacent to Pomorie Lake and the coastal lagoon system. Due to the highly irregular micro-topography of the area, potential flooding is likely to be spatially localized rather than uniformly distributed across the municipality.

Overall, the results indicate that the coastal-flooding hazard in Pomorie is governed by the combined effects of elevated sea levels, low atmospheric pressure, and persistent onshore winds. While the relatively short observation period does not permit estimation of long-term return periods, the recorded events demonstrate that local topographic conditions create a measurable degree of exposure and vulnerability to episodic coastal flooding. Future assessments would benefit from longer observational records, high-resolution topographic models, and detailed flood-inundation mapping to support more comprehensive risk evaluation and adaptation planning. The findings contribute to a better understanding of coastal-flooding processes in the Pomorie area and may support future climate-risk assessment and adaptation efforts at the local level.

The local analysis also showed that elevated water levels in Pomorie are associated with specific meteorological conditions. Low atmospheric pressure plays an important role: the highest mean water level and the highest observed extremes occurred during pressure conditions below 1005 hPa. However, pressure alone does not explain the full variability. Wind direction was found to be particularly important. Northeasterly and easterly winds were strongly associated with high-water observations, indicating that persistent onshore wind forcing is a key driver of elevated water levels in the Pomorie coastal zone. More than 40% of all high-water observations occurred under NE/E winds. Strong wind speed alone was less explanatory; its significance increased mainly when combined with favourable onshore wind direction.

The local topographic interpretation further supports the hazard relevance. Several areas along the Old Town waterfront, the northern beach area and the coastal zone near the Sunset Resort complex are located at approximately 0–1 m above sea level, with some locally depressed areas possibly slightly below sea level. By contrast, the central urban area is generally higher, around 2–4 m above sea level, with local elevations around St. George Monastery reaching approximately 3 m. This means that coastal flooding is unlikely to affect the municipality uniformly. Instead, flood susceptibility is expected to be highly localised, depending on the combination of water level, wave action, wind direction, micro-topography and the presence or absence of local protective or drainage structures.

The main limitation of the hazard assessment is that the global coastal flood maps do not fully account for local coastal defences, small-scale drainage systems, local topographic barriers, detailed bathymetry or the hydraulic interaction between the sea, the lake and the lagoon system. The local water-level record is also too short to derive robust long-term return periods. Nevertheless, the local monitoring data provide valuable evidence of the mechanisms that can lead to elevated water levels and therefore help to interpret the global workflow results in a more realistic way.

1.2. Risk assessment

The flood-risk assessment combines the coastal flood hazard layers with exposure and vulnerability information. In the CLIMAAX workflow, the main exposure layer is the JRC LUISA land-use dataset for 2018 at 100 m resolution, clipped to the Pomorie area of interest. This dataset identifies the spatial distribution of urban areas, commercial and industrial land, agricultural land, natural areas, infrastructure and water bodies. The vulnerability component is represented by JRC depth-damage curves, which assign damage ratios to different land-use and infrastructure classes depending on flood depth. The damage curves were adapted using Bulgaria-specific economic input, including GDP/capita, in order to obtain indicative economic damage estimates.

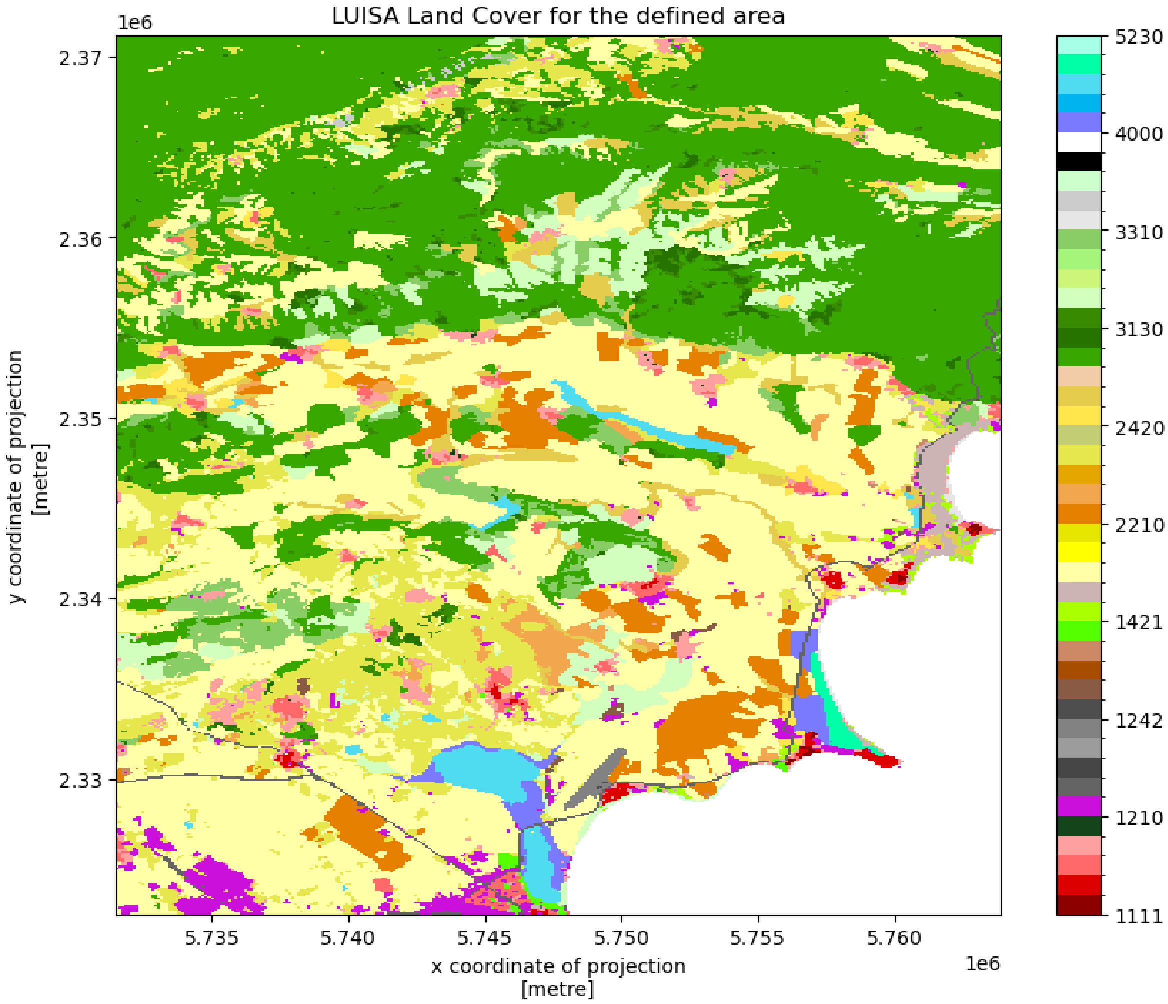


Figure A1-7. LUISA land-use exposure map for the Pomorie coastal flood-risk assessment
Source: CLIMAAX coastal flood risk workflow, based on JRC LUISA 2018 land-use data clipped to the Pomorie area of interest.

The risk output is therefore not only a map of where water may occur, but a combined view of where flood water overlaps with exposed and vulnerable land uses. This distinction is important for Pomorie. The highest economic risk does not necessarily occur where modelled flood depth is greatest, but where inundation intersects with high-value and highly functional assets, such as hotels, waterfront commercial areas, residential zones, transport links, public infrastructure, tourism facilities and coastal services.

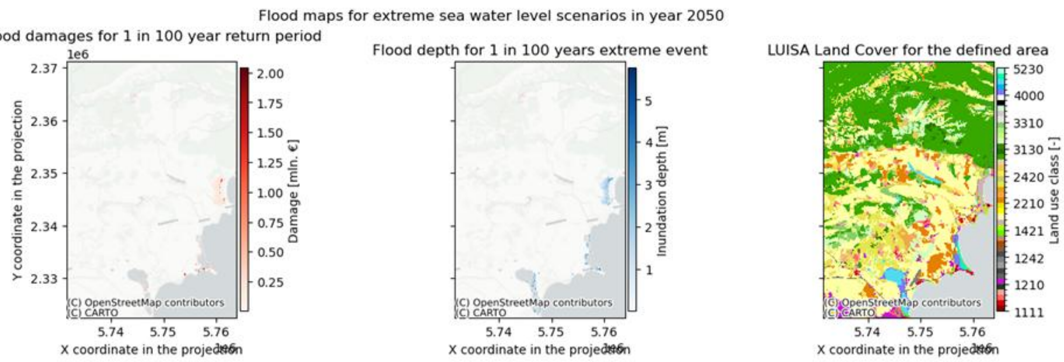


Figure A1-8. Combined view of flood depth and exposed land use for a selected coastal flood scenario *Source: CLIMAAX coastal flood risk workflow, combining Global Flood Maps and LUISA land-use data.*

The workflow results indicate several priority risk zones. First, the Pomorie town peninsula and adjacent waterfront areas are important because of the concentration of residents, visitors, cultural and public functions, businesses and transport access. Flooding in this zone may have direct physical impacts, but also indirect impacts through access disruption, emergency response constraints and interruption of commercial and tourism activities. Second, the low-lying isthmus and road connections are critical because they support access between the peninsula, the mainland and surrounding settlements. Third, coastal tourism infrastructure and beach-related assets are economically sensitive, particularly during the tourism season. Fourth, Pomorie Lake, the salinas and associated lagoon/wetland areas are environmentally and economically important and may be affected by changes in water level, salinity, erosion, sediment dynamics and contamination pathways during flood events.

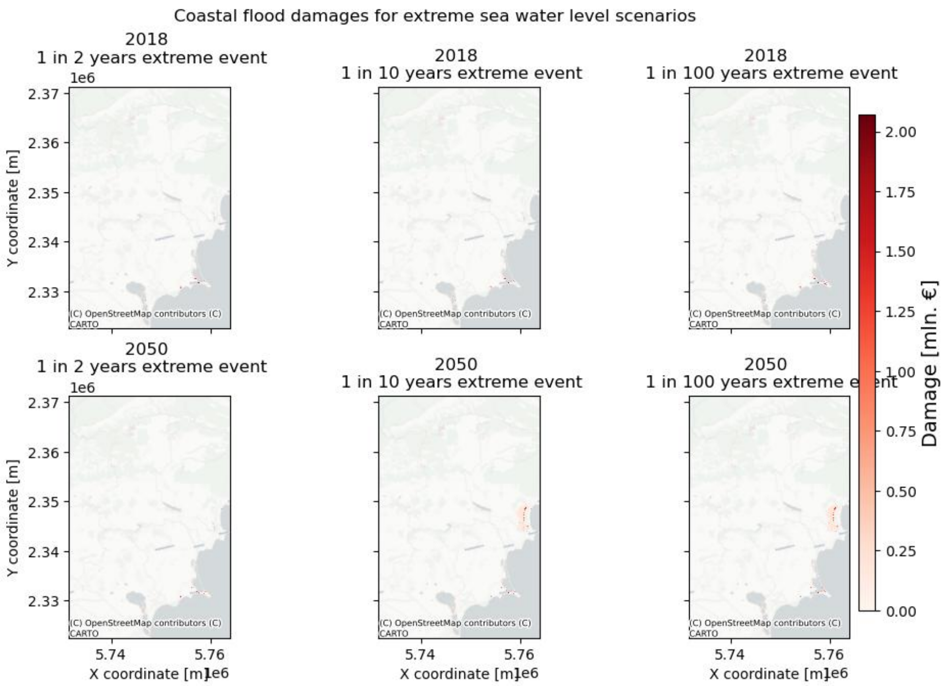


Figure A1-9. Indicative coastal flood damage map for Pomorie under selected scenario *Source: CLIMAAX coastal flood risk workflow, DamageScanner calculation based on flood depth, LUISA exposure and JRC damage curves.*

The risk analysis also considered indirect impacts. For the population, flooding may limit access to emergency medical services, disrupt evacuation routes and increase the exposure of elderly people, people with disabilities, sick individuals, pregnant women, children and tourists unfamiliar with local risk conditions. For the economy, the most relevant indirect effects include temporary loss of tourism revenue, damage to coastal businesses, reduced attractiveness of beach areas, disruption of transport and clean-up costs. For infrastructure, relevant indirect effects include interruptions to water supply, wastewater management, electricity distribution, road access and public services. For the environment, the main concerns include disturbance of protected areas, lagoon ecosystems and water bodies, as well as possible mobilisation of pollutants in low-lying urban and agricultural zones.

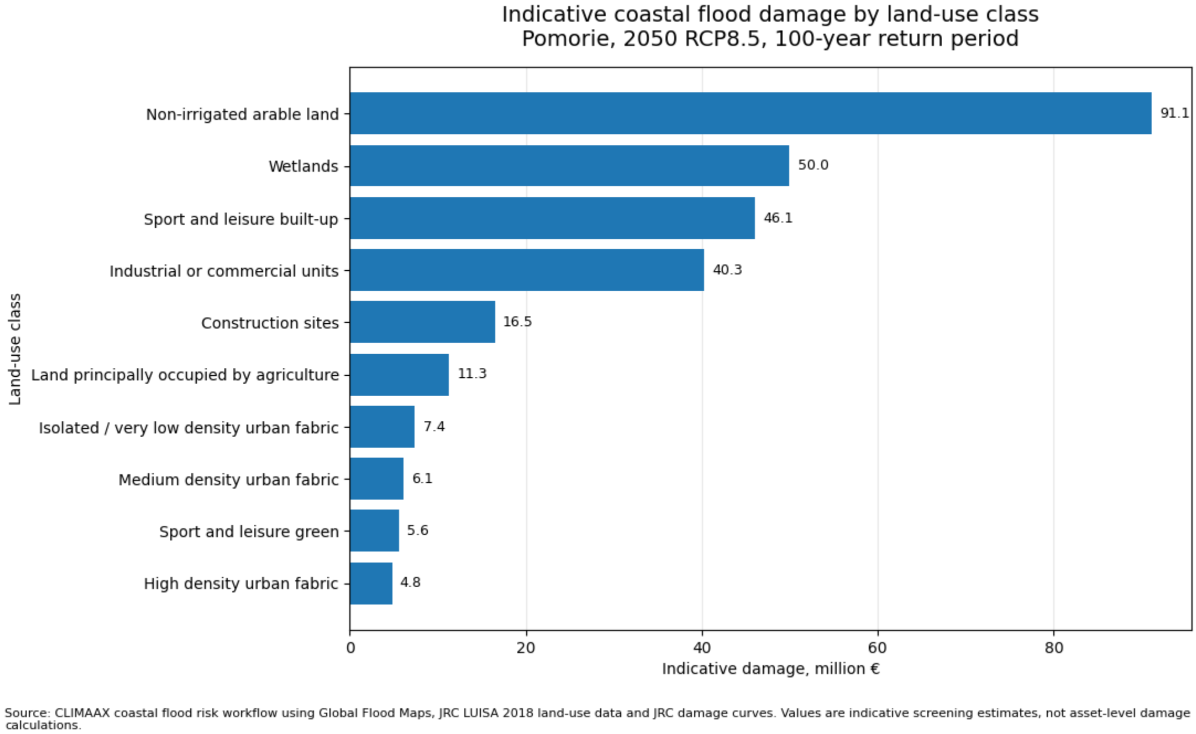


Figure A1-10. Indicative coastal flood damage by land-use class for Pomorie under the 2050 RCP8.5 100-year return-period scenario.

Source: CLIMAAX coastal flood risk workflow, based on Global Flood Maps, JRC LUISA 2018 land-use data and JRC damage curves. Values are indicative screening estimates and should not be interpreted as asset-level damage calculations.

The national PFRA framework was used as a supplementary reference for interpreting flood consequences. The PFRA methodology evaluates past and future flood consequences through a hierarchy of categories, subcategories, criteria and indicators. The main categories are human health, economic activity, environment and cultural heritage. This structure is useful for Pomorie because it ensures that flood risk is not interpreted only as potential economic damage, but also as a multi-sectoral municipal risk affecting people, infrastructure, ecosystems and heritage.

The uploaded PFRA data for the Black Sea Basin include past flood events in Pomorie Municipality, including coastal/marine flooding in Pomorie town and river flooding in the area of Galabets / the Hadzhiyska River. The past records confirm that flood processes in the municipality are not limited to one mechanism. Coastal flooding, rainfall-driven flooding, river overflow and infrastructure/drainage limitations may interact. This is particularly relevant for Phase 2 because the assessment covers multiple climate hazards, including coastal flooding and heavy rainfall. For future work, the official flood hazard and risk maps from the Black Sea Basin Directorate should be included as an additional validation and comparison layer.

The PFRA assessment of Areas of Potential Significant Flood Risk also identifies the wider coastal section “Black Sea – from Sveti Vlas to Pomorie” as relevant for several consequence categories. This supports the conclusion that the Pomorie coastal zone forms part of a wider Black Sea coastal flood-risk corridor, where human health, infrastructure, immovable property, economic activities and cultural values may all be affected.

Figure A1-11. National PFRA reference for flood-risk relevance in the Pomorie coastal area
Source: Preliminary Flood Risk Assessment for the Black Sea Basin District.

The following additional impact metrics and risk outputs were introduced or strengthened in Phase 2 compared to Phase 1:

- locally derived high-water and very-high-water thresholds based on observed water-level anomalies;
- frequency indicators for high-water observations and affected days;
- interpretation of elevated water levels in relation to atmospheric pressure and wind direction;
- identification of NE/E wind conditions as a key local driver of coastal water-level extremes;
- interpretation of exposure through local topography and known coastal assets;
- qualitative assessment of indirect impacts on tourism, emergency access, public services, water/wastewater infrastructure and ecosystems;
- cross-checking of CLIMAAX workflow outputs against the PFRA consequence categories.

The main limitation of the risk assessment is that economic damage estimates remain indicative. They are based on European-scale land-use data and generalized damage curves rather than detailed local building footprints, cadastral values, infrastructure inventories, asset-level replacement costs or historical damage records. In addition, future socio-economic exposure was not dynamically modelled. The assessment uses current land use as a baseline and interprets future risk under the assumption that coastal exposure may remain high or increase if tourism, infrastructure and urban development continue to concentrate in low-lying coastal zones. More precise future risk estimation would require local building and infrastructure datasets, cadastral information, updated population and seasonal visitor distribution, asset-level criticality data and locally validated flood-depth maps.

Overall, the Phase 2 coastal-flooding analysis confirms that Pomorie Municipality faces a spatially uneven but locally significant flood risk. The most relevant risk is concentrated in low-lying coastal areas where elevated sea levels, storm surge, low atmospheric pressure and persistent NE/E onshore winds can coincide with exposed infrastructure, tourism assets, residential areas, transport connections and sensitive ecosystems. The results provide a stronger evidence base for prioritising adaptation measures such as improved monitoring, detailed local flood modelling, drainage and access-route assessment, protection of critical infrastructure, nature-based coastal protection, emergency planning for vulnerable groups and integration of coastal flood risk into spatial and tourism development planning.

2. Hazard #2 - Heavy Rainfall/Extreme Precipitation - finetuning to local context

Heavy rainfall was selected as a separate hazard because its risk mechanisms differ from those of coastal flooding, even though both hazards may produce local inundation and may interact under compound-event conditions. In Pomorie Municipality, heavy rainfall is particularly relevant for urban drainage, road infrastructure, low-lying neighbourhoods, tourist areas, agricultural land and the sensitive coastal-lagoon environment around Pomorie Lake. Short-duration, high-intensity rainfall may generate rapid surface runoff, overload drainage systems and cause local flooding even when monthly or annual precipitation totals are not exceptionally high.

The Phase 2 assessment fine-tuned the CLIMAAX heavy-rainfall workflow by applying it to the Pomorie area of interest and by interpreting the modelled climate-scenario outputs against local high-resolution precipitation observations. The workflow was used to assess how current impact-relevant rainfall thresholds may change under future climate conditions. The local analysis was used to clarify the observed rainfall regime, including the frequency of wet days, the concentration of rainfall within a limited number of events, short-duration intensity, and the occurrence of dry periods. This combination makes the assessment more locally meaningful than the use of regional climate projections alone.

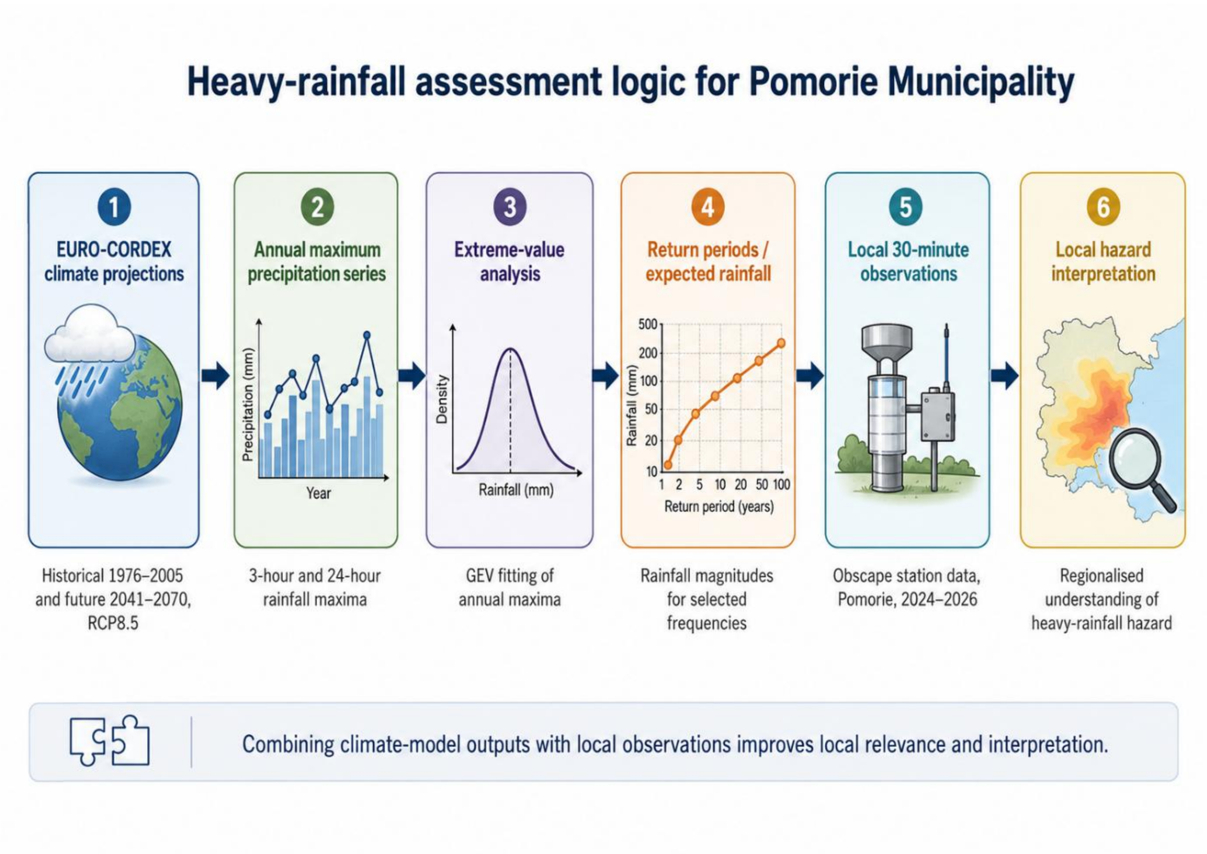


Figure A2. Heavy-rainfall assessment logic for Pomorie Municipality

Table A2.1 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
EURO-CORDEX precipitation flux data at approximately 12 km spatial resolution, accessed through the Climate Data Store and processed through the CLIMAAX Heavy Rainfall workflow. The analysis used the historical period 1976–2005 and the future period 2041–2070. The model chain used in the uploaded workflow was ICHEC-EC-EARTH / KNMI-RACMO22E under RCP8.5.	Critical impact-based rainfall threshold used in the risk workflow: 50 mm / 24 h associated with a 5-year return period. This threshold was used to assess how the magnitude and frequency of potentially impactful rainfall may change under future climate conditions.	Pomorie Municipality area of interest, defined through the workflow bounding box. The exposure context includes the urban area of Pomorie, the Old Town peninsula, low-lying coastal and lake-adjacent areas, roads, stormwater drainage infrastructure, tourist facilities, agricultural land, Pomorie Lake and the salinas.	Annual maximum precipitation series for 3-hour and 24-hour durations; return-period estimates for selected rainfall durations; future return period for the current critical threshold; future precipitation magnitude if the current return period is maintained; raster outputs showing current return period, return-period shift and precipitation factor.
Annual maximum precipitation datasets generated for 3-hour and 24-hour durations for the historical and future periods. Extreme-value analysis was applied to estimate expected precipitation amounts for selected return periods.	Local vulnerability factors: limited drainage capacity in urbanized areas, sealed surfaces, road and access-route sensitivity, erosion-prone areas, agricultural fields vulnerable to waterlogging, and possible exposure of vulnerable population groups during sudden local flooding.	Current socio-economic exposure was used as the baseline. No detailed future land-use, population or asset-distribution projection was applied in this iteration. Future exposure was interpreted qualitatively, assuming continued concentration of tourism, services and infrastructure in coastal and urbanized areas.	For the 2041–2070 period, the 50 mm / 24 h threshold currently associated with a 5-year return period is projected to require approximately 39% higher precipitation to maintain the same frequency. If the rainfall magnitude remains fixed at 50 mm / 24 h, the return period changes from 5 years to approximately 3 years, indicating increased frequency.
Local automatic meteorological station data from Pomorie, collected with high-resolution Obscape sensors at 30-minute	Local observational indicators used for contextual vulnerability interpretation:	Site-specific local exposure: the monitoring station is located in the urban area of Pomorie, at the	Local impact-relevant indicators: highest daily precipitation total, monthly totals, number of days ≥20 mm and ≥30

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
intervals for the period 04 October 2024 – 12 June 2026. Daily precipitation totals and moving 30-minute, 1-hour, 3-hour and 6-hour accumulations were calculated.	number of wet days, heavy-rainfall days, rainfall-event duration, maximum short-duration intensity and concentration of rainfall within a limited number of events.	tip of the Old Town peninsula, at the land-sea interface. Its observations are therefore particularly relevant for the urban coastal setting, but not fully representative of the entire municipality.	mm, maximum 30-minute, 1-hour, 3-hour and 6-hour precipitation totals, top rainfall events by accumulated precipitation and by mean intensity.
Long-term annual precipitation series for Pomorie/Burgas covering 1894–2023, used to assess background precipitation variability and long-term tendencies.	Long-term vulnerability interpretation: high natural variability of precipitation, absence of a strong trend in annual totals, but possible increasing relevance of intra-seasonal variability, short-duration intense events and dry spells.	Wider municipal exposure: settlements, transport links, agricultural land, tourism areas, lake and lagoon ecosystems, and disaster-response systems.	Long-term trend indicator: weak positive trend in annual precipitation totals, approximately 0.7 mm/year, with very low explanatory power, indicating that natural interannual variability remains dominant.

2.1. Hazard assessment

The heavy-rainfall hazard assessment was based on both climate-scenario modelling and local observational data. The CLIMAAX workflow used EURO-CORDEX precipitation projections to generate rainfall datasets for current and future climate conditions. The historical period was represented by 1976–2005, while the future climate period was represented by 2041–2070 under RCP8.5. The workflow extracted annual maximum precipitation values for 3-hour and 24-hour durations, which are particularly relevant for short-duration runoff generation and urban drainage stress.

The workflow then applied extreme-value analysis to estimate precipitation amounts associated with different return periods. This makes it possible to compare how rainfall magnitudes and frequencies may change under future climate conditions. For Pomorie, the analysis area was defined by the selected bounding box and the generated precipitation datasets were saved for the municipality-specific assessment.

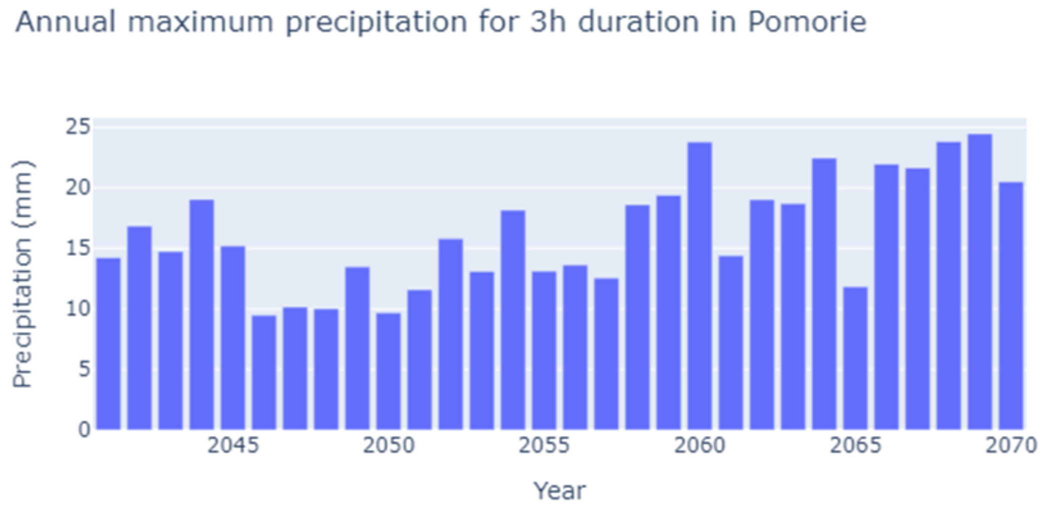


Figure A2-1. Annual maximum precipitation series for the selected Pomorie grid cell. *Source: CLIMAAX heavy-rainfall hazard workflow using EURO-CORDEX precipitation projections.*

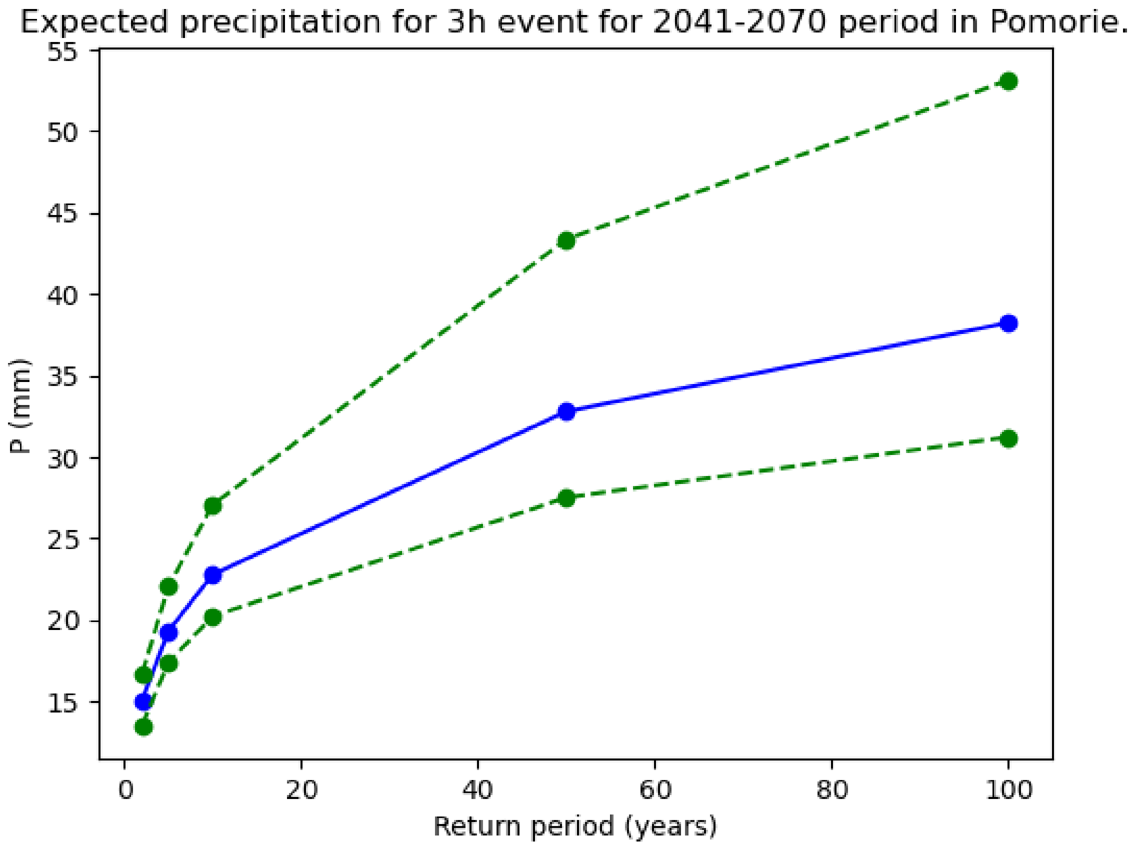


Figure A2-2. Expected precipitation amounts for selected return periods under historical and future climate conditions.

Source: CLIMAAX heavy-rainfall hazard workflow; GEV-based extreme-value analysis of annual maximum precipitation.

The local observational analysis provides important regionalisation of the model outputs. It is based on 30-minute precipitation measurements from an automatic meteorological station located in the urban area of Pomorie, at the tip of the Old Town peninsula. The record covers the period from 04 October 2024 to 12 June 2026. Daily precipitation totals were calculated from the 30-minute measurements, and moving accumulation periods were used to calculate maximum precipitation totals for 30-minute, 1-hour, 3-hour and 6-hour durations.

The full expert analysis based on local observational data is presented below, as an evidence base for the regionalisation of the heavy-rainfall hazard.

Analysis of rainfall events and heavy rainfall occurrences in Pomorie based on local observational data

Heavy rainfall represents one of the most significant climate-related hazards affecting settlements and infrastructure in coastal areas. Even when total monthly or annual precipitation amounts are not exceptionally high, short-duration high-intensity rainfall events may cause local flooding, overloading of drainage systems, erosion processes, damage to transport infrastructure, and material losses in urbanized areas. Such events may also adversely affect agriculture through soil waterlogging, mechanical damage to crops, and the intensification of erosion processes. For this reason, the analysis of rainfall-event frequency, intensity, and duration constitutes an important component of climate risk assessment and the planning of climate change adaptation measures.

A distinctive feature of the present study is that it is based on local instrumental observations collected at high temporal resolution within the territory of the town of Pomorie. The use of actual measurements makes it possible to identify both short-duration high-intensity rainfall events and prolonged dry periods with a level of accuracy that is difficult to achieve using spatially aggregated climate products. Although climate models and reanalysis datasets provide valuable information on regional climate characteristics, trends, and future scenarios, they are often unable to fully reproduce the local manifestations of precipitation processes and their pronounced spatial and temporal variability. In this context, results derived from local observations provide an important basis for validating model outputs and developing more reliable climate risk assessments. The integration of instrumental observations, reanalysis products, and climate scenarios offers an opportunity for a more comprehensive understanding of contemporary climate conditions and supports the development of effective adaptation measures for future climate change.

The present analysis is based on data collected by an automatic meteorological station equipped with high-precision Obscape sensors. The station is located within the urban area of Pomorie, at the tip of the Old Town peninsula, at the interface between land and sea, at coordinates (...). The station provides precipitation measurements at 30-minute intervals for the period 4 October 2024 – 12 June 2026. For the purposes of the analysis, daily precipitation totals were calculated by interpreting each recorded value as the amount of precipitation accumulated during the preceding 30 minutes. Daily totals were computed for the period extending from 00:30 of a given day to 00:00 of the following day.

The analysis of monthly maximum 24-hour precipitation totals (Figure A2-3) indicates that no extreme rainfall events comparable to the most severe cases documented along the Bulgarian Black Sea coast occurred during the study period. The highest daily precipitation total was recorded on 2 June 2026 and reached 34.357 mm. The second-highest value was registered on 17 May 2026, amounting to 32.725 mm. Throughout the entire study period, no days with precipitation exceeding 50 mm were observed, indicating the absence of exceptionally rare and extremely intense rainfall events.

Particular attention should be given to the frequency of heavy-rainfall days. The analysis shows that only five days with daily precipitation totals equal to or exceeding 20 mm were recorded during the entire study period. Of these, only two days reached or exceeded the threshold of 30 mm. These findings indicate a relatively low frequency of intense rainfall events during the analysed period.

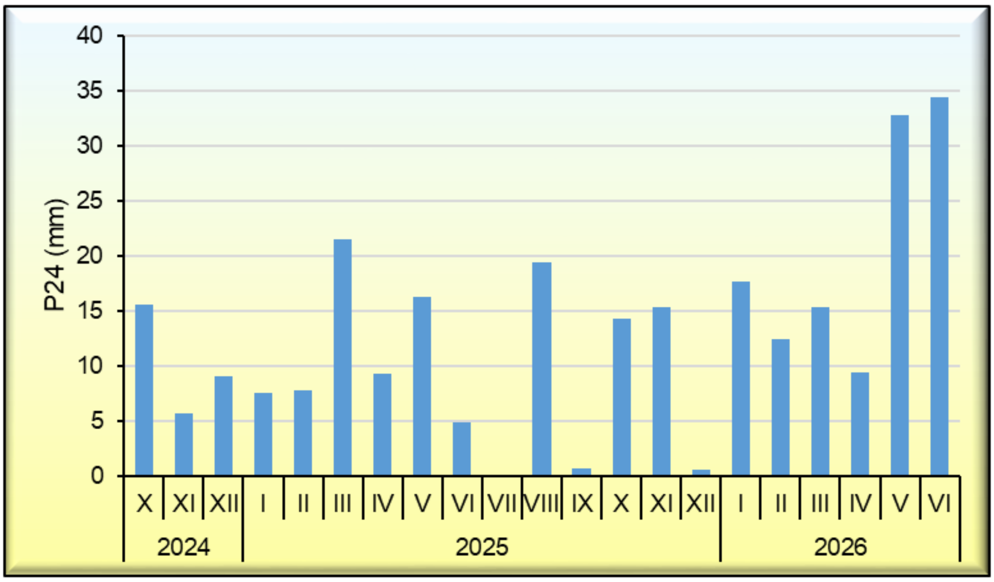


Fig.A2-3.Monthly maximum 24-hour precipitation (P24) in Pomorie for the period 04.10.2024-12.06.2026

At the same time, monthly precipitation totals (Figure A2-4) reveal considerable temporal variability in the precipitation regime. The highest monthly totals were recorded in May 2026 (74.834 mm), February 2026 (66.351 mm), and October 2025 (66.249 mm). At the opposite end of the spectrum are July 2025, when no precipitation was recorded, and September 2025, when the monthly total amounted to only 0.765 mm.

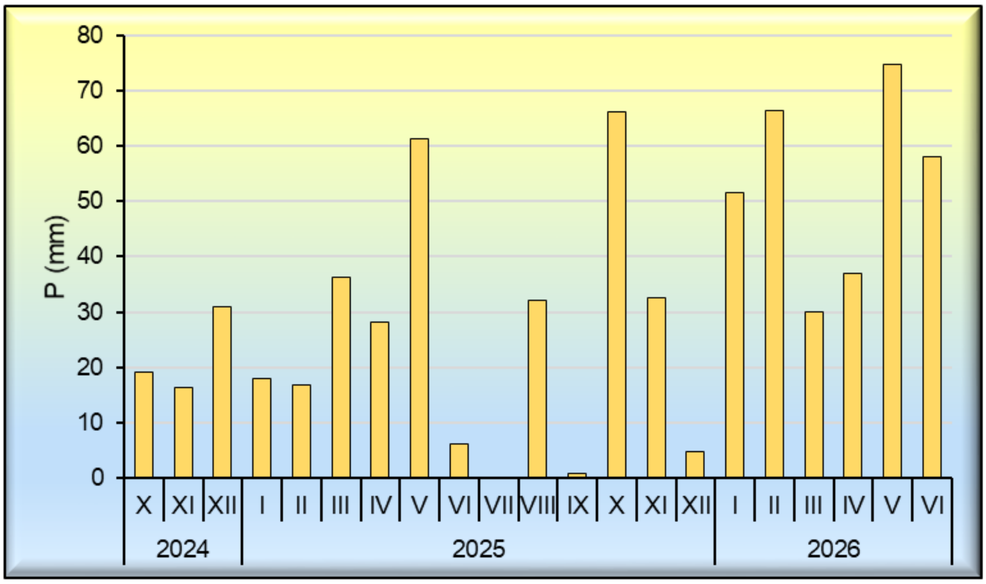


Fig. A2-4. Monthly precipitation amounts (P) in Pomorie for the period 04.10.2024-12.06.2026

Particularly informative is the analysis of the number of wet days (days with daily precipitation totals ≥ 1 mm) and the average precipitation per wet day (Figure A2-5). The results indicate that precipitation in Pomorie is relatively infrequent but often concentrated within a limited number of events. For example, only three wet days were recorded in August 2025, yet the average precipitation per wet day reached 10.721 mm. A similar pattern was observed in May 2026, when the average precipitation per wet day amounted to 10.134 mm.

Special attention should be paid to early June 2026. Although the available data cover only the first twelve days of the month, the average precipitation per wet day reached 19.114 mm. This exceptionally high value is attributable to the concentration of precipitation within two highly intense events recorded on 2 and 4 June 2026, when daily totals of 34.357 mm and 21.743 mm, respectively, were observed.

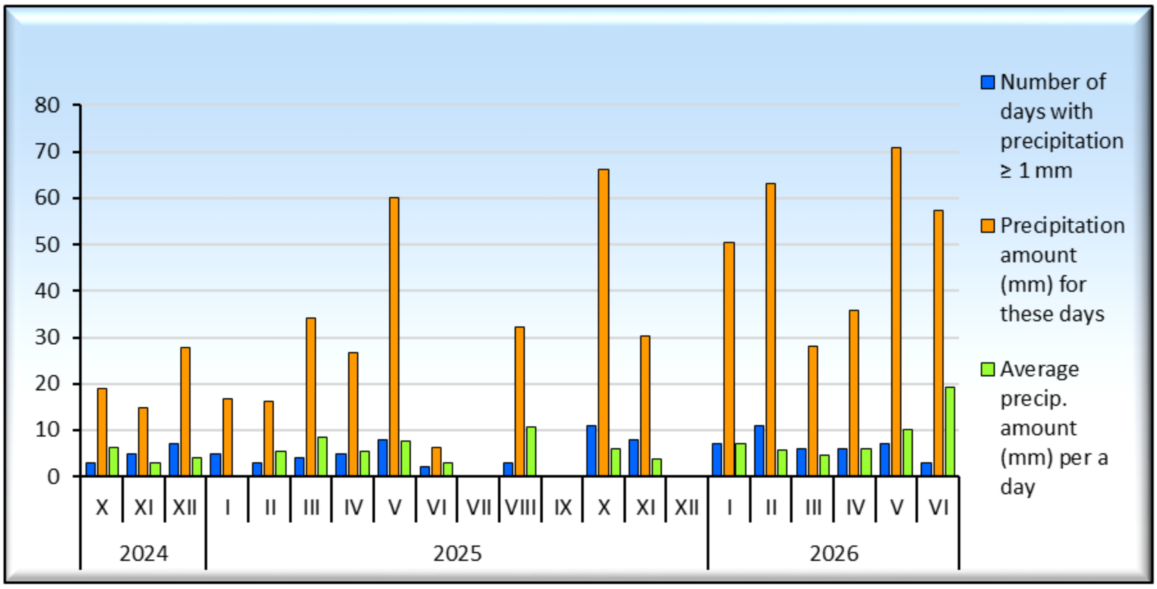


Fig.A2-5. Number of wet days (precipitation amount ≥ 1 mm per a day) and average precipitation (mm) per wet day in Pomorie for the period 04.10.2024-12.06.2026

In addition to daily precipitation totals, an assessment of rainfall intensity was carried out using moving accumulation periods of different durations. Maximum precipitation amounts were calculated for 30-minute, 1-hour, 3-hour, and 6-hour periods (Table A2-2). This approach provides a more detailed characterization of short-duration rainfall events and their potential to generate rapid surface runoff and local flooding.

The results indicate that the most intense rainfall episode during the study period occurred on 2 June 2026. During this event, 17.185 mm of precipitation fell within 30 minutes, while 31.392 mm accumulated within a 3-hour period and 34.357 mm within 6 hours. These values demonstrate that a substantial proportion of the rainfall was concentrated within a very short time interval.

Another notable event occurred on 4 June 2026, when 10.779 mm of precipitation were recorded within 30 minutes and 21.743 mm within a 3-hour period. Elevated short-duration rainfall intensities were also observed on 17 May 2026 and 12 February 2026. Overall, the results show that the highest rainfall intensities were concentrated within a limited number of events, primarily during the spring and early summer of 2026.

Table A2-2. Maximum precipitation totals for different accumulation durations

Duration	Maximum precipitation amount	End of the presipitation interval
30 min	19.5	02.06.2026, 16:00
1 hour	28.7	02.06.2026, 16:30
3 hours	34.3	02.06.2026, 18:30
6 hours	34.4	02.06.2026, 20:00

The analysis of individual rainfall events provides additional insight into the characteristics of the local precipitation regime. Rainfall events were defined as sequences of precipitation intervals separated by at least six consecutive hours without measurable rainfall. The ranking of the ten largest events by total accumulated precipitation (Table A2-3) shows that the most significant events were concentrated predominantly toward the end of the observation period, particularly during 2026.

The largest event occurred on 2 June 2026, producing a total of 34.357 mm of precipitation over approximately four and a half hours. The second-largest event was recorded on 21–22 May 2026, with a cumulative rainfall amount of 26.605 mm. Other prominent events occurred in March 2025, August 2025, November 2025, February 2026, and March 2026, indicating that substantial rainfall events were observed during different seasons of the year.

Table A2-3. Top 10 rainfall events by total accumulated precipitation

Beginning	End	Duration* (h)	Amount (mm)
02.06.2026 16:00	02.06.2026 20:00	4.5	34.4
21.05.2026 15:30	22.05.2026 08:30	17.5	26.6
04.11.2025 23:00	08.11.2025 21:00	94.5	23.9
17.03.2025 07:00	18.03.2025 04:30	22.0	23.3
04.06.2026 17:00	04.06.2026 19:00	2.5	21.7
25.08.2025 06:30	25.08.2025 15:30	9.5	19.4
17.05.2026 12:00	17.05.2026 18:30	7.0	19.3
17.02.2026 15:00	18.02.2026 04:30	14.0	**18.921**
29.03.2026 02:30	30.03.2026 12:00	34.0	**18.870**
08.01.2026 06:00	08.01.2026 13:30	8.0	**17.680**

**Note: Event duration was derived from consecutive 30-minute precipitation intervals. Because each observation represents precipitation accumulated over the preceding 30 minutes, the calculated duration may exceed the difference between the reported start and end times by 0.5 hours.*

The ranking of rainfall events by mean rainfall intensity (Table A2-4) reveals additional features of the precipitation regime. The highest average intensity was recorded on 4 June 2026, when 21.743 mm of precipitation fell over approximately two and a half hours, corresponding to an average intensity of 8.70 mm h^{-1}. The second most intense event occurred only two days earlier, on 2 June 2026, with an average intensity of 7.63 mm h^{-1}.

It is noteworthy that the two most intense events occurred within a period of only two days, indicating an episode of exceptionally high rainfall activity in the area. These events were characterized not only by substantial rainfall totals but also by a pronounced concentration of precipitation in time, increasing the likelihood of rapid runoff generation and local flooding.

Table A2-4. Top 10 rainfall events by mean intensity

Beginning	End	Duration* (h)	Amount (mm)	Intensity (mm/h)
04.06.2026 17:00	04.06.2026 19:00	2.5	21.7	8.70
02.06.2026 16:00	02.06.2026 20:00	4.5	34.4	7.63
26.04.2025 23:30	27.04.2025 02:30	3.5	9.70	2.77
17.05.2026 12:00	17.05.2026 18:30	7.0	19.3	2.75
23.05.2026 23:00	24.05.2026 00:30	2.0	5.1	2.55
24.10.2025 14:00	24.10.2025 18:00	4.5	10.6	2.35
28.05.2025 20:30	28.05.2025 21:30	1.5	3.5	2.35
31.08.2025 19:30	31.08.2025 23:30	4.5	10.3	2.28
08.01.2026 06:00	08.01.2026 13:30	8.0	17.7	2.21
28.03.2025 20:00	28.03.2025 21:00	1.5	3.2	2.15

**Event duration was calculated according to the methodology described under Table A2-3.*

A comparison between Tables A2-3 and A2-4 demonstrates that the events with the highest accumulated precipitation do not necessarily correspond to those with the highest rainfall intensity. Some events are characterized by longer duration and larger cumulative rainfall amounts, whereas others exhibit extremely high intensities over comparatively short periods. The latter category is particularly relevant from a risk-management perspective, as such events may overwhelm drainage infrastructure and generate significant surface runoff in urban environments.

The results indicate that, although the frequency of extreme rainfall events during the study period was relatively low, individual short-duration events were capable of producing substantial rainfall amounts within only a few hours. This finding highlights the importance of considering not only daily and monthly precipitation totals but also the intra-day structure, duration, and intensity of rainfall events when assessing climate-related hazards.

The results show that the precipitation regime in Pomorie during the analysed period was characterized by a relatively low frequency of extreme rainfall events, but also by a pronounced concentration of precipitation within a limited number of episodes. Particularly noteworthy are the events recorded during May and June 2026, when both the highest daily precipitation totals and the highest short-duration rainfall intensities were observed.

The analysis of individual rainfall events demonstrates that even under moderate monthly precipitation conditions, short-lived but intense rainfall episodes may generate significant surface runoff and increase the risk of local flooding. These findings underline the necessity of incorporating not only daily and monthly precipitation totals, but also the temporal structure, duration, and intensity of rainfall events into climate risk assessments.

From a risk-management perspective, it is recommended that local high-resolution rainfall monitoring systems be maintained and further developed, that the capacity of stormwater drainage infrastructure be periodically evaluated, and that emergency response plans for heavy rainfall and local flooding be regularly updated. Particular attention should be paid to short-duration convective rainfall events, which may generate substantial precipitation amounts within only a few hours and consequently produce impacts that are disproportionate to their relatively short duration.

Long-Term Trends and Expected Changes in the Precipitation Regime

To assess the long-term characteristics and tendencies of the precipitation regime in the Pomorie area, a historical series of annual precipitation totals covering the period 1894–2023 was analysed (Figure A2-6). The length of the record provides a valuable basis for evaluating both long-term tendencies and the natural variability of precipitation over more than a century of observations.

The analysis of annual precipitation totals reveals substantial interannual variability, which is characteristic of the climatic conditions of Eastern Bulgaria and the Black Sea coastal region. Throughout the observation period, wetter and drier years alternated, with a considerable range between minimum and maximum annual precipitation totals. This pattern indicates that natural climatic variability remains the dominant factor shaping the local precipitation regime.

The linear trend line indicates the presence of a weak positive trend, described by the equation:

$$y = 0.7x + 469.42$$

The calculated slope corresponds to an increase in annual precipitation totals of approximately 0.7 mm per year, or about 7 mm per decade. Over the entire observation period, this would imply an overall increase of roughly 90 mm in annual precipitation. However, the coefficient of determination ($R^2 = 0.0271$) indicates that the linear trend explains only about 2.7% of the observed variability. Consequently, more than 97% of the fluctuations in annual precipitation totals are associated with natural climatic variability and factors that cannot be adequately represented by a simple linear relationship.

The results do not provide evidence of a substantial or unequivocal long-term change in the total annual precipitation amounts in the study area. Although a weak positive tendency is observed, its magnitude remains considerably smaller than the natural year-to-year variability of the precipitation regime. Such behaviour is typical of precipitation series, where long-term statistical trends are generally less pronounced than those observed for temperature-related variables.

At the same time, the absence of a strong trend in annual precipitation totals does not imply the absence of changes in the precipitation regime itself. The analysis of local observations for the period 2024–2026 demonstrates the occurrence of short-duration high-intensity rainfall events, the concentration of a substantial proportion of precipitation within a limited number of days, and the development of prolonged dry periods. These findings are consistent with trends reported in many parts of Europe, where increasing intra-seasonal and intra-annual variability of precipitation has been observed despite relatively modest changes in total annual precipitation amounts.

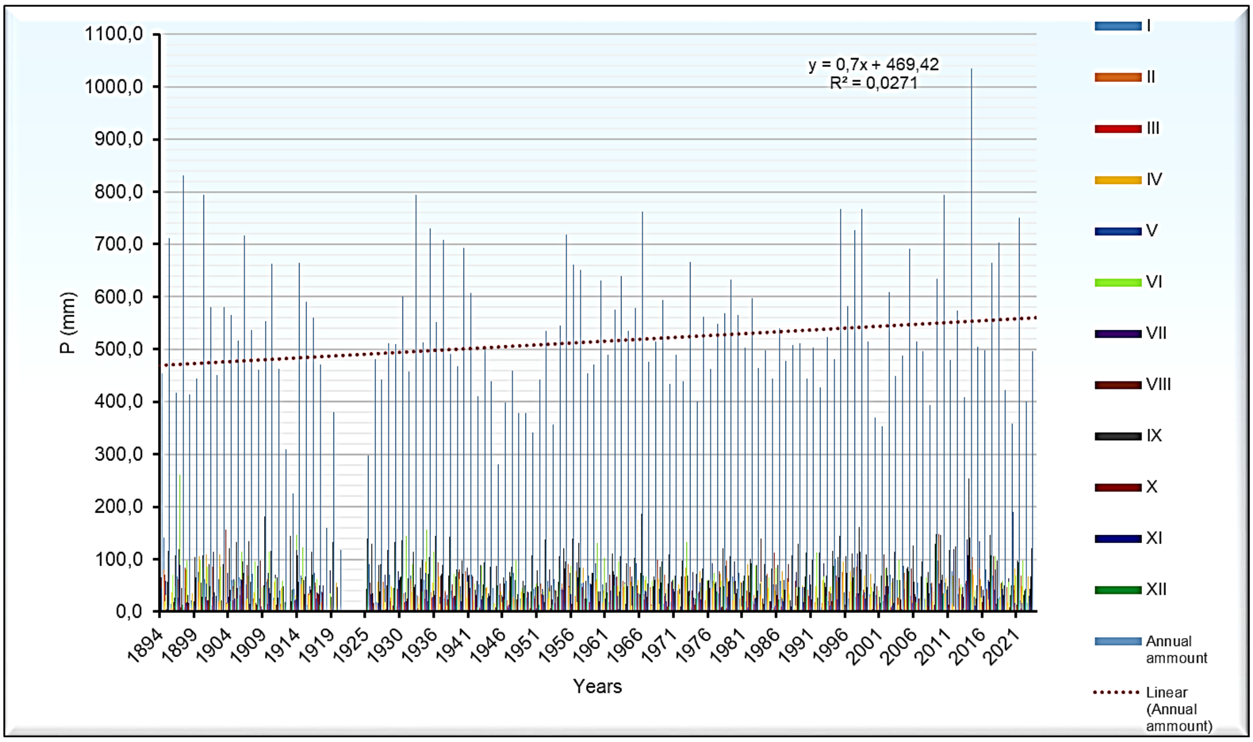


Fig.A2-6. Multi-year course and trend of annual precipitation amount (P) in Pomorie/Burgas, 1894-2023

Statistical extrapolation of the observed trend

Based on the identified linear trend, an indicative statistical extrapolation was performed for future time horizons. The trend slope of approximately +0.7 mm per year suggests a gradual increase in average annual precipitation totals if the historical tendency continues unchanged in the future.

Nevertheless, such extrapolation should be interpreted with caution. The very low coefficient of determination (R^2=0.0271) demonstrates that the observed trend accounts for only a small fraction of the total variability in the precipitation record. Consequently, the extrapolated values should be regarded solely as a statistical indication of the possible direction of change rather than as a climate projection or forecast.

The analysis further suggests that future changes are more likely to affect the temporal distribution of precipitation than its total annual amount. This conclusion is supported by the local observational record from 2024–2026, which indicates a tendency towards precipitation concentration within a limited number of intense rainfall events, separated by extended dry periods. Therefore, future modifications of the precipitation regime are likely to be associated primarily with changes in rainfall frequency, intensity, and seasonal distribution rather than with major changes in total annual precipitation amounts.

The findings presented in this study provide an evidence-based foundation for the assessment of local precipitation-related hazards and may contribute to future climate risk assessments and adaptation planning in the Pomorie area.

During the local observation period, no rainfall events exceeding 50 mm in 24 hours were recorded. The highest 24-hour precipitation total was 34.357 mm on 2 June 2026, while the second-highest daily total was 32.725 mm on 17 May 2026. Only five days with daily precipitation totals equal to or above 20 mm were identified, and only two days reached or exceeded 30 mm. This indicates that the short local record did not include exceptionally rare or extreme daily rainfall events comparable to the most severe cases documented along the Bulgarian Black Sea coast.

At the same time, the local data show that rainfall in Pomorie may be concentrated in a limited number of events. Monthly precipitation totals varied considerably. The highest monthly totals were recorded in May 2026, February 2026 and October 2025, while July 2025 had no recorded precipitation and September 2025 was almost dry. The analysis of wet days also shows that some months had relatively few rainfall days, but relatively high average precipitation per wet day. This pattern is important for risk assessment because short periods of concentrated rainfall may create runoff and drainage problems even when total monthly rainfall is moderate.

The most intense short-duration rainfall episode occurred on 2 June 2026. According to the local accumulation analysis, the maximum recorded values reached approximately 19.5 mm in 30 minutes, 28.7 mm in 1 hour, 34.3 mm in 3 hours and 34.4 mm in 6 hours. A second notable event occurred on 4 June 2026, when 21.7 mm fell within approximately 2.5 hours. These events demonstrate that rainfall intensity and intra-day rainfall structure are essential for understanding heavy-rainfall hazards in Pomorie.

The local event analysis further confirms that rainfall totals and rainfall intensity do not always identify the same hazardous events. Some events accumulated larger totals over longer durations, while others produced intense rainfall over a few hours. From a hazard perspective, short-duration, high-intensity events are particularly important because they may produce rapid surface runoff and overwhelm drainage systems before an emergency response can be fully activated.

The long-term annual precipitation series for Pomorie/Burgas covering 1894–2023 shows substantial interannual variability. A weak positive linear trend is present, approximately 0.7 mm/year, but the coefficient of determination is very low. This means that the linear trend explains only a small share of the observed variability and does not provide evidence of a strong or unequivocal long-term increase in total annual precipitation. However, the absence of a strong trend in annual totals does not exclude changes in rainfall structure. For local risk management, the more relevant concern is the combination of short-duration intense events, dry periods, high variability and future increases in the frequency of currently critical rainfall thresholds.

The main limitation of the hazard assessment is the spatial resolution of the EURO-CORDEX data. A 12 km climate-model grid cannot fully represent local convective rainfall cells, coastal effects, small catchments, urban drainage conditions or micro-scale rainfall variability across the municipality. The local observational record is also short and based on one station, so it cannot be used to derive robust long-term return periods. Nevertheless, it provides valuable evidence for interpreting the modelled scenario outputs in the local Pomorie context.

2.2. Risk assessment

The heavy-rainfall risk assessment was implemented as a threshold-based climate risk assessment. Unlike the coastal-flooding workflow, it does not estimate direct economic damages through depth-damage curves. Instead, it evaluates how a locally relevant critical rainfall threshold may change under future climate conditions in terms of magnitude and frequency.

The selected critical threshold in the uploaded workflow was 50 mm/24 h, associated with a 5-year return period. This threshold was used as an impact-relevant marker for rainfall conditions that may produce significant local effects, including urban surface runoff, drainage overload, road disruption, erosion and potential damage to buildings, infrastructure and agricultural land. The risk workflow calculates two types of output. First, it estimates how much the rainfall magnitude would need to change in the future if the current return period is held constant. Second, it estimates how the return period changes if the current rainfall magnitude is held constant.

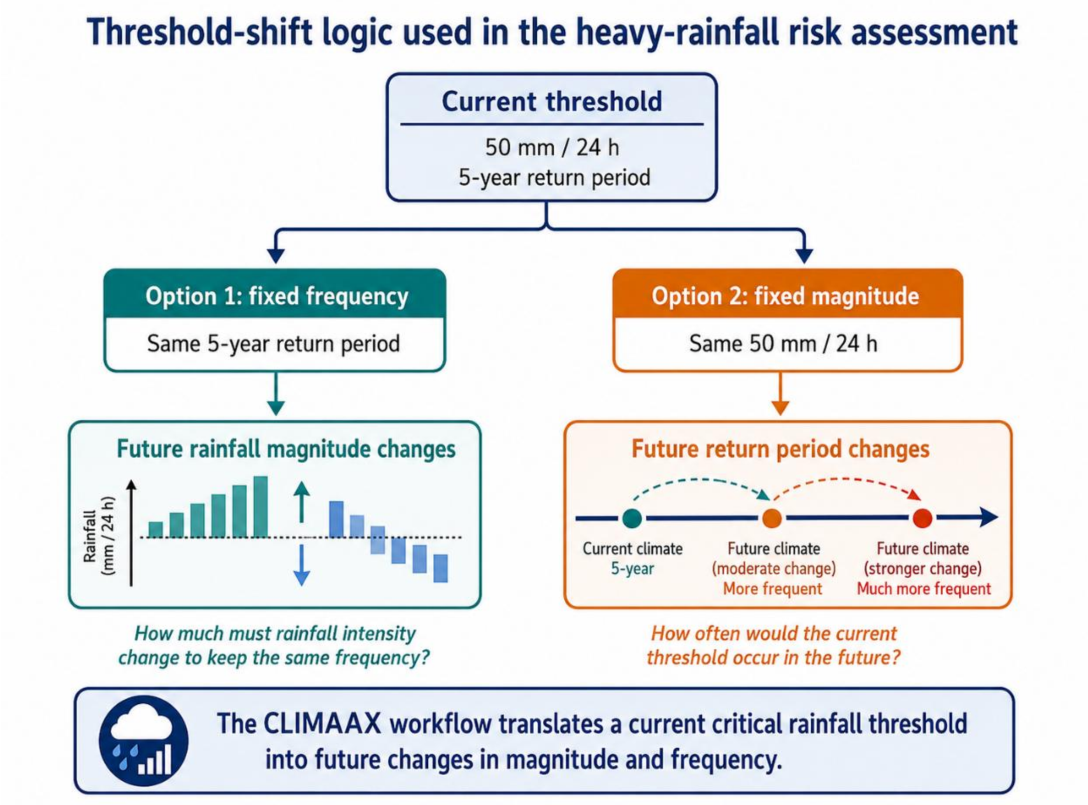


Figure A2-6. Threshold-shift logic used in the heavy-rainfall risk assessment
Source: Authors' elaboration based on the CLIMAAX heavy-rainfall risk workflow.

For the period 2041–2070 under RCP8.5, the workflow indicates that if the current 5-year frequency is maintained, the 50 mm / 24 h rainfall threshold would increase by approximately 39%. Conversely, if the magnitude remains fixed at 50 mm/24 h, its return period would decrease from 5 years to approximately 3 years. This means that a rainfall event currently treated as a 5-year threshold event may become more frequent under the future climate scenario. From a risk-management perspective, this is a clear signal that drainage, emergency planning and spatial planning should not rely only on current return-period assumptions.

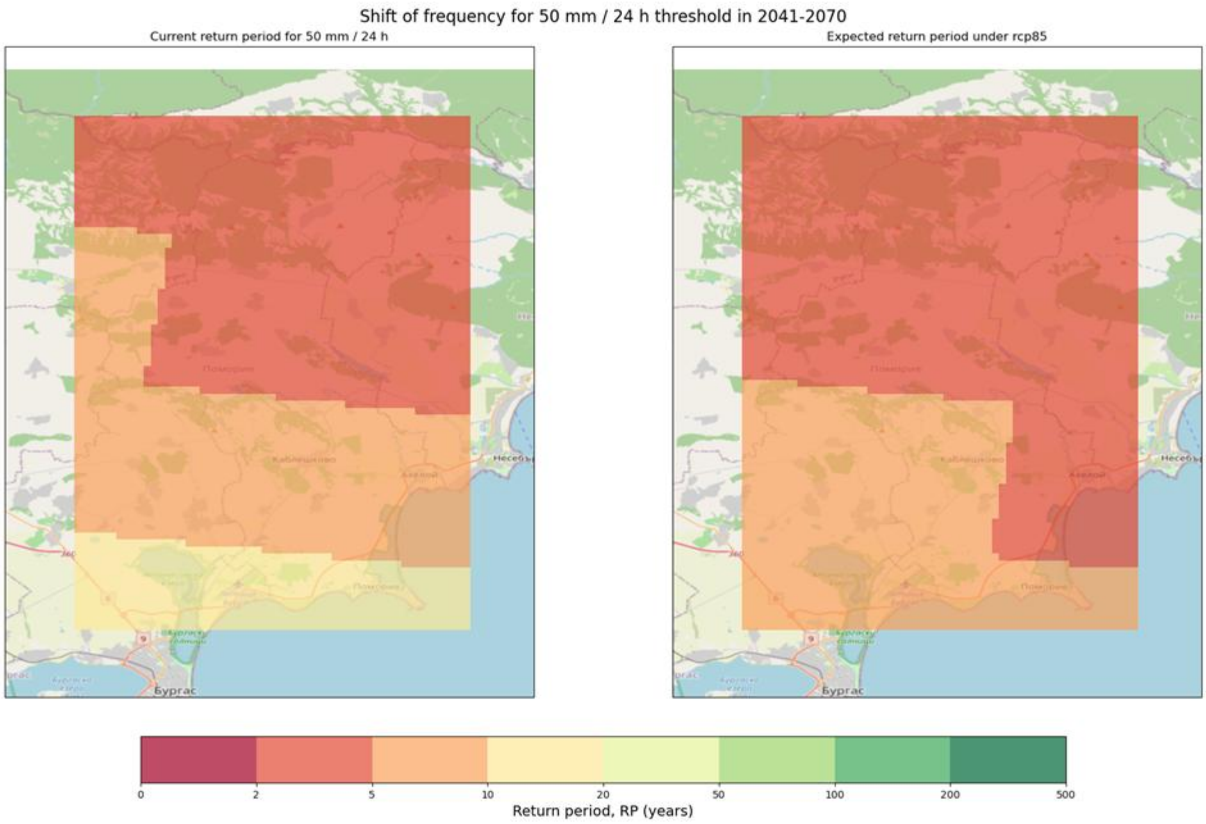


Figure A2-7. Future return-period shift for the current 50 mm / 24 h rainfall threshold in Pomorie

Source: CLIMAAX heavy-rainfall risk workflow, EURO-CORDEX ICHEC-EC-EARTH / KNMI-RACMO22E, RCP8.5, 2041–2070.

The regional outputs generated by the workflow include a current return-period raster for the 50 mm / 24 h threshold, a future return-period shift raster and a precipitation factor raster for RCP8.5. These rasters provide a spatially explicit indication of how the threshold may change across the Pomorie area of interest. However, due to the 12 km model resolution, they should be interpreted as strategic screening outputs rather than detailed design information for specific streets, culverts, underpasses or drainage collectors.

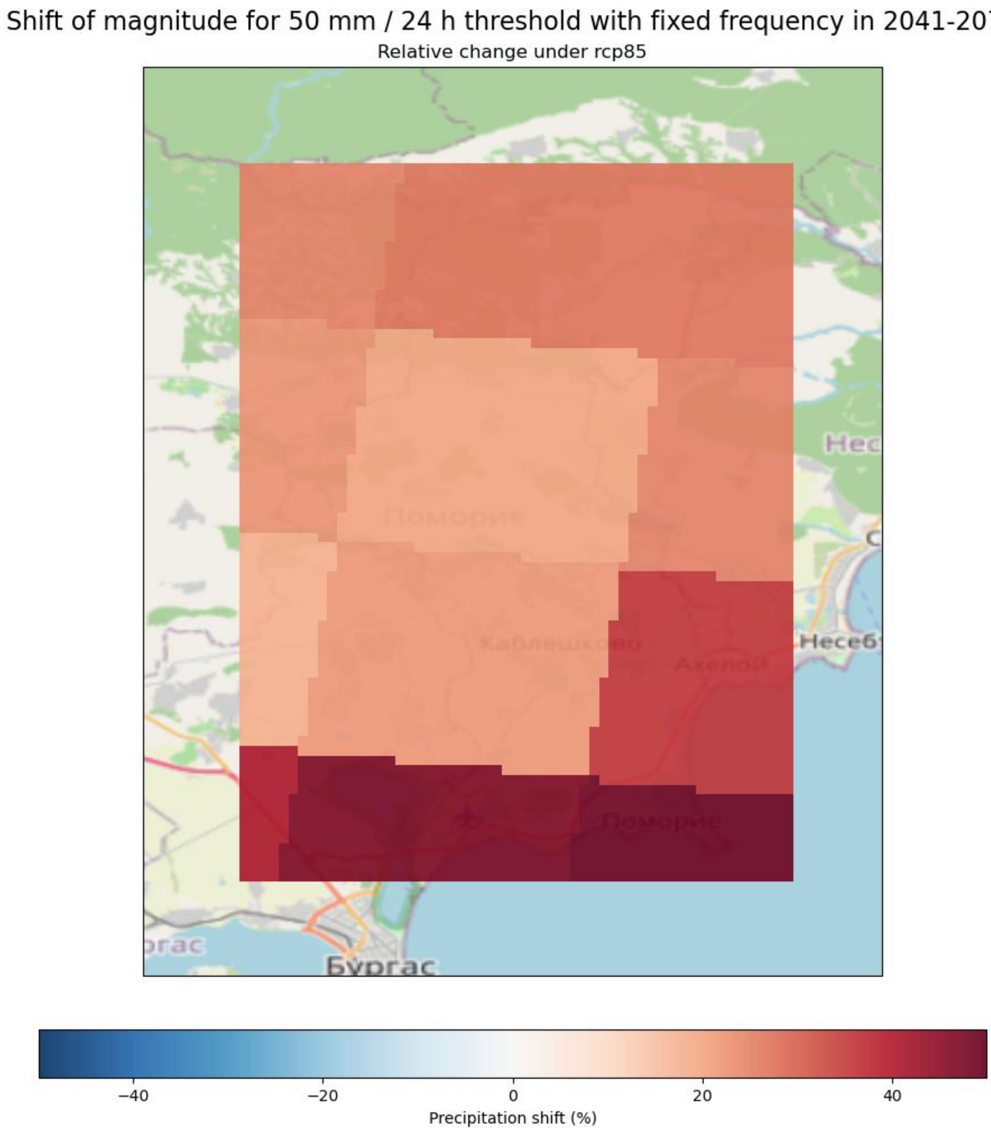


Figure A2-8. Future precipitation factor for the 50 mm / 24 h rainfall threshold under RCP8.5
Source: CLIMAAX heavy-rainfall risk workflow, EURO-CORDEX ICHEC-EC-EARTH / KNMI-RACMO22E, RCP8.5, 2041–2070.

The local observational analysis helps interpret the modelled risk outputs. Although the 2024–2026 local record did not include events exceeding 50 mm / 24 h, it did show that rainfall can be concentrated within short periods. The events of 2 and 4 June 2026 are especially relevant because they generated substantial precipitation within only a few hours. Such events may cause impacts that are disproportionate to their daily or monthly totals, particularly where drainage capacity is limited or where runoff is rapidly concentrated on sealed urban surfaces.

The main exposed systems in Pomorie include stormwater drainage infrastructure, urban roads, access routes to and within the town, waterfront areas, tourist facilities, public buildings, residential areas, agricultural fields, Pomorie Lake and the salinas. Short-duration rainfall may also create indirect impacts, including traffic disruption, temporary isolation of specific locations, damage to road surfaces, basement flooding, erosion of unpaved or sloped areas, contamination of surface waters through polluted runoff, interruption of services and increased pressure on emergency-response institutions.

Heavy rainfall may also interact with coastal flooding. If extreme precipitation coincides with elevated sea levels, storm surge or poor drainage outflow conditions, water may accumulate more easily in low-lying coastal and lake-adjacent areas. This compound-risk pathway is particularly relevant for the Pomorie peninsula, the isthmus, coastal tourist zones and areas near Pomorie Lake. Therefore, heavy-rainfall risk should be assessed not only as a standalone hazard, but also as part of the wider flood-risk system of the municipality.

The main limitation of the risk assessment is that it does not yet include detailed local drainage capacity, sewer-network data, cadastral/building data, road underpass inventories, historical damage records or high-resolution hydraulic modelling. Future socio-economic exposure was not modelled dynamically. Current land use and current infrastructure exposure were used as a baseline, while future risk was interpreted qualitatively in light of continued urban, tourism and infrastructure concentration in exposed areas.

Overall, the Phase 2 heavy-rainfall analysis shows that Pomorie currently experiences a relatively low frequency of very high daily rainfall events in the short local observation record, but that individual short-duration events can produce substantial rainfall within only a few hours. Under the future climate scenario, the current 50 mm / 24 h impact threshold is expected to become more frequent. This supports the need for continued local rainfall monitoring, assessment of stormwater drainage capacity, identification of local runoff hotspots, integration of heavy-rainfall thresholds into early-warning and emergency-response procedures, and coordination between rainfall-risk and coastal-flooding adaptation measures.

3. Hazard #3 - Drought - finetuning to local context

Drought was selected as a separate hazard because of its relevance for agriculture, water resources, soil moisture, vegetation, ecosystems and the wider socio-economic resilience of Pomorie Municipality. Unlike heavy rainfall and coastal flooding, drought develops over longer time scales and may not produce immediate visible damage. However, prolonged precipitation deficits can reduce soil moisture, affect crop development, increase irrigation demand, reduce water availability, stress urban green systems and negatively affect wetlands, lake ecosystems and agricultural productivity.

The Phase 2 drought assessment combines three complementary layers. First, the CLIMAAX relative drought workflow was used to assess drought hazard and relative drought risk at NUTS3 level, using historical and future climate-scenario precipitation datasets. Second, the agricultural drought workflow was used to assess potential crop yield losses and revenue losses under rainfed-only conditions and limited irrigation availability. Third, a local dry-spell analysis was performed using high-resolution precipitation observations from Pomorie, which provided municipality-specific evidence on the duration and character of rain-free and climatologically dry periods.

This combination makes the assessment more relevant for Pomorie because drought risk in the municipality is not limited to one sector. It affects arable crops, vineyards, orchards, vegetable production, pasture and livestock systems, water demand, public green areas, tourism-related landscaping and environmentally sensitive areas such as Pomorie Lake and the salinas. The local context is particularly important because dry spells in the coastal part of Southeastern Bulgaria often coincide with high summer temperatures and intense evaporation, amplifying the effect of precipitation deficits.

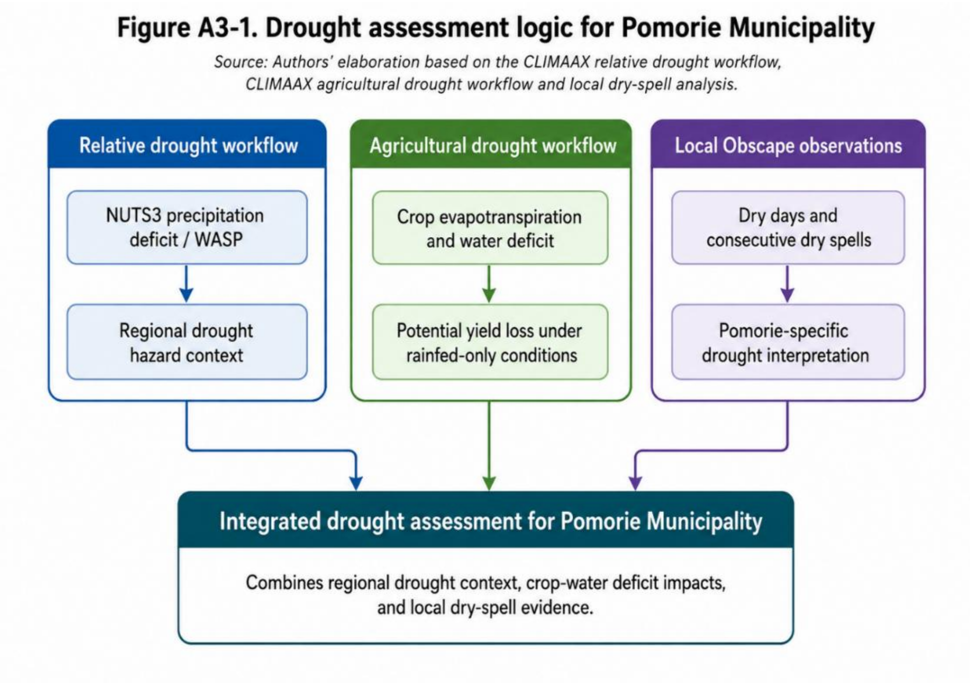


Figure A3-1. Drought assessment logic for Pomorie Municipality. *Source: Authors' elaboration based on the CLIMAAX relative drought workflow, CLIMAAX agricultural drought workflow and local dry-spell analysis.*

Table A3-1. Data overview workflow #3

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
Relative drought workflow: monthly total precipitation for NUTS3 regions in Bulgaria. The workflow uses pre-processed ISIMIP 3b bias-adjusted atmospheric climate input data, based on the ensemble average of five CMIP6 global climate models. The historical period is 1981–2015. Future periods include 2031–2060 and 2071–2100 under SSP1-2.6, SSP3-7.0 and SSP5-8.5.	Relative drought vulnerability indicators: GDP per capita and rural population share, used as generic proxies for economic and social vulnerability to drought.	NUTS3-level exposure indicators: cropland, livestock density, population and water-stress indicators. These represent exposure to agricultural activity, animal husbandry, human water demand and competition for water resources.	Drought hazard index based on WASP/ precipitation-deficit metrics; relative drought exposure; relative drought vulnerability; relative drought risk score and relative risk category at NUTS3 level.
Agricultural drought hazard workflow: EURO-CORDEX daily climate data for precipitation flux, maximum and minimum temperature, relative humidity, wind speed and solar radiation at approximately 12 km resolution. The uploaded workflow used the NUTS2 region BG34 / Yugoiztochen and a future example period 2046–2050 under RCP2.6, with the CNRM-CERFACS-CM5 / KNMI-RACMO22E model chain selected in the workflow.	Agricultural vulnerability proxy: irrigation availability. Areas with lower irrigation availability are interpreted as more vulnerable to precipitation scarcity and soil-water deficits.	Agricultural exposure data: crop production from MapSPAM 2020, crop value from GAEZ for staple crops, and crop-specific EUROSTAT prices for non-staple crops. The crop list included wheat, barley, rapeseed, sunflower, temperate fruits and tomatoes.	Potential crop yield loss under rainfed-only conditions; potential revenue loss from lack of irrigation, expressed as lost opportunity cost; spatial maps showing yield/revenue loss and irrigation availability.
Local Pomorie dry-spell analysis based on 30-minute precipitation records from the Obscape station in Pomorie, converted to	Local vulnerability factors: rainfed agricultural production, seasonal irrigation demand,	Local exposure: arable land, vineyards, orchards, vegetable production, pasture, livestock	Maximum consecutive dry days; number of dry days by month; identification of completely rain-

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
daily totals. The station is located in the Old Town peninsula area at the land-sea interface. The analysed period is 04 October 2024 – 12 June 2026. A dry day was defined as daily precipitation below 1 mm.	limited soil-water storage, high summer evaporation, exposed crops during sensitive growth stages, dependence of urban green systems and tourism landscapes on water availability, and sensitivity of wetlands and lake ecosystems to water balance changes.	systems, Pomorie Lake, salinas, urban green areas, tourism infrastructure and water users. Additional agricultural context was taken from the 2024 Burgas agricultural report.	free periods versus climatologically dry periods with micro-rainfall; qualitative risk interpretation for agriculture, ecosystems, water management and urban/tourism functions.
Future socio-economic condition: the relative drought workflow includes future cropland, population, GDP and water-stress-related exposure/vulnerability proxies. The agricultural drought workflow uses current production/value and irrigation datasets as baseline exposure and vulnerability layers, without detailed local future crop-structure projections.	Future vulnerability interpretation: continued pressure on water resources, potential increase in irrigation demand, possible changes in crop suitability, and increased sensitivity of rainfed production during longer dry periods.	Future exposure interpretation: current agricultural and socio-economic exposure was used as the main baseline. No municipality-level future crop, irrigation-network or land-use scenario was available in this phase.	Future risk interpretation: strategic indication of areas and sectors where drought hazard, exposure and vulnerability may become more relevant; basis for prioritising irrigation efficiency, drought monitoring, crop adaptation and water-resource planning.

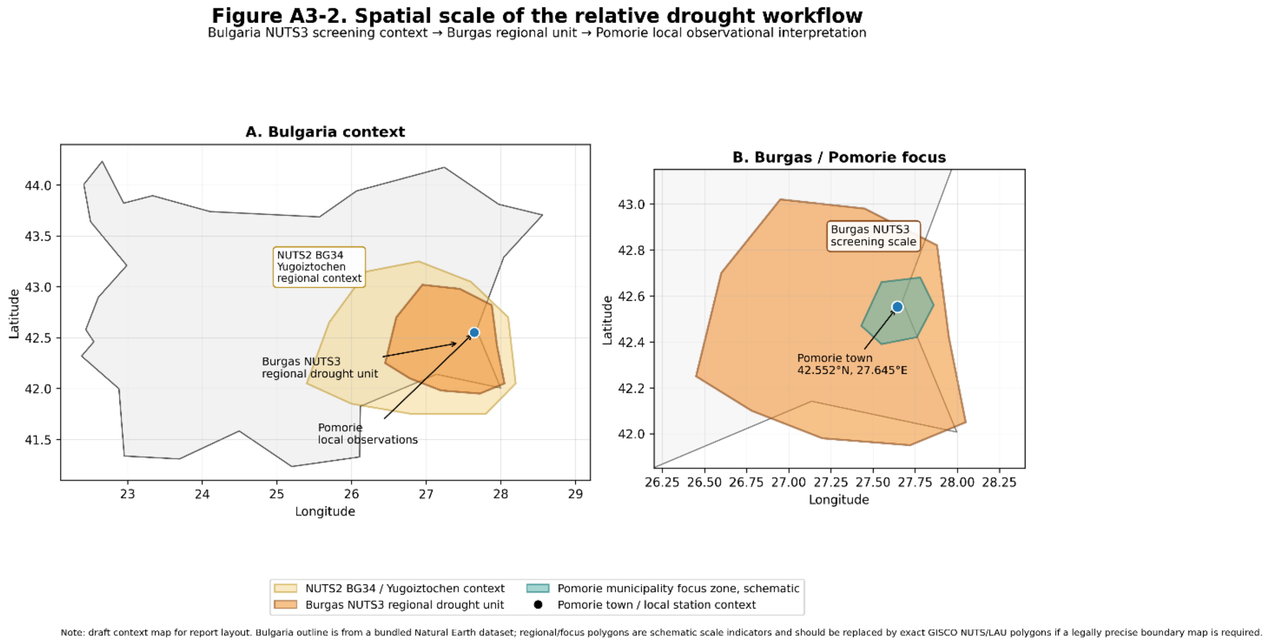


Figure A3-2. Spatial scale of the relative drought workflow: Bulgaria NUTS3 regions and Pomorie Municipality within Burgas Province.

Source: CLIMAAX relative drought workflow and NUTS regional data.

3.1. Hazard assessment

The drought hazard assessment was performed through the CLIMAAX relative drought workflow and further regionalised through local dry-spell observations. The relative drought workflow estimates drought hazard as the probability of exceeding severe precipitation deficits, using monthly precipitation totals at NUTS3 level. The workflow uses historical and future climate datasets and expresses drought hazard through WASP-based drought metrics. These values allow comparison of drought hazard between NUTS3 regions and across future scenarios.

For Pomorie Municipality, the NUTS3-level output is useful as a regional screening layer because Pomorie itself is not represented as a separate statistical unit in the workflow. The relevant administrative unit is the Burgas NUTS3 region, which provides a broader regional drought-hazard context.

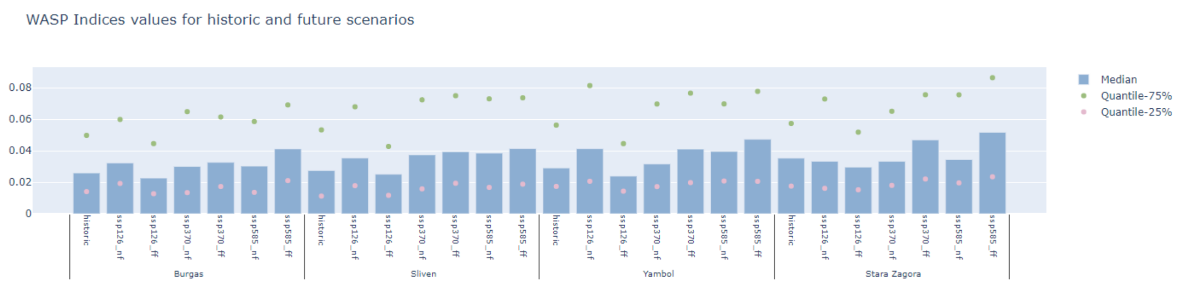


Figure A3-3. Relative drought hazard values for Burgas and neighbouring NUTS3 regions under historical and future scenarios.

Source: CLIMAAX relative drought hazard and risk visualisation workflow.

However, NUTS3-level outputs cannot capture the local microclimatic and land-use variability of the municipality. For this reason, the local observational analysis is particularly important.

The local dry-spell analysis was based on daily precipitation totals calculated from 30-minute measurements collected by the automatic Obscape station in Pomorie. A dry day was defined as a day with less than 1 mm of precipitation. This threshold excludes trace precipitation and very light rainfall events that are not sufficient to provide meaningful moisture replenishment for soils, crops or vegetation.

The full local expert analysis of dry conditions in Pomorie is presented below, as the local observational evidence base for the drought hazard assessment.

Analysis of dry conditions in Pomorie based on local observational data

Prolonged dry spells represent the counterpart of precipitation-related climate risk and may exert a substantial influence on water resources, soil moisture, vegetation, and agricultural production. In the coastal areas of Southeastern Bulgaria, where the Municipality of Pomorie is located, such periods often coincide with the warmest part of the year, when high temperatures and intense evaporation further amplify the effects of precipitation deficits. For this reason, the assessment of the frequency and duration of dry spells constitutes a key component of climate vulnerability analyses and adaptation planning.

The analysis of dry spells was based on daily precipitation totals derived from 30-minute records collected by an automatic meteorological station equipped with high-precision Obscape sensors. The station is located within the urban area of Pomorie, at the tip of the Old Town peninsula, at the interface between land and sea, at coordinates Latitude N 42.552436° and Longitude E 27.644691°. The station has been operating since 4 October 2024 and remains active at present. For the purposes of the analysis, a dry day was defined as any day with a precipitation total below 1 mm. This definition is consistent with widely applied climatological approaches to dry-spell identification and allows traces of precipitation and very light rainfall events with negligible significance for the water balance to be excluded.

The results indicate a pronounced predominance of dry days throughout a substantial part of the observation period (Figure A3-4). In several months, the number of days with precipitation below 1 mm exceeded 80–90% of all days. The most striking examples are July, September, and December 2025, when all days within the respective months fell below the 1 mm threshold and were therefore classified as dry according to the adopted criterion.

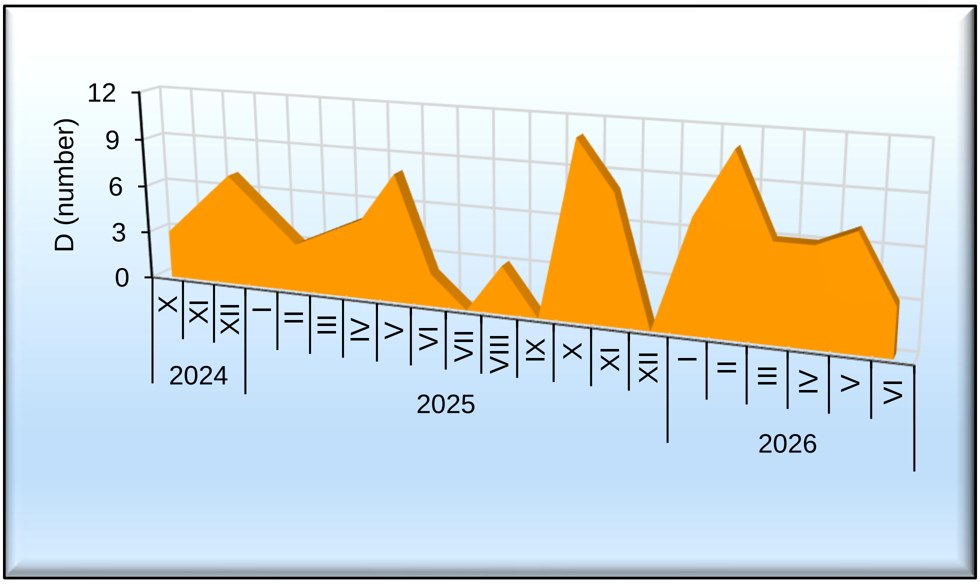


Fig. A3-4. Monthly number of days with precipitation below 1 mm (D) in Pomorie

A particularly important indicator is the maximum duration of consecutive dry days (CDD). The calculations show that the longest dry spell during the entire study period lasted 51 consecutive days, from 29 June to 18 August 2025 (Table A3-2). During this interval, not a single day recorded a precipitation total reaching 1 mm.

Table A3-2. Top 10 longest dry periods (P < 1 mm) in Pomorie

Beginning	End	Duration (number of consecutive days)
29.06.2025	18.08.2025	51
29.11.2025	06.01.2026	39
01.09.2025	01.10.2025	31
13.10.2024	10.11.2024	29
27.02.2026	22.03.2026	24
26.01.2025	15.02.2025	21
08.04.2025	25.04.2025	18
26.12.2024	10.01.2025	16
03.03.2025	16.03.2025	14
31.05.2025	13.06.2025	14

The second-longest dry spell extended from 29 November 2025 to 6 January 2026 and lasted 39 days. It was followed by dry periods of 31 days (1 September – 1 October 2025) and 29 days (13 October – 10 November 2024). The occurrence of several prolonged dry spells within a relatively short time interval reflects considerable seasonal and intra-annual variability in the local precipitation regime.

Particularly interesting results emerge when distinguishing between climatologically dry periods and completely rain-free periods. To this end, an additional verification was performed to determine whether any measurable precipitation (P > 0 mm) occurred during the longest dry spells. The analysis demonstrates that not all dry periods are of the same nature.

The longest dry spell (29 June – 18 August 2025) proved to be completely rain-free. No measurable precipitation was recorded during any of its 51 consecutive days. The same applies to the period from 13 October to 10 November 2024, which lasted 29 days. These cases represent genuinely rain-free periods in the strict sense of the term.

By contrast, the second-longest dry spell (29 November 2025 – 6 January 2026) exhibited a different character. Although no day within this interval reached the 1 mm threshold, numerous micro-rainfall events were recorded. The cumulative amount of these events approached 6 mm, while the highest daily total reached 0.578 mm. This allows the period to be classified as climatologically dry, but not as completely rain-free.

These findings indicate that dry spells in Pomorie can be divided into two principal categories. The first category comprises genuinely rain-free periods, during which no measurable precipitation is recorded. The second category is characterized by the occurrence of isolated very weak rainfall events that remain below the threshold defining a wet day and do not result in substantial moisture replenishment.

Overall, the analysis shows that dry conditions occupied a considerable proportion of the period from 4 October 2024 to 12 June 2026 in Pomorie. This was particularly evident during the summer and early autumn of 2025, when the longest rain-free period was recorded. The occurrence of several dry spells lasting more than one month indicates a significant potential for the development of soil moisture deficits and agrometeorological drought conditions. The results underline the importance of dry spells as a key element of the local climate regime and as a factor that should be taken into account in climate risk assessments and water-resource management. This includes monitoring seasonal precipitation deficits, maintaining drought early-warning systems, and promoting more efficient water-use practices in both agriculture and urban environments.

It should be emphasized that the results presented here are derived from actual local observations conducted within the territory of Pomorie at high temporal resolution. In the analysis of dry spells, such data are of particular value because they allow the precise determination of the onset, termination, and duration of rain-free intervals, as well as the distinction between genuinely rain-free periods and periods interrupted by isolated, very weak rainfall events. Such information is difficult to obtain with sufficient accuracy from spatially averaged climate models or reanalysis products. Consequently, local instrumental observations provide a reliable basis for drought-risk assessment, the monitoring of seasonal precipitation deficits, and the development of adaptation measures tailored to the specific characteristics of the area.

Prolonged dry spells should be regarded not only as a climatic characteristic but also as a factor with potentially significant socio-economic implications.

The results show a pronounced prevalence of dry days during substantial parts of the observation period. In several months, the number of days with precipitation below 1 mm exceeded 80–90% of all days. July, September and December 2025 were especially significant, as all days in these months were classified as dry according to the adopted threshold.

The most important local drought indicator is the maximum duration of consecutive dry days. The longest dry spell during the analysed period lasted 51 consecutive days, from 29 June to 18 August 2025. During this period, no day reached the 1 mm precipitation threshold. This is a highly relevant result because it occurred during the warm season, when evapotranspiration demand is high and precipitation deficits may rapidly translate into soil moisture deficits and agricultural stress.

Several additional dry spells were also recorded. The second-longest dry spell lasted 39 days, from 29 November 2025 to 6 January 2026. It was followed by a 31-day dry period from 1 September to 1 October 2025 and a 29-day dry period from 13 October to 10 November 2024. The occurrence of several dry periods lasting close to or more than one month indicates that drought-related risk in Pomorie is not limited to isolated summer episodes, but forms part of the local intra-annual precipitation regime.

The local analysis also distinguishes between two types of dry spells. The first type consists of genuinely rain-free periods, during which no measurable precipitation occurs. The 51-day period from 29 June to 18 August 2025 and the 29-day period from 13 October to 10 November 2024 fall into this category. The second type consists of climatologically dry periods with isolated micro-rainfall events below the 1 mm threshold. The 39-day period from 29 November 2025 to 6 January 2026 belongs to this category: although the period did not include a wet day, small precipitation amounts were recorded, with a total of around 6 mm and a maximum daily amount of 0.578 mm. This distinction is important because micro-rainfall may slightly affect surfaces but does not substantially replenish soil moisture or reduce agricultural drought risk.

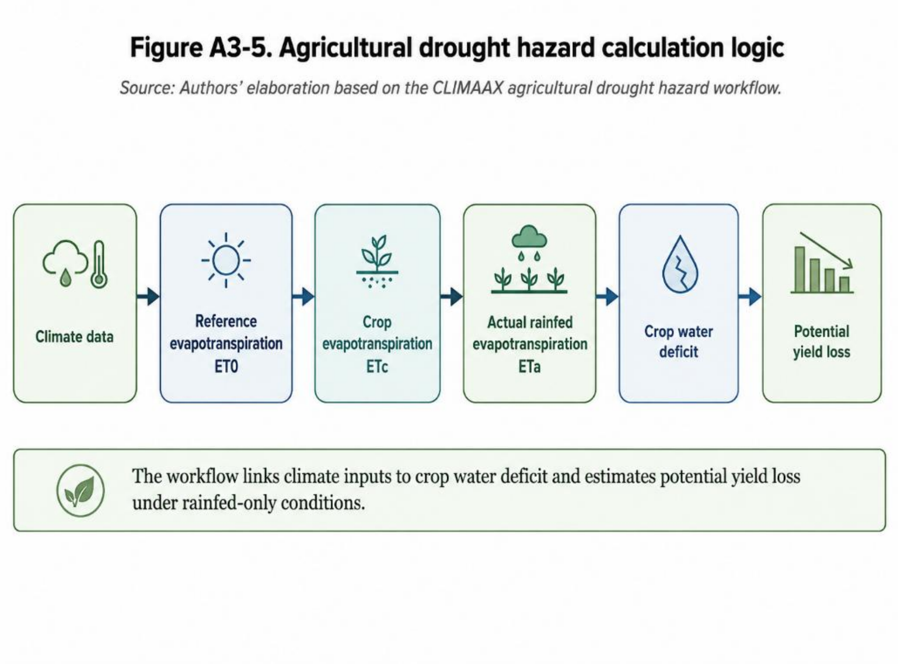
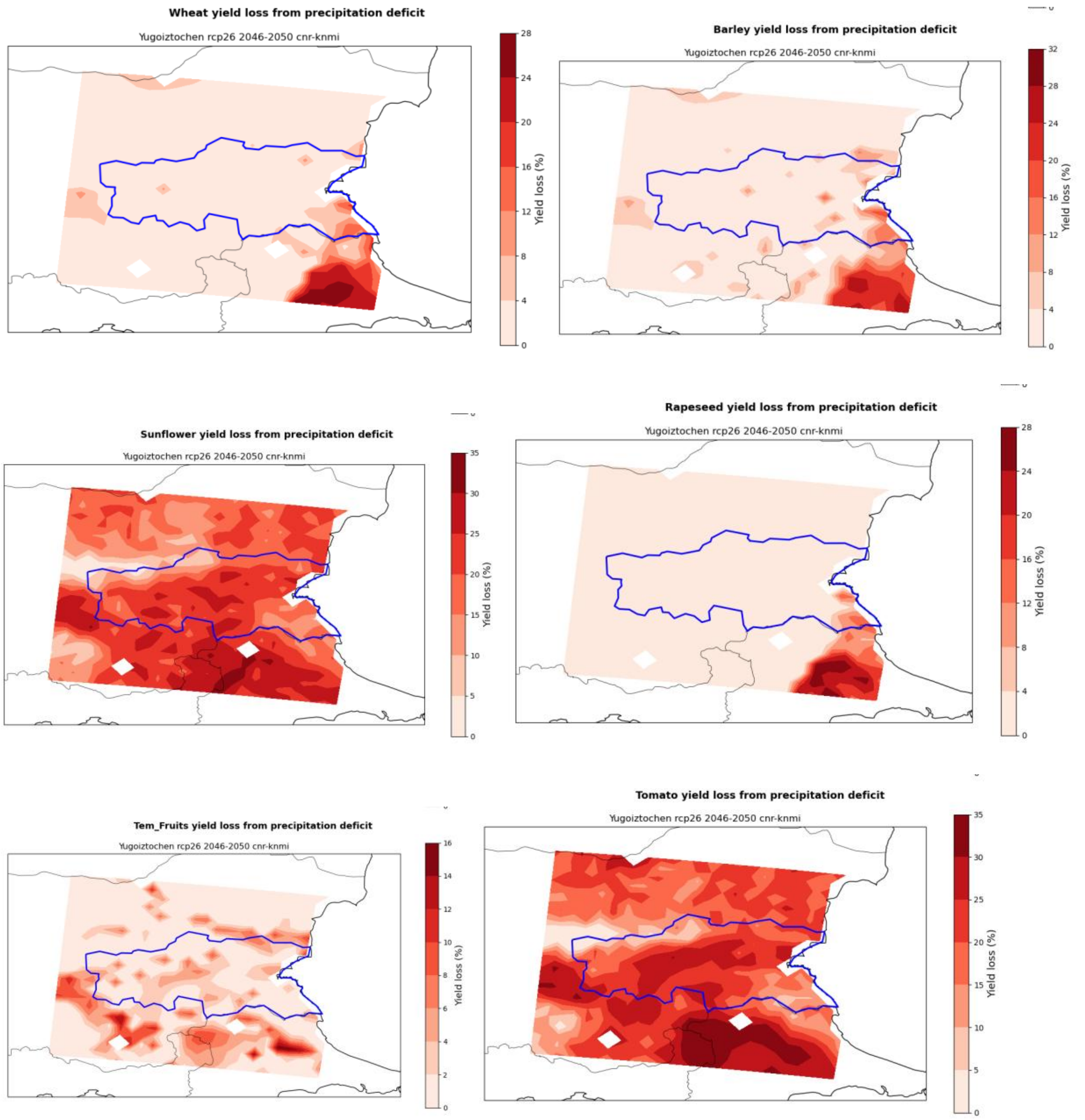


Figure A3-5. Agricultural drought hazard calculation logic.

Source: Authors' elaboration based on the CLIMAAX agricultural drought hazard workflow.

The agricultural drought hazard assessment provides a second hazard layer by focusing on crop-water deficits. The workflow calculates reference evapotranspiration using the FAO Penman-Monteith approach and combines it with crop-specific parameters to estimate crop evapotranspiration requirements. The difference between potential crop water demand and water availability is then used to estimate potential yield loss under rainfed-only conditions. In the uploaded workflow, the assessment was implemented for the NUTS2 region BG34 / Yugoiztochen, which includes Pomorie Municipality within the wider Southeastern Bulgaria context.

The crop parameters used in the workflow include crop coefficients, growing-period length, rooting depth, depletion factor and crop water-yield response factor. The selected crops included key crops relevant to the wider regional agricultural context, such as wheat, barley, rapeseed, sunflower, temperate fruits and tomatoes. This is appropriate for Pomorie and Burgas Province, where arable crops, vineyards, orchards and vegetables are part of the agricultural profile.



Figures A3-6 (a-f). Potential yield loss under rainfed-only conditions for selected crop in BG34 / Yugoiztochen region.

Source: CLIMAAX agricultural drought hazard workflow.

The main limitation of the drought hazard assessment is scale. The relative drought workflow is designed for national/NUTS3 comparison and is not a municipality-level drought model. The agricultural drought workflow is more spatially detailed but still relies on regional climate projections, global agricultural datasets and generalized crop parameters. The local dry-spell analysis is highly relevant but covers only a short observation period and one station. Therefore, the combined interpretation should be treated as a strategic screening assessment rather than a definitive drought-frequency or crop-loss model.

3.2. Risk assessment

The drought risk assessment combines hazard, exposure and vulnerability in two different ways. The relative drought workflow calculates a composite drought risk score from drought hazard, exposure and vulnerability indicators. The agricultural drought workflow estimates potential yield and revenue losses from irrigation deficit. The local analysis then provides a Pomorie-specific interpretation of the risk mechanisms.

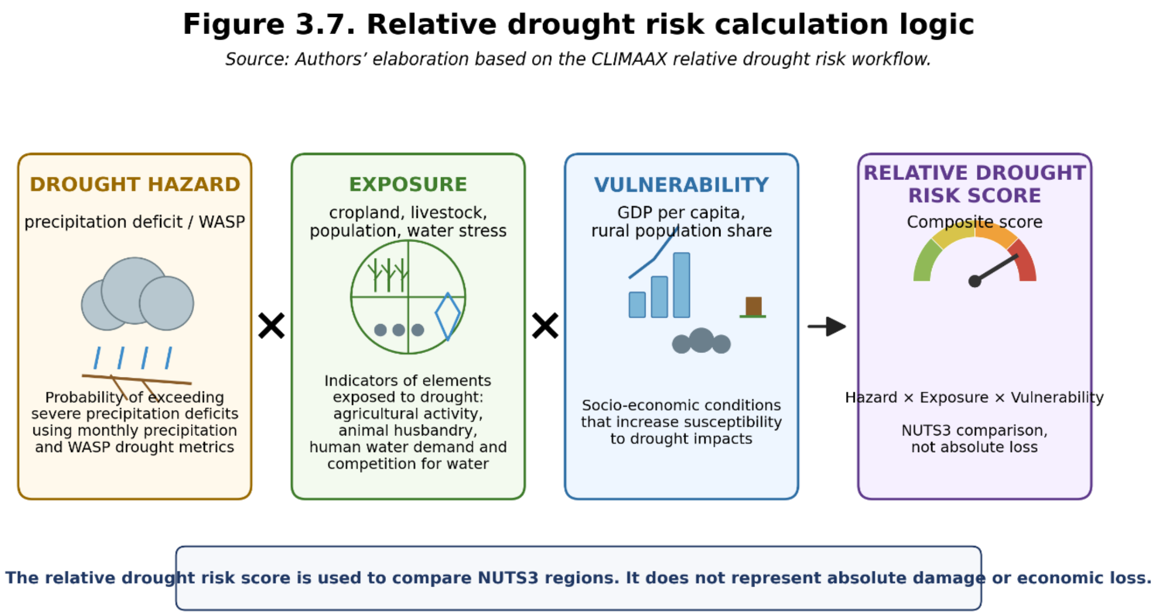
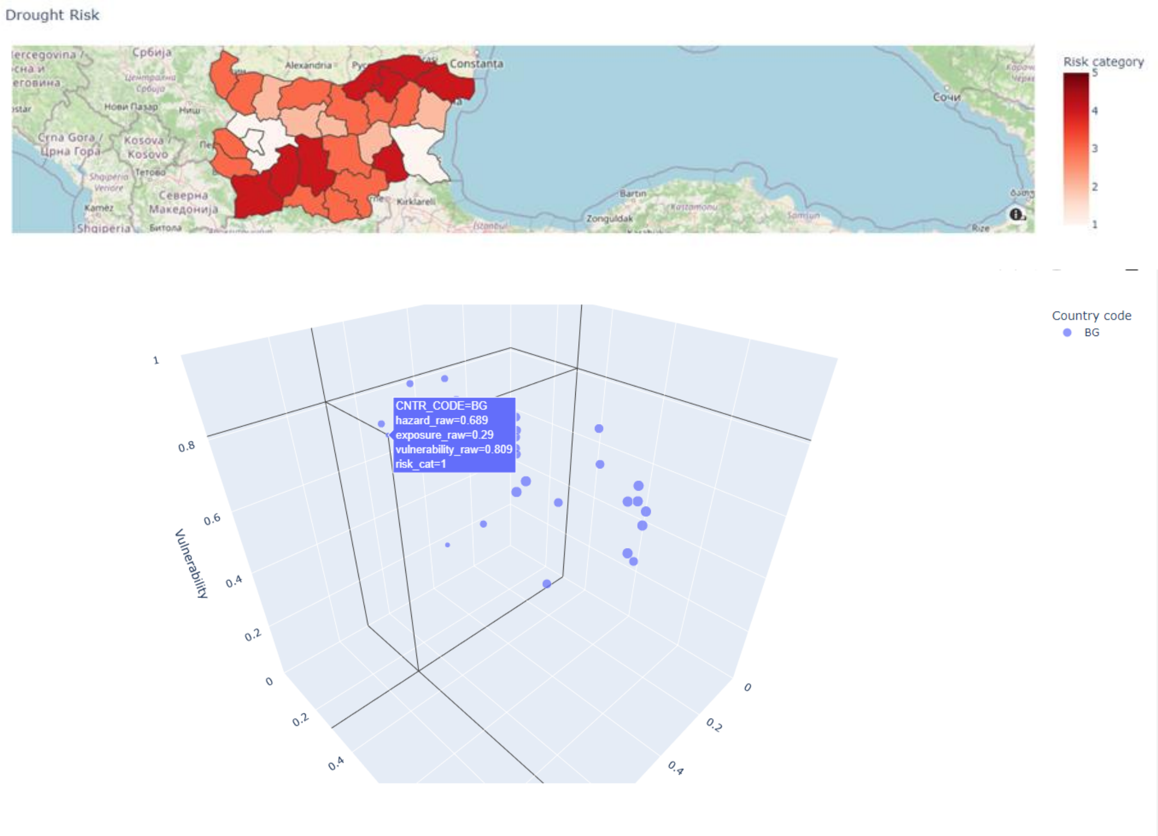


Figure A3-7. Relative drought risk calculation logic.

Source: Authors' elaboration based on the CLIMAAX relative drought risk workflow.

The relative drought risk workflow is useful because it places the Burgas/Pomorie area in a wider national and regional context. It uses cropland, livestock, population and water stress as exposure indicators, while GDP per capita and rural population share are used as vulnerability proxies. The resulting risk categories are relative to the selected national set of NUTS3 regions. Therefore, they should not be interpreted as absolute loss estimates. Instead, they indicate where drought risk is higher or lower compared with other regions included in the same assessment.



Figures A3-8. Relative drought risk categories for Bulgarian NUTS3 regions. *Source: CLIMAAX relative drought risk workflow.*

The agricultural drought risk workflow is more directly relevant to Pomorie's economic structure because it translates crop water deficit into potential yield loss and potential revenue loss. In this workflow, exposure is represented by crop production and crop value, while vulnerability is represented by irrigation availability. Revenue loss is interpreted as the lost opportunity cost of growing crops without sufficient irrigation under water-limited conditions. This is particularly relevant for crops with high exposure and/or high economic value, including cereals, oilseeds, fruits and vegetables.

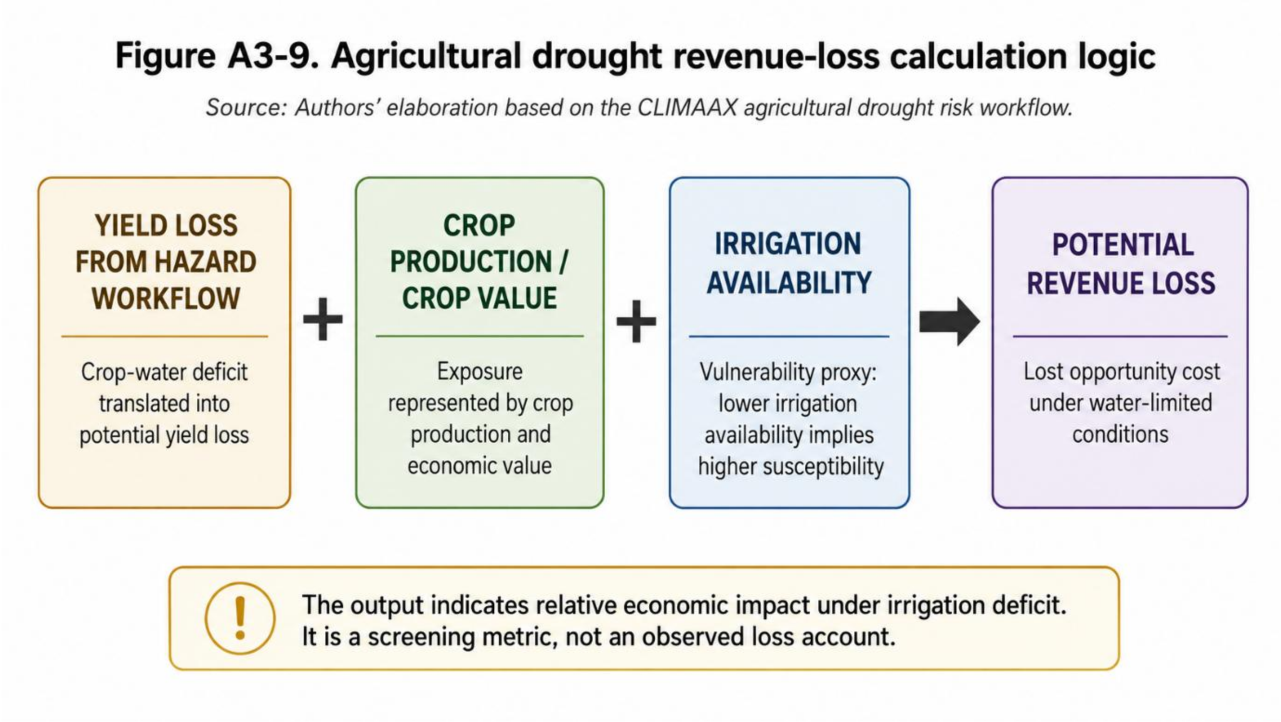
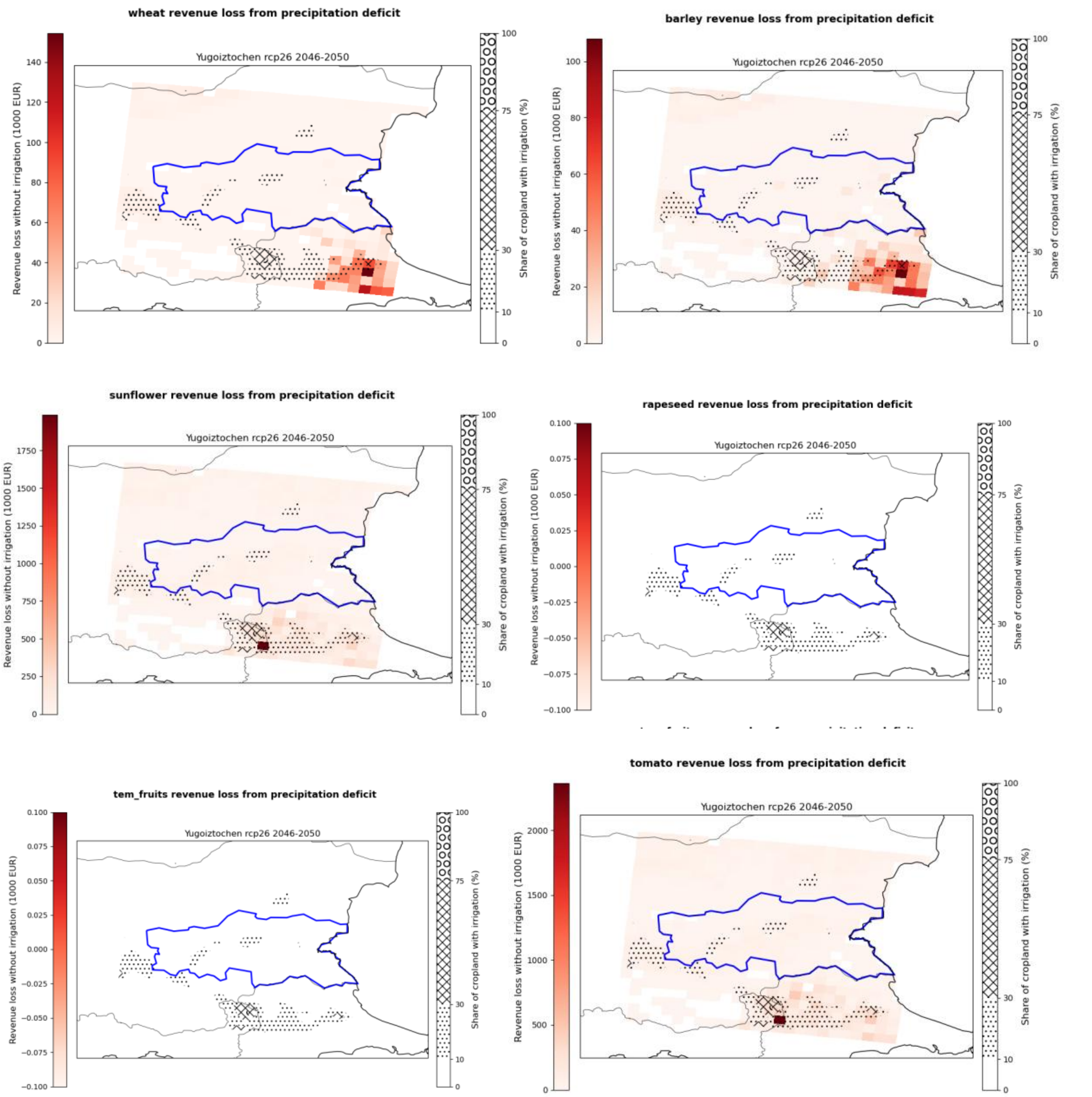


Figure A3-9. Agricultural drought revenue-loss calculation logic.

Source: Authors' elaboration based on the CLIMAAX agricultural drought risk workflow.

The local agricultural context confirms the relevance of drought as an impact pathway. According to the 2024 Burgas agricultural report, the maize yield in the region was low, with an average of 185 kg/da, and the report explicitly links the low yield to drought during the vegetation period. Sunflower also recorded low average yields in 2024. This local evidence supports the interpretation that drought and dry conditions can translate into measurable agricultural impacts, particularly for spring crops exposed to summer precipitation deficits.

For Pomorie Municipality, drought risk is relevant for several exposed sectors and systems. In agriculture, the most exposed elements include arable crops, vineyards, orchards, vegetables, pasture and livestock systems. Rainfed crops and fields with limited irrigation access are particularly vulnerable.



Figures A3-10 (a-f). Potential agricultural revenue loss from irrigation deficit for selected crop/crop group in BG34 / Yugoiztochen.

Source: CLIMAAX agricultural drought risk workflow.

Spring and summer crops are especially sensitive when long dry spells coincide with critical phenological stages. Perennial crops may also be affected through cumulative soil moisture deficits, reduced fruit development, stress on young plantations and increased irrigation needs.

The following expert analysis of wildfire occurrence is included because wildfire is treated here as a secondary climate-related risk associated with prolonged dry periods and drought conditions.

Wildfire Occurrence and Drought Conditions

Information provided by the Municipal Administration of Pomorie and the Regional Directorate Fire Safety and Civil Protection indicates that .ten significant wildfire and vegetation-fire events were recorded within Pomorie Municipality during the period 2021–2025 (Table A3-2, Figure A3-11). The documented incidents affected approximately 3,550 dka of forest, shrub, pasture, and agricultural land.

Table A3-2. Major wildfire and vegetation-fire events recorded in Pomorie Municipality (2021–2025)

Date	Location	Burned area (dka)	Land cover affected	Reported cause	:eteorological conditions
12.09.2021	Kabeleshkovo	<1	Forest vegetation	Under investigation	Sunny weather
14.05.2022	Kozichino	<1	Dry grassland	Under investigation	Sunny weather
15.08.2023	Pomorie	5	Broadleaf forest	Lightning	Sunny weather with moderate wind
25.09.2023	Poroy	<1	Forest vegetation	Negligence with open fire	Sunny weather
07.10.2023	Kozichino	4	Coniferous forest	Negligence with open fire	Sunny weather with moderate wind
08.08.2024	Aleksandrovo	200	Pasture and agricultural land	Violation of fire-safety regulations	Sunny weather with strong wind
26.08.2024	Poroy	3	Broadleaf forest	Under investigation	Sunny weather
08.08.2024	Poroy	4	Broadleaf and coniferous forest	Natural causes	Sunny weather with strong wind
05.07.2025	Bata	47	Forest and pasture	Negligence with open fire	Sunny weather with strong wind
09.07.2025	Bata	3288	Forest, pasture and agricultural land	Short circuit in overhead power line	Sunny weather with strong and gusty wind

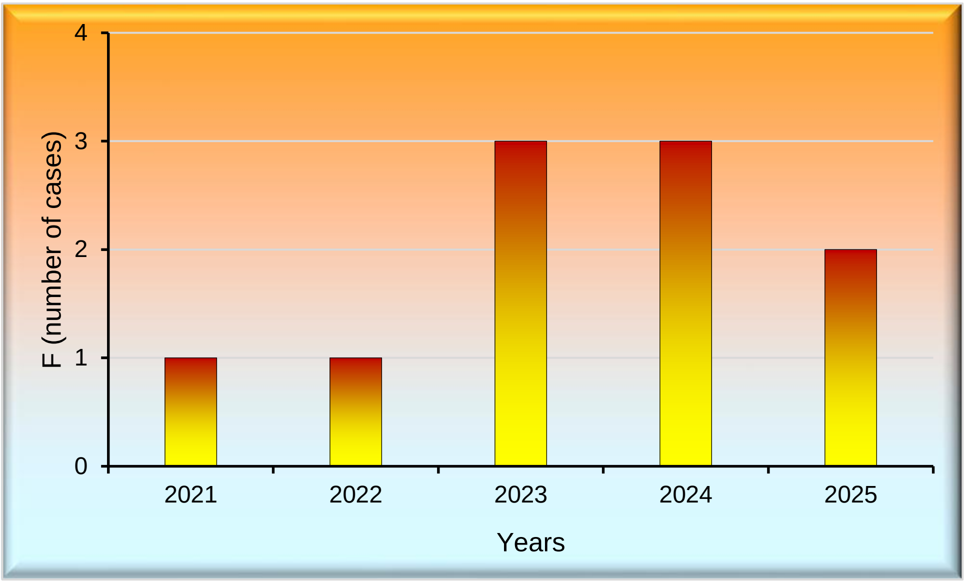


Fig.A3-11. Number of fire cases (F) in Pomorie municipality (2021-2025)

The temporal distribution of the events reveals a pronounced concentration during the warm season, particularly between July and September, coinciding with periods of elevated temperatures, reduced soil and vegetation moisture, and increased drought susceptibility. Most incidents occurred under sunny weather conditions, frequently accompanied by moderate or strong winds, which may have facilitated fire ignition and spread.

The recorded causes include both anthropogenic and natural factors, such as negligence involving open fire, violations of fire-safety regulations, technical failures in power infrastructure, and lightning. Nevertheless, the observed meteorological conditions suggest that drought and prolonged dry periods likely increase vegetation flammability and contribute to higher wildfire susceptibility across the municipality.

The largest documented event occurred on 9 July 2025 near the village of Bata, where approximately 3,288 dka of forest, pasture, and agricultural land were affected. Together with the 200-dka fire recorded near Aleksandrovo in August 2024, this event demonstrates that although most recorded fires were relatively small, individual incidents can generate substantial environmental impacts.

The available records suggest that wildfire occurrence in Pomorie is currently episodic and largely influenced by human activities; however, climatic conditions may increasingly contribute to fire-conducive environments in the future.

Consequently, wildfire occurrence may be regarded as a secondary climate-related hazard associated with drought conditions and prolonged summer dry periods in Pomorie Municipality.

Although wildfire occurrence cannot currently be considered among the dominant climate-related hazards in Pomorie Municipality, the documented events demonstrate that drought conditions may contribute to increased vegetation-fire susceptibility. Considering projections indicating a potential increase in air temperatures, more frequent heatwaves, and longer dry periods in the future, conditions favourable for wildfire ignition and spread may become more common. Consequently, wildfire occurrence should be regarded as a secondary climate-related risk that may gain greater relevance under future climate-change conditions.

Water-resource and ecosystem impacts should also be considered. Prolonged dry spells may reduce surface runoff, increase pressure on groundwater and irrigation sources, affect small water bodies and drainage channels, and contribute to water-balance changes in Pomorie Lake and adjacent wetland and salina systems. These effects may interact with high temperatures and evaporation, especially in summer. For the urban and tourism sectors, drought may increase water demand for landscaping, gardens, public green areas, accommodation facilities and beach-related services.

Indirect impacts were considered qualitatively. They include higher irrigation and production costs, reduced crop quality and yields, increased pressure on water allocation between agriculture, tourism and households, deterioration of urban green spaces, increased wildfire susceptibility in dry vegetation, ecological stress in wetland areas, and potential economic losses for farms and agri-food value chains. Drought can also interact with heatwaves, increasing crop stress and public-health pressure during the summer season.

The main limitations of the risk assessment are related to data availability and scale. Detailed local irrigation-network data, farm-level crop distribution, actual irrigated areas, groundwater abstraction, reservoir and water-supply data, soil maps at high resolution, and historical drought-damage records were not available for full integration. The agricultural drought workflow uses 2020 crop production data and 2015 irrigation availability data, which may not fully represent current conditions. The relative drought workflow provides a comparative rather than absolute risk category. For these reasons, the outputs should be used to identify priority sectors and areas for further investigation rather than to estimate precise economic losses.

Overall, the Phase 2 drought assessment confirms that drought is a significant and multi-sectoral risk for Pomorie Municipality. The most important local signal is the occurrence of long dry spells, including a 51-day rain-free period during the summer of 2025. This creates conditions for soil moisture deficit, agricultural stress and increased water demand. The agricultural evidence from Burgas Province confirms that drought during the vegetation period can materially affect yields. The results support the need for improved drought monitoring, local soil-moisture and precipitation tracking, assessment of irrigation capacity and efficiency, crop-specific adaptation planning, and integration of drought scenarios into water-resource, agricultural and ecosystem-management decisions.

4. Hazard #4 - Heatwaves - finetuning to local context

Heatwaves were selected as a separate hazard because of their direct relevance for human health, tourism, urban comfort, energy demand, labour productivity, agriculture, ecosystems and water demand. In coastal municipalities such as Pomorie, heat-related risk has a specific character. The Black Sea moderates daytime temperature extremes, but may also contribute to warmer nights and higher humidity, reducing physiological recovery during the night and increasing perceived heat discomfort. For this reason, heat risk in Pomorie cannot be assessed only through maximum daytime temperature. It also requires attention to tropical nights, humidity, wind conditions, solar radiation and the distribution of vulnerable population groups.

The Phase 2 heatwave assessment combines three complementary layers. First, the CLIMAAX EuroHEAT workflow was used to assess future heatwave occurrence based on pre-computed EURO-CORDEX heatwave indicators. Second, the Xclim-based workflow was used as a flexible methodological layer for calculating heatwave indicators using user-defined thresholds for daily maximum and minimum temperature. Third, a local observation-based analysis was used to interpret actual thermal conditions in Pomorie, including long-term temperature trends and recent high-resolution measurements from the coastal monitoring station.

This combination is important because the climate-model workflows provide future scenario information, while the local observations reveal the specific thermal behaviour of the Pomorie coastal environment. The local record indicates a strong maritime influence: daytime temperature extremes are moderated, but night-time temperatures remain elevated during the warm season. This creates a heat-risk profile that is different from inland urban areas and should be reflected in local adaptation planning.

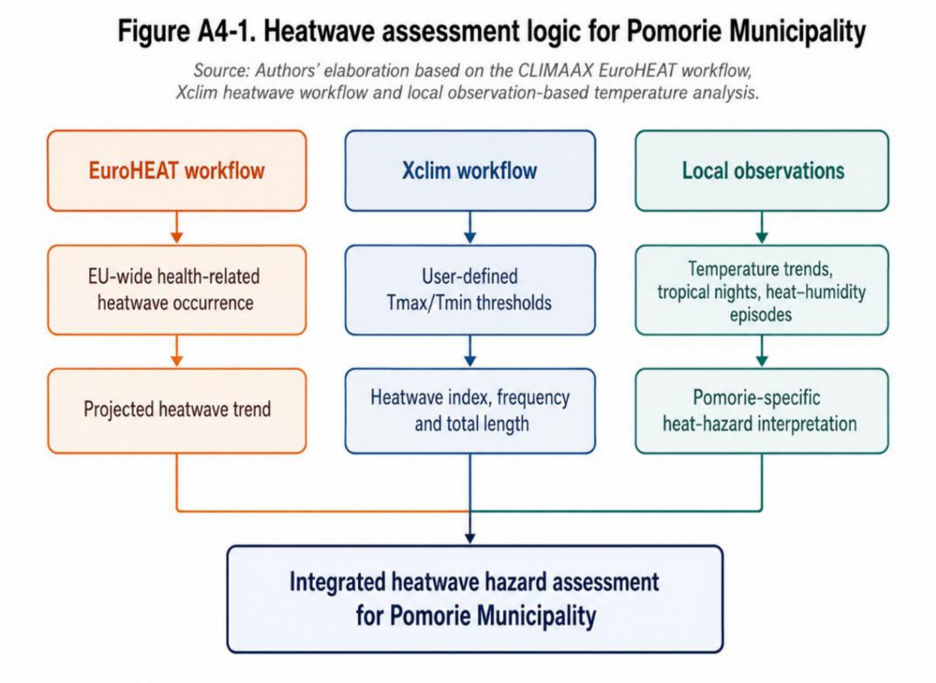


Figure A4-1. Heatwave assessment logic for Pomorie Municipality. *Source: Authors' elaboration based on the CLIMAAX EuroHEAT workflow, Xclim heatwave workflow and local observation-based temperature analysis.*

Table A4-1. Data overview workflow #4

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
EuroHEAT heatwave occurrence data from Copernicus Climate Data Store, based on EURO-CORDEX climate projections at approximately 12 km resolution. The health-related EU-wide definition identifies heatwave days during June–August when maximum apparent temperature and minimum temperature exceed their monthly 90th percentile thresholds for at least two days. Data are available for 1986–2085 under RCP4.5 and RCP8.5. For Pomorie, the manual point used was approximately 42.55°N, 27.65°E, with the nearest grid-cell centre at approximately 42.50°N, 27.70°E.	Vulnerable population groups from WorldPop, focusing on age groups particularly sensitive to heat, including young children and older people. The Burgas district workflow uses both male and female population layers for age 1–5 and older-age groups such as 65, 70, 75 and 80.	Regional exposure: Burgas district / Pomorie Municipality within the selected administrative region. Local exposure includes the Old Town peninsula, densely built-up residential areas, tourist accommodation areas, public spaces, transport stops, health and social-care facilities, beaches, urban green spaces and outdoor workplaces.	Projected heatwave occurrence per year; trend in heatwave occurrence under RCP4.5 and RCP8.5; relative change in heatwave occurrence for near future and further future; regional heatwave-risk classes for vulnerable population groups using a 10x10 risk matrix.
Xclim heatwave hazard workflow based on daily maximum and minimum 2 m air temperature from EURO-CORDEX climate-model data at 12 km resolution. The workflow allows the use of user-defined thresholds for maximum temperature, minimum temperature and minimum event duration. The Pomorie bounding box was defined as approximately 27.399243–27.680081°E and 42.538932–42.90717°N, with a manual point near 42.56°N, 27.64°E.	Threshold-based vulnerability interpretation: heat-health risk depends not only on daytime maxima, but also on warm nights, persistence, humidity, ventilation, age, health status, housing quality, access to cooling, outdoor work and visitor exposure.	Current socio-economic exposure was used as the baseline. No detailed future land-use, tourism-population or building-level exposure scenario was applied in this iteration.	Heatwave index, heatwave frequency and heatwave total length; annual values for selected scenarios; comparison between RCP4.5 and RCP8.5; identification of increasing heatwave hazard under future climate conditions.

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
Regional heatwave risk workflow for Burgas district, combining EuroHEAT hazard data with WorldPop vulnerable population data. The workflow compares future periods 2016–2045 and 2046–2075 against the reference period 1976–2015.	Vulnerability classes derived from the concentration of vulnerable population groups. These classes are relative within the selected region and should not be interpreted as absolute vulnerability levels.	Administrative-region exposure for Burgas district. The workflow is suitable for regional-scale comparison, but not for detailed street-level urban heat-island assessment.	Relative change in heatwave occurrence; classified magnitude of projected hazard change; combined heatwave-risk class for vulnerable population groups. The uploaded Burgas workflow shows lower relative change classes for the near future and much higher classes for 2046–2075, especially under RCP8.5.
Local observation-based temperature analysis for Pomorie. Long-term monthly mean air temperature series for Pomorie/Burgas, 1894–2023, and high-resolution local meteorological data for 04 October 2024 – 14 June 2026. The local station is located on the Old Town peninsula, directly exposed to the marine environment.	Local vulnerability interpretation based on tropical nights, very warm nights, heat–humidity episodes and compound heat-discomfort conditions. Vulnerable groups include older people, young children, people with chronic illness, outdoor workers, tourists, socially isolated persons and people in poorly ventilated buildings.	Local exposure: coastal urban areas, inland built-up sectors, accommodation facilities, outdoor public spaces, beaches, markets, transport stops, social and health facilities, schools/kindergartens, and areas with limited shade or ventilation.	Long-term warming trend; annual, January and July temperature trends; absolute maximum and minimum temperatures; number of hot days, tropical nights and heat–humidity episodes; compound heat-discomfort indicators combining temperature, humidity, wind speed and solar radiation.
Satellite-derived heat exposure methodology based on Landsat 8 land surface temperature at 30 m resolution and WorldPop vulnerable population at 100 m resolution.	Vulnerability represented by density of vulnerable population groups. The method can be improved with local census, health,	Local surface exposure: built-up areas, paved surfaces, low-vegetation zones, public spaces and potentially	Local heat-risk map based on risk = heat exposure x vulnerable population density. This is a methodological layer for future refinement because it requires

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
	social-care and critical-facility datasets.	overheated surfaces.	suitable cloud-free satellite scenes and local validation.

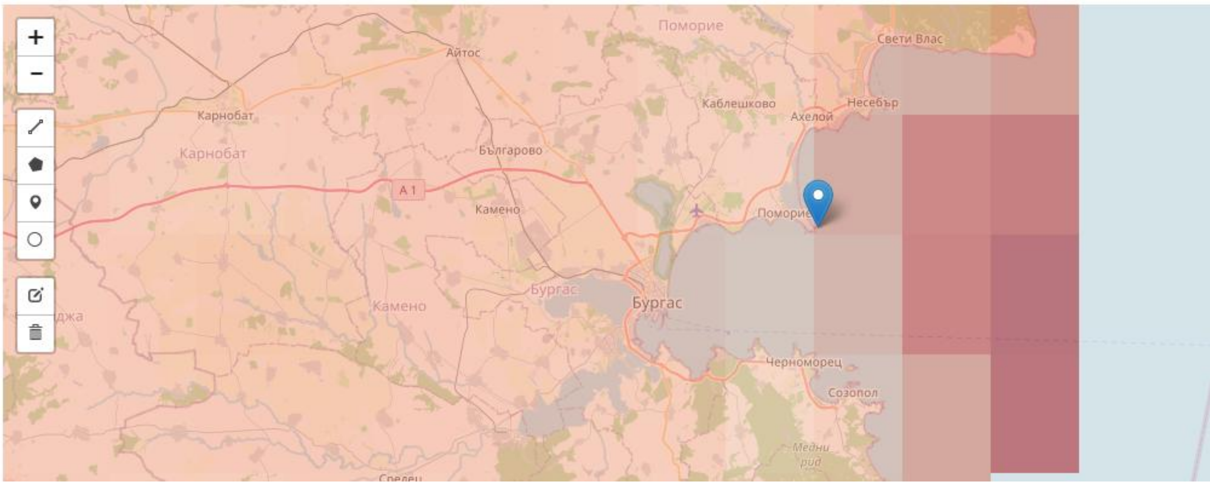


Figure A4-2. Pomorie location and nearest EuroHEAT grid cell used for the heatwave hazard assessment.
Source: CLIMAAX EuroHEAT heatwave hazard workflow.

4.1. Hazard assessment

The heatwave hazard assessment was based on EURO-CORDEX climate projections, EuroHEAT heatwave indicators, Xclim heatwave indices and local observation-based temperature analysis.

The EuroHEAT workflow uses pre-computed heatwave occurrence data from the Copernicus Climate Data Store. The health-related EU-wide EuroHEAT definition identifies heatwave days during the summer period when both maximum apparent temperature and minimum temperature exceed their monthly 90th percentile thresholds for at least two consecutive days. This definition is particularly relevant for public health because it considers both daytime heat and night-time conditions, as well as the effect of humidity through apparent temperature.

For Pomorie, the EuroHEAT workflow used a manual location near the town and extracted the nearest 12 km grid cell. The workflow produced yearly heatwave occurrence series for 1986–2085 under RCP4.5 and RCP8.5. National heatwave-definition outputs were not available for Bulgaria, so the health-related EU-wide EuroHEAT definition was used as the main model-based hazard layer.

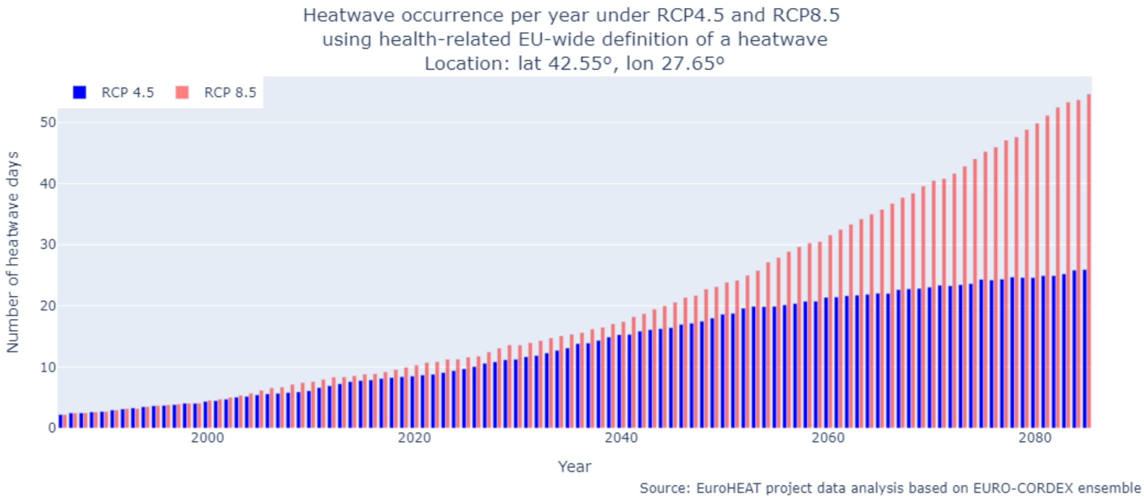


Figure A4-3. Projected yearly heatwave occurrence for the nearest Pomorie EuroHEAT grid cell under RCP4.5 and RCP8.5.

Source: CLIMAAX EuroHEAT heatwave hazard workflow, EU-wide health-related heatwave definition.

The Xclim workflow provides an alternative and more flexible approach. It calculates heatwave indicators directly from EURO-CORDEX daily maximum and minimum temperature data. The main advantage of this approach is that the user can define absolute temperature thresholds and minimum duration criteria that correspond better to the local or national heat-health context.

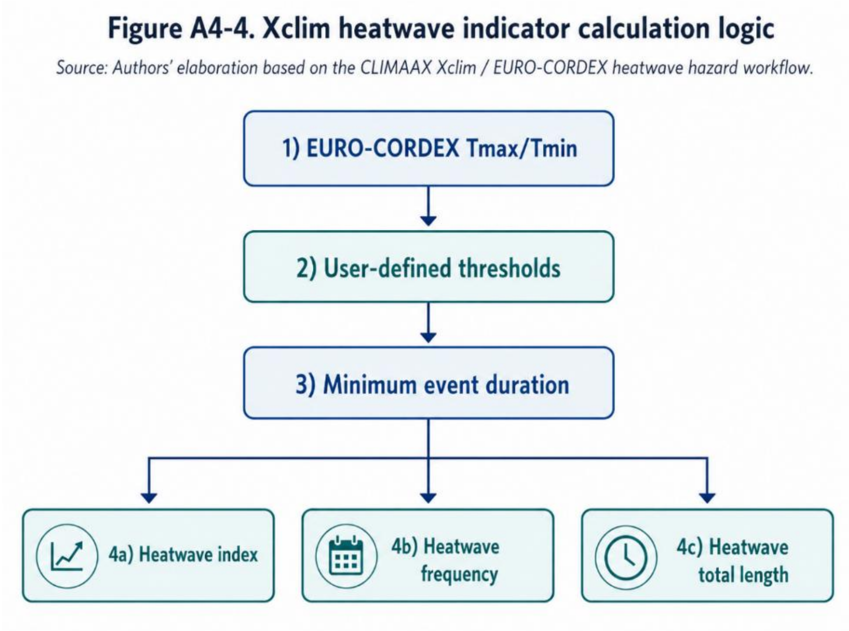
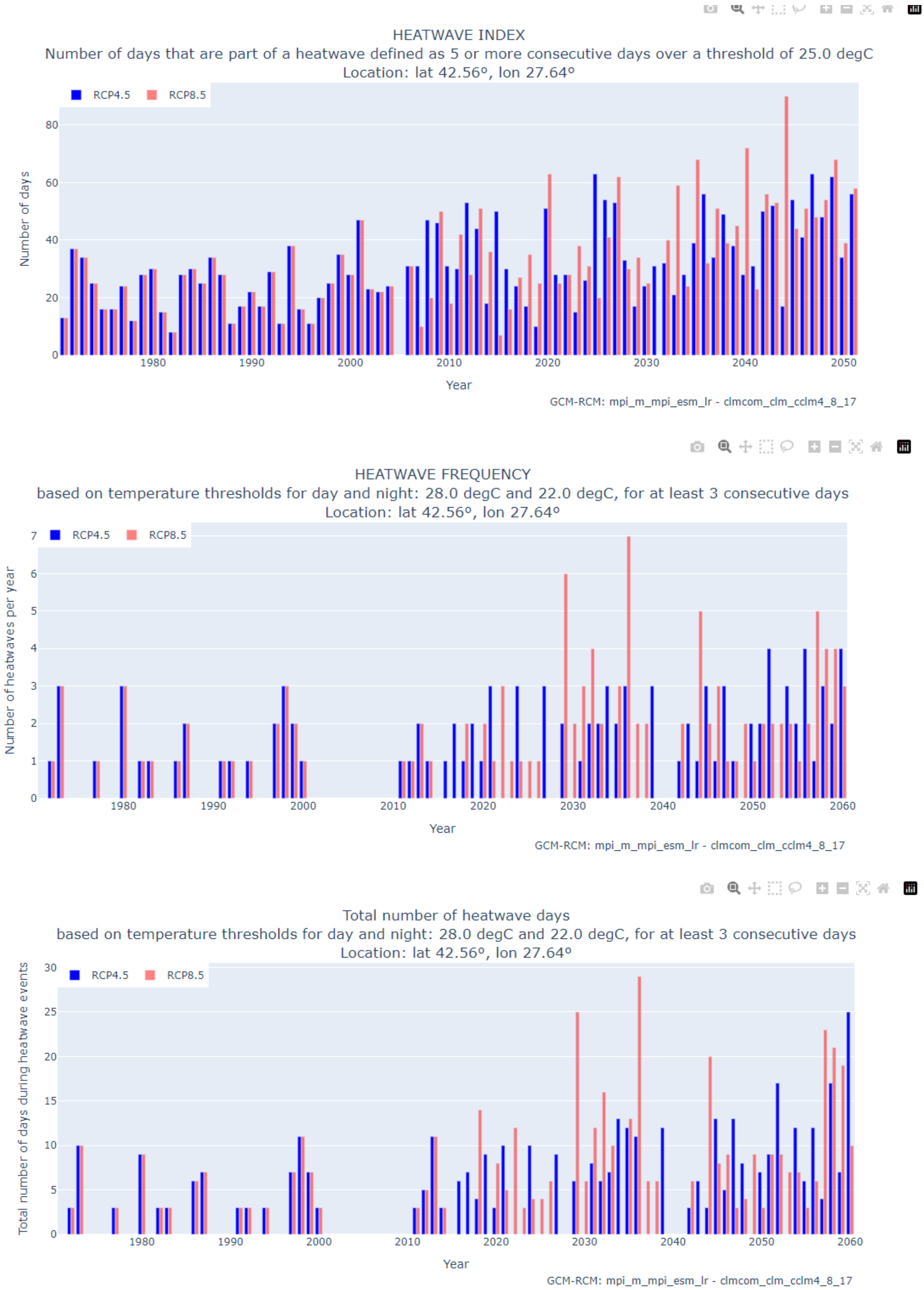


Figure A4-4. Xclim heatwave indicator calculation logic.

Source: Authors' elaboration based on the CLIMAAX Xclim / EURO-CORDEX heatwave hazard workflow.

The workflow can produce heatwave index, heatwave frequency and total heatwave length. Its limitation is that it is computationally more demanding and, in the uploaded implementation, relies on a single selected GCM-RCM model combination. Therefore, the results should be interpreted as indicative and ideally tested across several model combinations.



Figures A4-5 (a-c). Xclim heatwave indicator results for the selected Pomorie point under climate scenarios.

Source: CLIMAAX heatwave hazard assessment based on EURO-CORDEX and Xclim.

The regional EuroHEAT-based results for Burgas district indicate a clear increase in future heatwave occurrence. The workflow compares projected heatwave occurrence for 2016–2045 and 2046–2075 with a 1976–2015 reference period. The uploaded results show that the projected relative change is more pronounced in the future, especially under RCP8.5. For the 2046–2075 period, the RCP8.5 outputs fall into the highest classes of projected heatwave-occurrence increase within the selected regional analysis. This confirms that heatwave hazard is expected to become more important for the wider Burgas/Pomorie area under climate change.

The local observation-based analysis provides a more nuanced interpretation for Pomorie itself. The long-term air-temperature series for Pomorie/Burgas covering 1894–2023 shows a clear positive warming trend. The mean annual temperature trend is positive, and the July trend is stronger than the annual and January trends. This indicates that warming has been particularly relevant during the warm season, which is the most important season for heat-related hazards.

The full local expert assessment of long-term temperature trends and contemporary heat conditions in Pomorie is presented below, as the local observational evidence base for the heatwave hazard assessment.

Long-term temperature trends and contemporary heat conditions in Pomorie based on local observations

Long-Term Air Temperature Trends in Pomorie

The assessment of long-term air temperature dynamics provides an essential basis for understanding the evolution of heat-related climate hazards and their implications for local climate risk. In contrast to precipitation, temperature is generally characterised by a more coherent long-term signal, allowing the identification of persistent tendencies associated with climate change. To evaluate the long-term evolution of thermal conditions in Pomorie, a historical series of monthly mean air temperatures covering the period 1894–2023 was analysed.

The dataset comprises 130 years of observations and includes monthly mean temperatures and annual mean air temperatures. Based on these data, long-term linear trends were calculated for the annual mean temperature as well as for January and July, representing the coldest and warmest months of the year, respectively.

The analysis reveals a clear long-term increase in mean annual air temperature in Pomorie (Figure A4-6). The fitted linear trend is described by the equation:

$T = 0.0101x + 12.041$

with a coefficient of determination of $R^2 = 0.1484$.

The positive slope indicates a persistent warming tendency throughout the observation period. Although substantial interannual variability remains evident, the long-term trend clearly points towards progressively warmer thermal conditions. The obtained coefficient of determination is considerably higher than that derived from the corresponding long-term precipitation analysis, indicating a more coherent and stable climatic signal in air temperature.

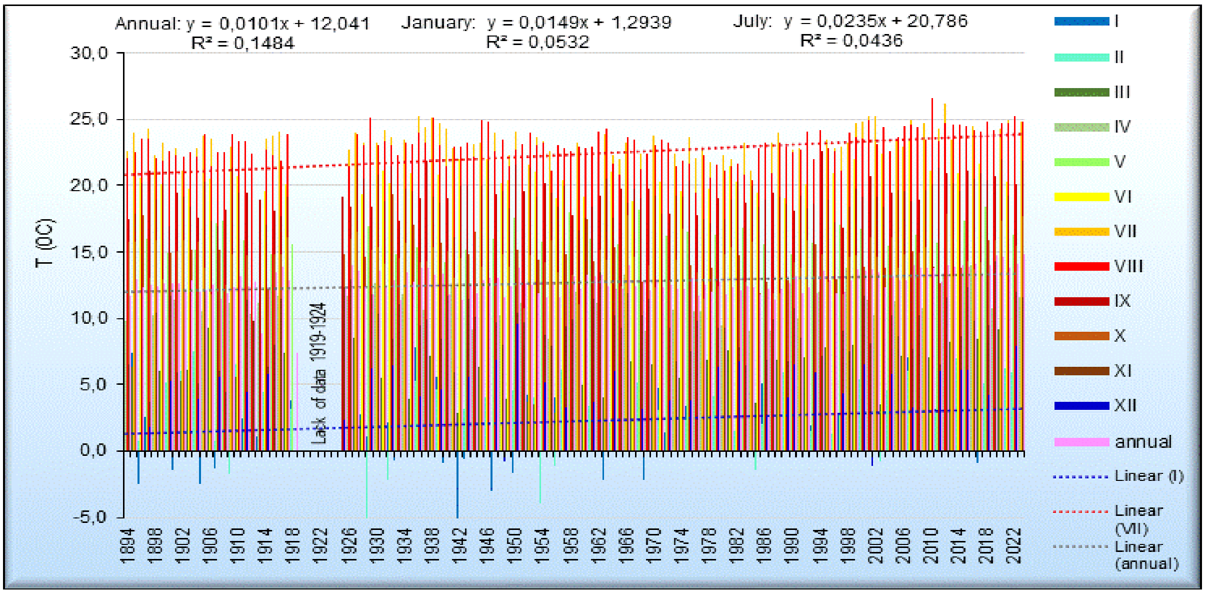


Fig.A4-6. Long-term course of monthly and annual average air temperature (T) in Pomorie/Burgas (1894-2023), with corresponding linear trends for January, July and annualy (Data source: National Institute of meteorology and hydrology at the Ministry of Environment of RB)

Additional insight is provided by the seasonal analysis of January and July temperatures. The January series exhibits a positive linear trend described by the equation:

$T = 0.0149x + 1.2939$ with $R^2 = 0.0532$.

The July series demonstrates an even stronger positive trend:

$T = 0.0235x + 20.786$ with $R^2 = 0.0436$.

The comparison between the annual, winter and summer temperature trends suggests that warming has not occurred uniformly throughout the year. The strongest increase is observed during July, indicating a more pronounced rise in summer temperatures compared with the annual average. January temperatures also display a positive tendency, although the rate of increase is lower than that observed in July.

These results suggest that the thermal regime of Pomorie has undergone a gradual warming during the past 130 years, with the most pronounced changes occurring during the warm season. This finding is particularly relevant in the context of heat-related hazards, as increasing summer temperatures may contribute to a higher frequency and intensity of hot days, tropical nights and heatwave events.

At the same time, the relatively modest coefficients of determination obtained for January and July indicate that long-term warming is superimposed on substantial year-to-year variability. Consequently, individual cold or warm years continue to occur despite the presence of an overall positive temperature trend.

The observed warming tendency provides an important climatological context for the analysis of recent thermal extremes and heatwave events based on high-resolution local observations from the period October 2024 – June 2026, presented in the following sections.

Indicative Statistical Extrapolation of the Historical Temperature Trend

In order to provide a preliminary indication of the possible future evolution of thermal conditions in Pomorie, a simple statistical extrapolation of the historical temperature trend was performed based on the linear relationship derived from the annual mean temperature series for the period 1894–2023.

The extrapolation is based on the trend equation:

$T = 0.0101x + 12.041$

which describes the long-term increase in annual mean air temperature observed during the historical period.

Assuming that the historical linear trend continues unchanged, the results suggest a gradual further increase in annual mean air temperature during the coming decades. Such an extrapolation indicates that warming is likely to persist throughout the twenty-first century, resulting in progressively warmer climatic conditions compared with those prevailing during the early part of the observational record.

Based on the observed linear trend, a simple statistical extrapolation suggests that annual mean air temperature in Pomorie could increase by approximately 0.3°C by the middle of the twenty-first century (around 2050) and by approximately 0.8°C by the end of the century (around 2100), relative to the climatic conditions observed at the end of the historical record. These estimates are derived solely from the continuation of the historical linear trend and should therefore be regarded as indicative rather than predictive values.

It should be emphasized, however, that this approach does not constitute a climate projection in the strict scientific sense. The analysis is based solely on the continuation of the historical statistical trend and does not incorporate greenhouse-gas emission scenarios, climate-model simulations, land-use changes, or other drivers that may influence future temperature evolution.

Consequently, the extrapolated values should be interpreted only as an illustrative indication of the direction and approximate magnitude of long-term change rather than as a prediction of future climatic conditions. Nevertheless, the persistent positive trend identified in the observational record provides robust evidence that the climatic background against which future heat-related hazards will develop is likely to become progressively warmer.

Thermal Conditions and Heat-Related Characteristics in Pomorie (04 October 2024 – 14 June 2026)

The assessment of local thermal conditions is an essential component of climate risk analysis, as elevated temperatures can affect human health, tourism, infrastructure, energy demand and overall environmental comfort. In coastal environments, however, thermal stress is not determined solely by air temperature. The combined influence of atmospheric humidity, wind conditions and solar radiation may significantly modify the thermal environment and the physiological perception of heat. Therefore, the present analysis examines both conventional temperature-based indicators and selected compound meteorological conditions associated with potential heat discomfort, using exclusively local observational data collected at 30-minute intervals between 4 October 2024 and 14 June 2026.

The monthly thermal regime derived from the observational record is presented in Fig.A4-7. Mean monthly air temperatures ranged from 2.8°C in February 2025 to 24.8°C in July 2025, reflecting the pronounced seasonal cycle typical of the western Black Sea coast. The warm season extended from May to September, with mean monthly temperatures exceeding 15°C, while the highest values occurred during July and August. Mean daily maximum temperatures reached 26.6°C in July 2025 and 26.4°C in August 2025, whereas mean daily minimum temperatures remained above 21°C during both months. This pattern indicates a substantial moderating influence of the Black Sea, which limits daytime temperature extremes while maintaining relatively warm nocturnal conditions.

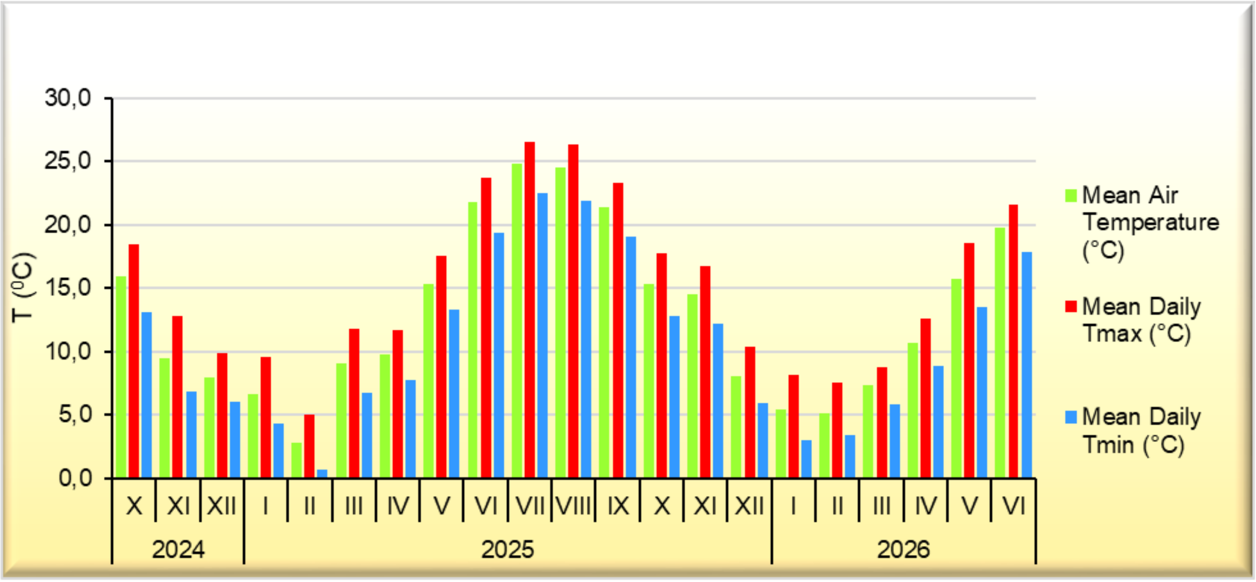


Fig.A4-7. Mean, maximum and minimum monthly air temperature in Pomorie (04.10.2024 – 14.06.2026)

The analysis of absolute temperature extremes confirms the absence of pronounced thermal extremes during the observation period (Table A4-2). The highest recorded air temperature was 28.8°C on 26 July 2025, while the lowest temperature reached −5.3°C on 18 January 2026. Although both values fall within the expected climatic range for the region, the relatively low summer maximum is noteworthy and highlights the strong maritime influence on local thermal conditions.

Table A4-2. Thermal indicators in Pomorie (04 October 2024 – 14 June 2026)

Indicator	Value
Absolute Tmax	28.8°C
Hot days ≥30°C	0
Heatwaves	0
Tropical nights ≥20°C	78
Very warm nights ≥22°C	42
Hot nights ≥25°C	1

This characteristic becomes even more evident when examining the occurrence of hot days (Table A4-2). No days with maximum air temperature equal to or exceeding 30°C were recorded during the study period, and consequently no days exceeded the higher threshold of

35°C. According to conventional climatological criteria, the station therefore experienced neither hot days nor very hot days during the analysed period.

Similarly, no heatwave events were identified using the adopted definition of at least three consecutive days with maximum air temperature equal to or exceeding 30°C (Table A4-2). The absence of heatwaves reflects the limited occurrence of high daytime temperatures and further confirms the moderating effect of the adjacent marine environment.

However, the analysis of nocturnal thermal conditions reveals a substantially different picture. As shown in Table A4-2, a total of 78 tropical nights (minimum air temperature ≥20°C) were recorded during the observation period. Moreover, 42 of these nights (54% of all tropical nights) exceeded the stricter threshold of 22°C, while one night remained above 25°C. These results indicate that although daytime temperatures rarely reached levels typically associated with heat stress, nocturnal cooling was frequently limited during the warm season. Such conditions may contribute to cumulative thermal discomfort by reducing opportunities for physiological recovery during the night.

The apparent contrast between the complete absence of hot days and the relatively large number of warm and tropical nights represents one of the most distinctive characteristics of the local thermal regime. It reflects the influence of the Black Sea, which acts as a thermal buffer, suppressing daytime temperature maxima while simultaneously maintaining elevated temperatures during the night. Consequently, the local heat environment cannot be adequately 64haracterized by temperature extremes alone.

To address this limitation, an additional assessment of potential heat-discomfort conditions was performed using combinations of air temperature, relative humidity, wind speed and solar radiation (Table A4-3). A total of 72 days recorded maximum air temperatures of at least 25°C. Of these, 32 days (44% of all days with Tmax ≥25°C) were simultaneously associated with relative humidity values of 70% or higher. When low wind speeds (≤2 m/s) were added as an additional criterion, only two days satisfied all conditions. Finally, only one day combined elevated temperature, high humidity, weak wind and strong solar radiation. These results suggest that although warm and humid conditions occurred relatively frequently, the generally good ventilation of the site substantially reduced the occurrence of more severe heat-discomfort situations.

Table A4-3. Heat discomfort conditions in Pomorie (04 October 2024 – 14 June 2026)

Criterion	Number of days
Tmax ≥ 25°C	72
Tmax ≥ 25°C & RH ≥ 70%	32
Tmax ≥ 25°C & RH ≥ 70% & Wind Speed ≤ 2 m/s	2
Tmax ≥ 25°C & RH ≥ 70% & Wind Speed ≤ 2 m/s & Solar Radiation ≥ 400 W/m²	1

The role of persistence was further examined through the identification of heat–humidity episodes, defined as periods of at least three consecutive days with maximum air temperature ≥25°C and relative humidity ≥70%. Three such events were identified during July 2025, indicating a marked concentration of compound heat–humidity conditions within the climatologically warmest period of the year (Table A4-4). Their durations ranged from three to five days, with the longest episode lasting five consecutive days and an average duration of four days. In total, twelve days were affected by persistent heat–humidity conditions. These episodes represent periods during which moderate temperatures, combined with elevated atmospheric moisture, may have generated appreciable thermal discomfort despite the absence of classical heatwaves.

Table A4-4. Consecutive heat–humidity episodes in Pomorie (04 October 2024 – 14 June 2026)

Event No.	Start Date	End Date	Duration (days)
1	05 July 2025	08 July 2025	4
2	13 July 2025	17 July 2025	5
3	23 July 2025	25 July 2025	3

Taken together, the results demonstrate that the thermal environment at the investigated site is 65haracterized by a pronounced maritime signature. Conventional temperature-based indicators suggest relatively limited heat hazard, with no hot days and no heatwave events recorded during the study period. Nevertheless, the occurrence of numerous tropical nights, the persistence of several heat–humidity episodes and the presence of compound meteorological conditions favourable to thermal discomfort indicate that heat-related impacts cannot be assessed solely through daytime temperature extremes. Instead, the interaction between temperature, humidity, wind conditions and radiative forcing plays a crucial role in shaping local thermal stress.

The interpretation of these findings should also consider the specific location of the monitoring station. Situated on the Old Town peninsula and directly exposed to the marine environment, the station reflects highly 65haracter coastal conditions that may differ from those experienced in the more densely built-up inland parts of Pomorie. The proximity of the sea contributes to reduced thermal amplitudes, moderation of daytime maxima and persistence of elevated night-time temperatures. Consequently, the results are most representative of the monitored coastal environment and may differ from thermal conditions occurring within the more densely built-up inland sectors of Pomorie.

Overall, three principal conclusions emerge from the analysis. First, the study period was 65haracterized by a complete absence of classical hot days and heatwave events, indicating a strong moderation of daytime thermal extremes by the adjacent Black Sea. Second, nocturnal conditions reveal a markedly different pattern, with 78 tropical nights and 42 very warm nights, demonstrating that elevated night-time temperatures constitute a more important component of local thermal stress than daytime heat extremes. Third, the application of compound temperature–humidity indicators identified several persistent heat–humidity episodes that would not have been detected using conventional temperature thresholds alone. These findings highlight the importance of considering multiple meteorological factors when assessing heat-related hazards in coastal environments.

The analysis provides an observation-based assessment of local thermal conditions derived exclusively from high-resolution local observations rather than modelled or reanalysis data. By relying on measured data, it offers valuable insight into the actual thermal behaviour of the coastal environment and establishes a robust basis for future climate risk assessments, heat-health evaluations and adaptation planning in the Pomorie area.

A simple statistical extrapolation of the historical annual temperature trend suggests continued warming during the twenty-first century. This extrapolation is not a climate projection and does not replace scenario-based modelling, but it supports the conclusion that the local climatic background is becoming progressively warmer.

The recent high-resolution local observations for 04 October 2024 – 14 June 2026 show that the monitored coastal site experienced no classical hot days and no heatwave events according to the threshold of at least three consecutive days with maximum temperature equal to or above 30°C. The highest recorded air temperature was 28.8°C, while no day reached 30°C. This reflects the strong moderating influence of the Black Sea on daytime temperatures at the monitoring location.

However, the nocturnal heat signal was much stronger. The local station recorded 78 tropical nights with minimum temperature equal to or above 20°C, 42 very warm nights with minimum temperature equal to or above 22°C, and one hot night above 25°C. This is a key finding for Pomorie. The coastal environment suppresses daytime temperature maxima, but it also reduces nocturnal cooling during the warm season. As a result, heat stress may accumulate through warm nights even when daytime temperatures do not meet standard heatwave thresholds.

The local analysis also assessed compound heat-discomfort conditions. A total of 72 days recorded a maximum temperature of at least 25°C. Of these, 32 days also had relative humidity equal to or above 70%. When low wind speed was added as a criterion, only two days satisfied all conditions. When strong solar radiation was also included, only one day satisfied the full set of heat-discomfort criteria. This indicates that ventilation from the coastal setting often reduces severe heat-discomfort conditions, but warm and humid episodes still occur.

Three persistent heat–humidity episodes were identified in July 2025. They lasted 4, 5 and 3 days respectively, with a total of 12 affected days. These episodes are important because they would not be detected by a classical maximum-temperature-only heatwave definition, yet they may still affect human comfort, sleep quality, tourism experience and vulnerable population groups.

The main limitation of the hazard assessment is the contrast in spatial scale. EURO-CORDEX and EuroHEAT data have a resolution of approximately 12 km and cannot capture urban heat-island effects, building density, street geometry, local shading, vegetation, surface materials or fine-scale coastal/inland differences within Pomorie. Conversely, the local station is highly representative of the monitored coastal location, but may understate heat exposure in more densely built-up inland sectors with weaker ventilation and higher surface heating. Therefore, both modelled and local observational results should be interpreted together.

4.2. Risk assessment

The heatwave risk assessment focuses mainly on human-health and social vulnerability, while also considering tourism, labour productivity, infrastructure, ecosystems and water demand. The main risk pathway is the overlap between increasing heatwave occurrence, warm nights, compound heat–humidity conditions and the presence of vulnerable population groups.

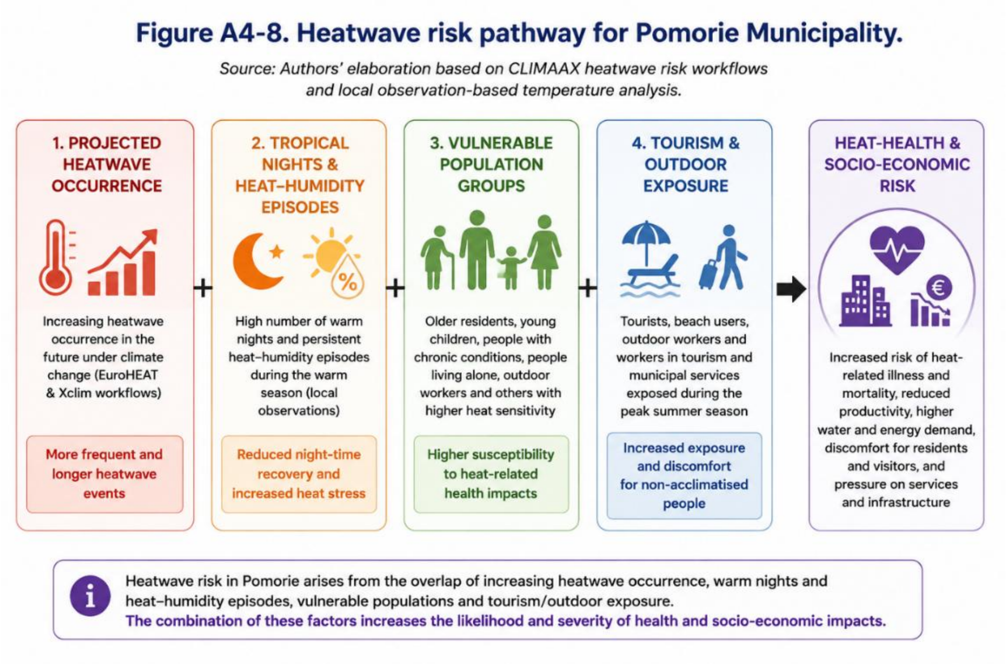


Figure A4-8. Heatwave risk pathway for Pomorie Municipality.

Source: Authors' elaboration based on CLIMAAX heatwave risk workflows and local observation-based temperature analysis.

The regional risk workflow for Burgas district combines EuroHEAT heatwave hazard data with WorldPop data on vulnerable population groups. The vulnerable groups include young children and older people, represented by male and female population layers for selected age groups. The workflow reclassifies projected heatwave-occurrence change and vulnerable population concentration into 10 classes and combines them through a 10x10 risk matrix. The resulting map identifies areas where the increase in heatwave occurrence coincides with higher concentration of vulnerable populations.

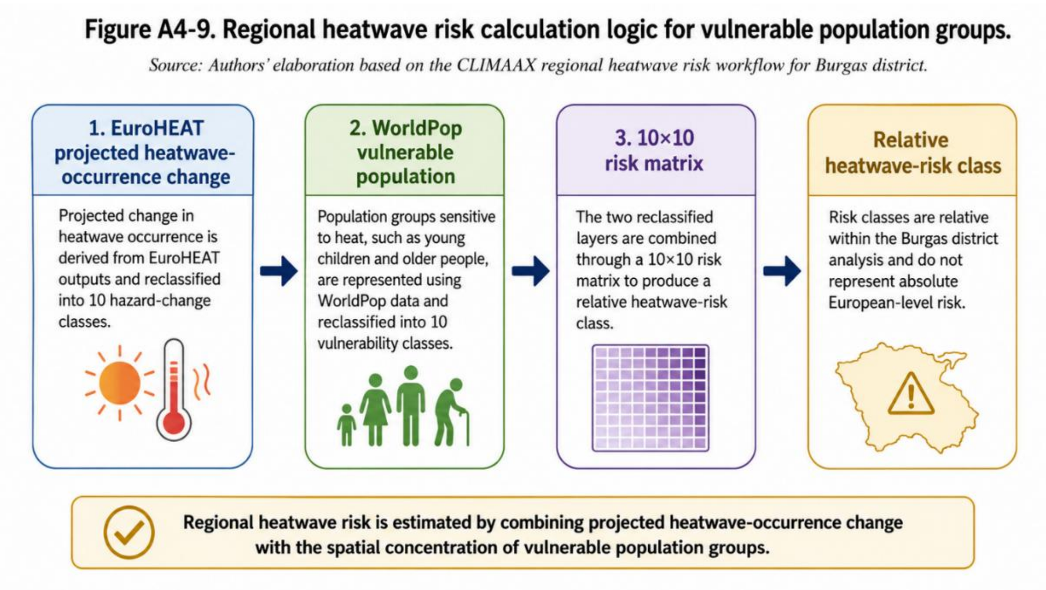


Figure A4-9. Regional heatwave risk calculation logic for vulnerable population groups.

Source: Authors' elaboration based on the CLIMAAX regional heatwave risk workflow for Burgas district.

The regional results indicate that heatwave risk for vulnerable population groups is expected to increase, especially in the further future and particularly under RCP8.5. However, these classes are relative to the selected region. A “high” or “very high” class does not mean that the area has the highest risk in Europe; it means that it is among the higher-risk areas within the selected Burgas district analysis. This distinction is important for accurate interpretation.

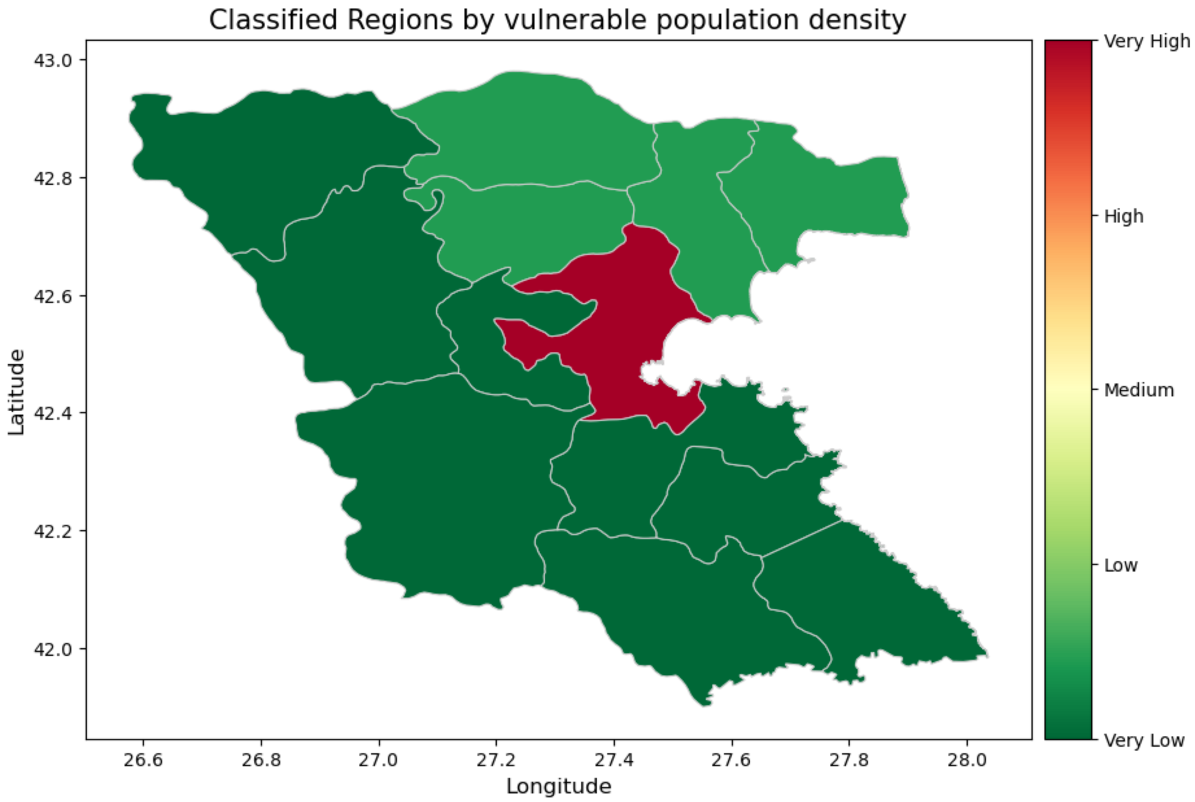


Figure A4-10. Projected heatwave-risk classes for vulnerable population groups in Burgas district.

Source: CLIMAAX heatwave risk workflow for Burgas district, combining EuroHEAT hazard change and WorldPop vulnerable-population data.

For Pomorie Municipality, the key exposed groups include older residents, young children, people with chronic health conditions, people living alone, outdoor workers, tourism-sector workers, beach users and visitors who may not be acclimatised to local conditions. Tourists are a particularly relevant exposure group because the peak tourism season overlaps with the warmest months and with periods of increased tropical-night occurrence.

The local observations indicate that risk in Pomorie may be driven less by extreme daytime maxima and more by warm nights, humidity and persistence. A large number of tropical nights may reduce night-time recovery, especially in poorly ventilated dwellings, accommodation facilities without adequate cooling, and densely built-up areas. This is relevant for elderly people, children and persons with pre-existing health vulnerabilities. Heat–humidity episodes may also increase discomfort for tourists, outdoor workers and people using beaches, promenades and public spaces.

Urban morphology and surface characteristics may further modify risk. The coastal station shows moderated daytime temperatures, but more inland and densely built-up sectors may experience higher land surface temperatures, lower ventilation and stronger urban heat-island effects. The satellite-based heat-risk methodology provides a relevant future refinement layer. By combining Landsat-derived land surface temperature at 30 m resolution with WorldPop vulnerable-population data at 100 m resolution, the municipality can identify overheated surfaces and areas where vulnerable residents are concentrated. This would be particularly useful for prioritising shading, tree planting, cool surfaces, water points, public-space redesign and targeted heat-health measures.

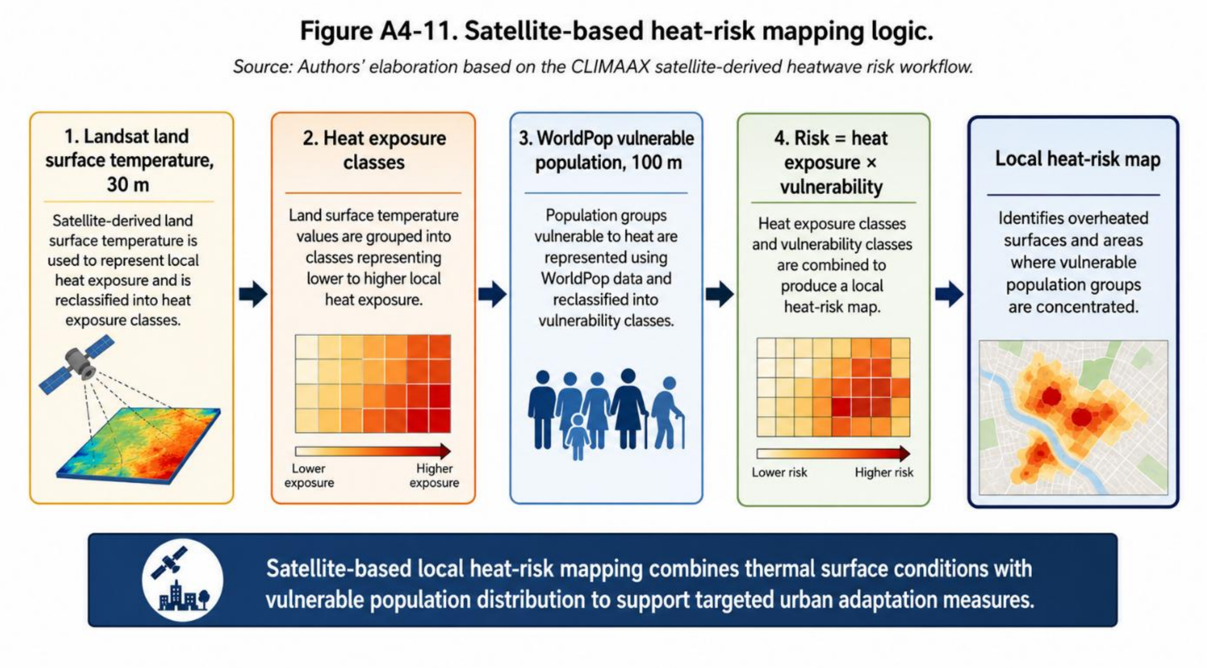


Figure A4-11. Satellite-based heat-risk mapping logic.

Source: Authors' elaboration based on the CLIMAAX satellite-derived heatwave risk workflow.

Indirect impacts were considered qualitatively. Heatwaves may increase electricity demand for cooling, affect outdoor work and municipal services, reduce comfort in tourism areas, intensify drought and water demand, stress urban vegetation, increase wildfire susceptibility in dry vegetation, and affect agricultural crops when combined with drought. Heat also interacts with other hazards. In particular, heatwaves may compound drought risk by increasing evapotranspiration and irrigation demand, while warm and humid conditions may increase public-health pressure during the summer tourist season.

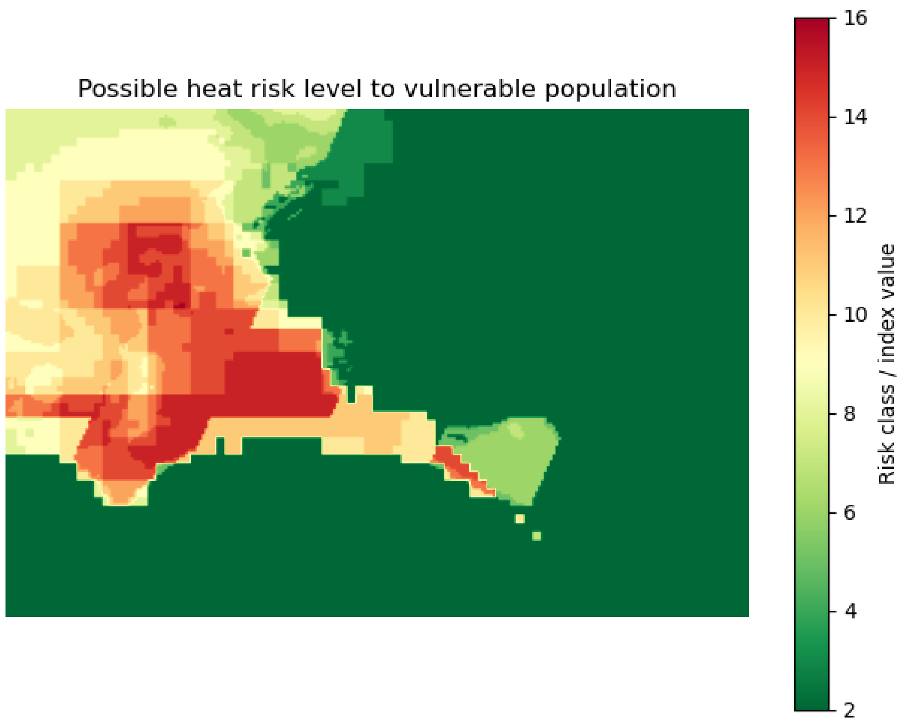


Figure A4-12. Example satellite-derived heat-risk mapping outputs: heat exposure, vulnerable population and combined risk.

Source: CLIMAAX satellite-derived heatwave risk workflow.

The main limitations of the risk assessment are related to data scale and the lack of detailed local vulnerability datasets. The regional workflow uses 12 km hazard data and population modelling, which is not sufficient for building-level or neighbourhood-level planning. WorldPop data may not fully represent seasonal tourism population, institutional populations, social isolation, housing quality or access to cooling. The local station is located in a strongly maritime environment and may not represent inland urban heat islands. The satellite-based risk workflow requires suitable cloud-free summer Landsat scenes and local validation.

Overall, the Phase 2 heatwave assessment shows that Pomorie's heat-risk profile is not adequately captured by classical daytime heatwave thresholds alone. The local coastal environment moderates daytime extremes, but warm nights and humid episodes create a relevant heat-stress pathway. At the same time, scenario-based EuroHEAT and Xclim workflows indicate that future heatwave occurrence is expected to increase, especially under high-emission conditions. The results support the need for local heat-health planning, monitoring of tropical nights and compound heat–humidity conditions, mapping of overheated urban surfaces, protection of vulnerable groups, urban greening and shading measures, and integration of heatwave risk into tourism, public-health and emergency-response planning.

5. Hazard #5 - Windstorms - finetuning to local context

Windstorms were selected as a separate hazard because of their relevance for coastal infrastructure, transport, tourism, agriculture, electricity and communication networks, buildings, trees and outdoor public spaces. In Pomorie Municipality, windstorm risk has a specific coastal character. The town and several exposed assets are located directly along the Black Sea coast, where marine exposure, unobstructed fetch, local pressure gradients and frontal systems may generate strong winds and damaging gusts. Windstorms may also interact with other hazards, especially coastal flooding, heavy rainfall and thunderstorms.

The Phase 2 windstorm assessment combines three complementary layers. First, the CLIMAAX windstorm selection workflow was used to identify historical storm events from the European windstorm track database that passed close to the area of interest. Second, the CLIMAAX windstorm hazard workflow was used to retrieve and process a storm footprint representing maximum 3-second wind gusts for a selected historical event. Third, the structural damage workflow was used to combine the storm footprint with land-use exposure and wind vulnerability curves. These model-based results were then interpreted against long-term wind and thunderstorm records and recent high-resolution local observations from the Pomorie coastal monitoring station.

This approach makes the assessment more locally relevant, but it should be interpreted correctly. The windstorm workflow is event-based and scenario-testing oriented. It does not provide a full probabilistic future windstorm risk assessment for Pomorie. Instead, it shows how a selected storm footprint would translate into potential damage under present exposure and vulnerability assumptions. The local observational analysis provides additional evidence on the frequency, direction and intensity of strong winds and gusts in the Pomorie coastal environment.

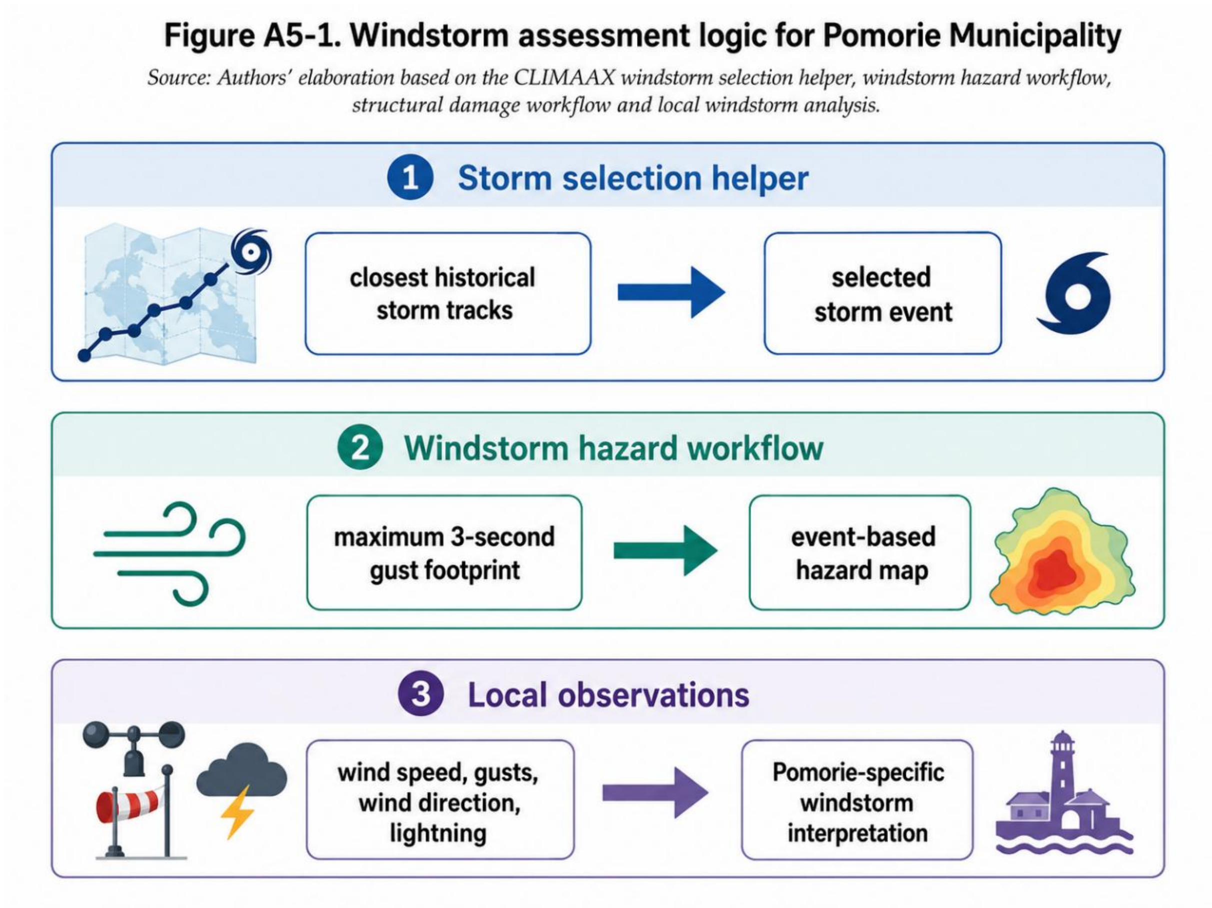


Figure A5-1. Windstorm assessment logic for Pomorie Municipality.

Source: Authors' elaboration based on the CLIMAAX windstorm selection helper, windstorm hazard workflow, structural damage workflow and local windstorm analysis.

Table A5-1. Data overview workflow #5

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
Windstorm tracks and footprints derived from reanalysis over Europe from 1940 to present, accessed through the Copernicus Climate Data Store. The selection helper used the Hodges tracking algorithm and identified storm events by distance to a selected point near the study area.	Vulnerability curves for different building/construction classes, adapted from published wind-damage functions. The curves relate 3-second wind gust speed to percentage of structural damage.	Pomorie area of interest defined by a bounding box. Exposure was represented through LUISA land-cover data clipped to the municipality area.	List of historical storms closest to the selected location; storm tracks; selected storm-event footprint; spatial map of maximum 3-second wind gusts.
Selected historical storm footprint: storm ID 1293,	LUISA land-use classes were linked to	LUISA land-cover classes, including	Event-based structural damage

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
with the CDS date configuration corresponding to 27 December 1999. The hazard variable is a maximum 3-second wind gust.	maximum structural damage values and to vulnerability curves according to the assumed building/asset composition of each land-use class.	urban fabric, industrial/commercial units, transport infrastructure, port areas, agricultural land, forests, wetlands, beaches, lagoons and water bodies.	map; damage by land-cover class; total estimated damage for the selected event.
Optional workflow functionality: relocation of historical storm footprints to test the effect of storms occurring in a different location. This can be used as a sensitivity test but should not be interpreted as a direct future projection unless supported by additional climate evidence.	Local vulnerability factors: exposed coastal infrastructure, roofs and lightweight structures, port and tourism facilities, outdoor commercial areas, street trees, electricity and communication lines, agricultural installations, greenhouses and temporary beach infrastructure.	Local exposure context: Pomorie Old Town peninsula, coastal promenades, port and waterfront areas, tourist accommodation zones, road access, beaches, agricultural land, vineyards, orchards, salinas and Pomorie Lake surroundings.	Qualitative identification of sectors and assets requiring attention during strong wind and gust events.
Local long-term wind and thunderstorm records from the Burgas meteorological station, 1965–2023, used as a regional proxy for the Pomorie area.	Local vulnerability interpretation based on long-term wind regime, thunderstorm occurrence and exposure of coastal systems.	Regional context: Burgas/Pomorie coastal area, with similar physical-geographical coastal characteristics.	Long-term mean wind speed, annual thunderstorm days, weak long-term trends, interannual variability.
Local automatic weather-station observations from Pomorie, 04 October 2024 – 14 June 2026, at 30-minute resolution. The station is located on an exposed coastal promontory.	Threshold-based local vulnerability interpretation: windstorm day defined as at least one 30-minute observation with mean wind speed ≥10 m/s; severe windstorm day	Immediate coastal exposure around the monitoring station and wider municipal interpretation for coastal infrastructure, tourism, transport, urban and agricultural assets.	Number of windstorm days and episodes; number of severe windstorm days and episodes; maximum sustained wind speed; maximum gust speed; directional distribution of strong winds and severe

Hazard data	*Vulnerability data*	*Exposure data*	*Impact metrics/Risk output*
	defined as gust speed ≥20 m/s.		gusts; lightning and compound wind–lightning indicators.
Future climate and future socio-economic conditions: no fully probabilistic local future windstorm scenario was applied in this iteration. Future conditions are addressed qualitatively through exposure sensitivity and through the workflow's ability to test relocated historical storm footprints.	Future vulnerability may increase if coastal development, tourism infrastructure, temporary structures, ageing buildings or dependence on overhead networks increase without corresponding strengthening and maintenance.	Current exposure was used as the baseline. No detailed future building, infrastructure, tourism or land-use scenario was available for this phase.	Strategic indication of present-day vulnerable assets and sectors; basis for future detailed stress-testing with stronger or differently located storm footprints.

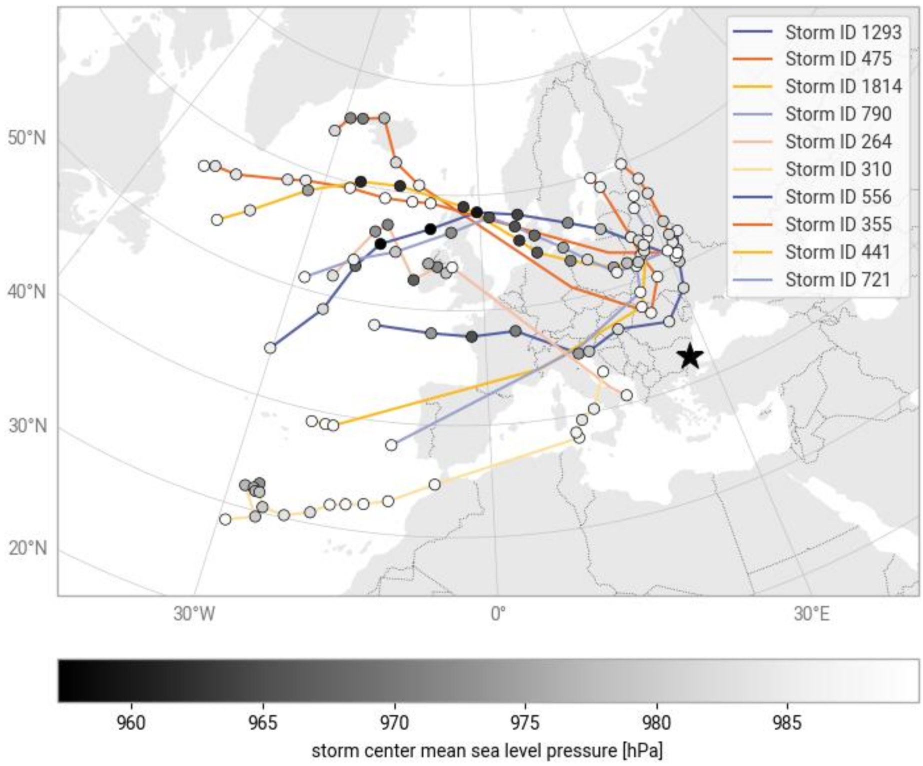


Figure A5-2. Historical windstorm tracks closest to the selected Pomorie location.
Source: CLIMAAX windstorm selection helper, based on windstorm tracks and footprints derived from reanalysis over Europe.

5.1. Hazard assessment

The windstorm hazard assessment was based on the CLIMAAX event-based windstorm workflow and additional local wind analysis. In the CLIMAAX workflow, windstorm hazard is represented by a storm footprint showing the maximum 3-second wind gust associated with a selected storm event. This is an appropriate hazard metric because short-duration gusts are often more relevant for damage than mean wind speed, especially for roofs, trees, temporary structures, signage, coastal installations and overhead networks.

The storm selection helper was used to identify historical storms whose tracks passed close to the selected location. The workflow uses storm tracks from the Copernicus Climate Data Store and allows sorting of storm events by distance from the area of interest. The Hodges tracking algorithm was used in the uploaded workflow. The closest storm IDs identified included storm 1293, which was then used in the hazard and damage workflows.

The selected event was storm 1293, with the corresponding CDS date configuration of 27 December 1999. The storm footprint was clipped to the Pomorie area of interest and processed for use in the structural damage workflow. The assessment therefore represents an event-based analysis of one historical storm footprint rather than a complete windstorm climatology.

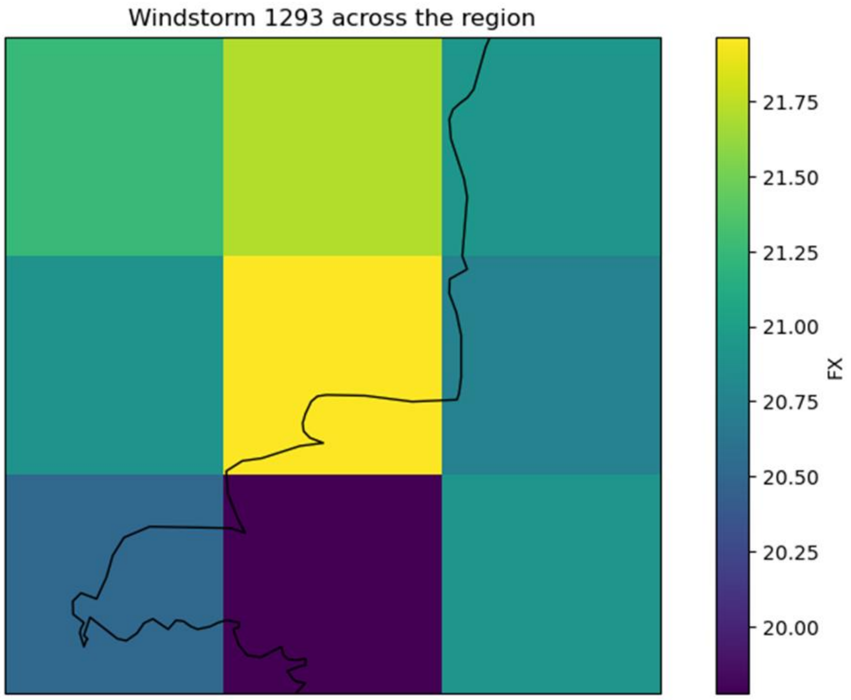


Figure A5-3. Maximum 3-second wind-gust footprint for selected storm 1293, clipped to the Pomorie area of interest.

Source: CLIMAAX windstorm hazard workflow, storm footprint from Copernicus Climate Data Store.

The workflow also includes functionality for storm relocation. This allows a historical storm footprint to be shifted spatially in order to test how damage would change if a storm occurred closer to the area of interest or followed a different track. This functionality is useful for sensitivity testing and adaptation planning, but it should not be interpreted as a direct future projection unless supported by additional climate-model evidence on future storm tracks and intensity.

The local observational analysis provides a much richer interpretation of the wind hazard in Pomorie.

The full local expert analysis of long-term wind and thunderstorm variability and recent windstorm conditions in the Pomorie area is presented below, as the local observational evidence base for the windstorm hazard assessment.

Long-Term Wind and Thunderstorm Variability and Recent Windstorm Conditions in the Pomorie Area: Evidence from Local Observations

Long-Term Wind Speed and Thunderstorm Characteristics in the Pomorie Area

Wind and thunderstorm activity are among the most important atmospheric phenomena affecting both natural systems and human activities. Strong winds may influence transportation, coastal infrastructure, tourism, agriculture and energy systems, while thunderstorms are frequently associated with hazardous weather conditions, including lightning, intense precipitation, local flooding and wind-related damage. Understanding their long-term variability is therefore essential for assessing weather- and climate-related risks in coastal environments.

The present analysis is based on long-term observational records of mean annual wind speed (V, m/s) and annual number of thunderstorm days (TS), obtained through the World Meteorological Organization's freely accessible climate database for the Burgas meteorological station. Although located approximately 20 km southwest of Pomorie, the station occupies a coastal setting with very similar topographic and physical-geographical characteristics, making it suitable for representing the long-term wind and thunderstorm regime of the study area.

The descriptive statistics of the analysed time series are presented in Table A5-2. The long-term mean wind speed amounts to 3.92 m/s, while annual values range from a minimum of 2.08 m/s to a maximum of 4.97 m/s. The most frequently observed value (mode) is 3.94 m/s, which is nearly identical to the long-term mean and indicates a relatively stable wind regime despite the presence of interannual fluctuations. The comparatively high average wind speed is consistent with the coastal location of the study area, where the open exposure to the Black Sea and the limited topographic obstruction favour enhanced air circulation throughout the year.

Table A5-2. Descriptive statistics of long-term wind speed and thunderstorm occurrence

Variable	Mean	Minimum	Maximum	Most Frequent Value (Mode)
Wind Speed (V, m/s)	3.9	2.1	5.0	3.9
Thunderstorm Days (TS)	33.0	2	52	38

The annual number of thunderstorm days exhibits considerably greater variability. The long-term mean reaches 33 days per year, while individual years range from only 2 thunderstorm days to a maximum of 52 days. The modal value of 38 days exceeds the long-term mean, suggesting that several years with unusually low thunderstorm occurrence contribute to lowering the average. Overall, the results indicate that thunderstorm activity represents a regular component of the local climate, reflecting the interaction between maritime and continental air masses characteristic of the western Black Sea region.

The temporal evolution of both variables is illustrated in Figures A5-4 and A5-5. Mean annual wind speed exhibits a weak positive linear trend (y = 0.0091x + 3.515), indicating a gradual increase of approximately 0.009 m/s per year. However, the associated coefficient of determination is very low (R^2 = 0.0251), demonstrating that the linear trend explains only about 2.5% of the observed variability. Consequently, the long-term behaviour of wind speed is dominated by substantial year-to-year fluctuations rather than by a persistent directional change.

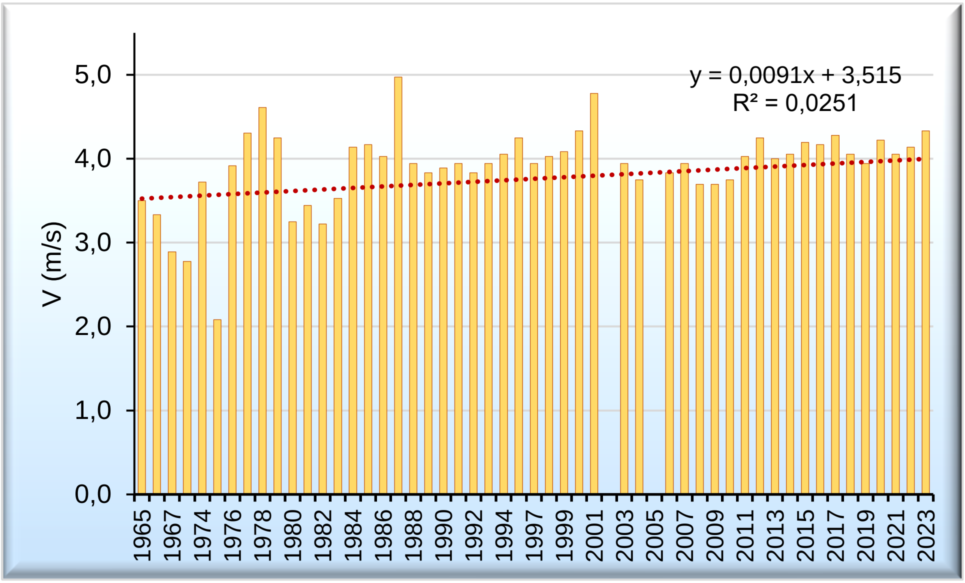


Fig.A5-4. Long-term course of annual average wind speed (V) in Pomorie/Burgas (1965-2023), with corresponding linear trend

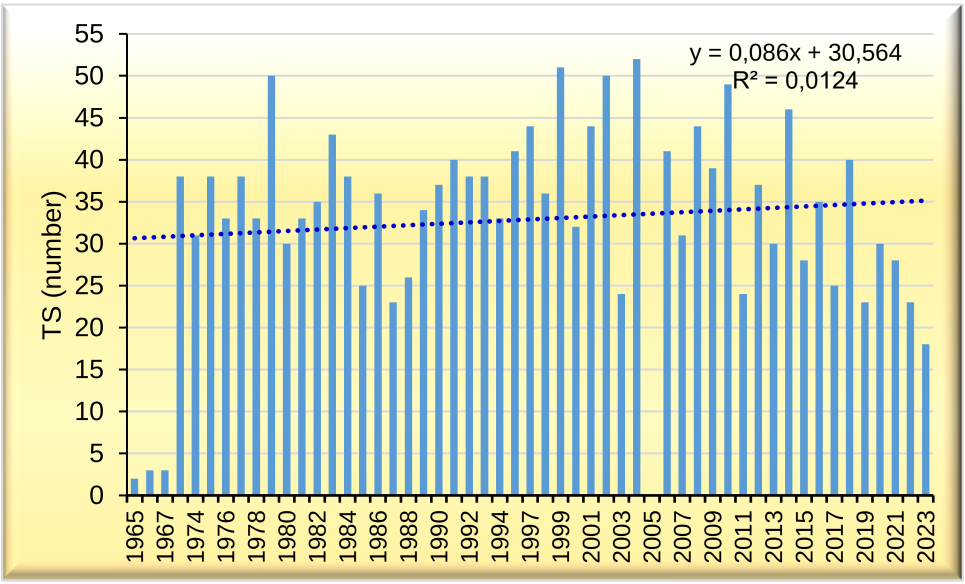


Fig.A5-5. Long-term course of annual average thunder storms (TS) in Pomorie/Burgas (1965-2023), with corresponding linear trend

A similar pattern is observed for thunderstorm occurrence. The annual number of thunderstorm days also displays a weak positive trend (y = 0.086x + 30.564), corresponding to an increase of approximately 0.09 days per year. Nevertheless, the explanatory power of the trend is extremely limited ($R^2 = 0.0124$), indicating that only about 1.2% of the variability can be attributed to the fitted linear relationship. Interannual fluctuations therefore greatly exceed any long-term tendency, and the observed changes cannot be interpreted as evidence of a robust systematic increase in thunderstorm activity.

Taken together, the analysed records reveal a climate characterised by relatively windy conditions and a regular occurrence of thunderstorms, both influenced by the coastal setting of the study area. At the same time, the very low coefficients of determination associated with the linear trends indicate that interannual variability remains the dominant feature of both time series. Although slight positive tendencies are present in the historical records, their statistical strength is insufficient to support reliable extrapolation of future wind speed or thunderstorm occurrence. Consequently, the available records do not provide convincing evidence of substantial long-term changes in either variable, highlighting the predominance of natural variability over any identifiable long-term trend.

Wind Storms

To complement the long-term regional assessment presented above, a high-resolution analysis of local windstorm conditions was conducted using observations from an automatic weather station located on an exposed coastal promontory extending into the Black Sea. The station provides meteorological measurements at 30-minute intervals for the period 4 October 2024 – 14 June 2026. Owing to its highly exposed location, the station captures meteorological conditions characteristic of the immediate coastal environment and should therefore be regarded as representative of local coastal exposure rather than of the entire urban area of Pomorie.

For consistency with the analyses of precipitation and heat-related hazards presented elsewhere in this study, daily values were derived using a climatological day extending from 00:30 to 00:00 of the following calendar day. Each 30-minute observation was assigned to the day represented by the corresponding observation interval.

Given that the present section focuses specifically on windstorm hazard rather than on general wind climatology, a threshold-based approach was adopted to identify potentially hazardous wind events. A windstorm day was defined as any day during which a mean wind speed of at least 10 m/s was recorded during one or more 30-minute observation intervals. Similarly, a severe windstorm day was defined as any day during which a wind gust speed of at least 20 m/s was observed. These thresholds were selected to distinguish potentially hazardous wind conditions from the more common background wind regime.

A windstorm episode was defined as a sequence of one or more consecutive windstorm days. Similarly, a severe windstorm episode was defined as a sequence of one or more consecutive severe windstorm days. Consecutive days meeting the respective threshold criteria were merged into a single event, allowing assessment not only of event frequency but also of event duration and persistence. This methodological approach ensures consistency with the analyses of heatwaves, heat–humidity episodes and prolonged dry periods presented elsewhere in this study.

Wind Regime Characteristics

The local wind regime recorded at the coastal monitoring station is characterised by relatively persistent air movement throughout the year, reflecting the highly exposed position of the station and the strong influence of the surrounding marine environment. Monthly mean wind speeds varied within a comparatively narrow range, from 3.5 m/s to 5.0 m/s, indicating a generally stable wind regime with limited seasonal contrasts (Figure A5-6). The highest monthly mean wind speed was recorded in December 2025 (5.0 m/s), followed by January 2026 (4.8 m/s), whereas the lowest values occurred in October 2024 and March 2026 (3.5 m/s).

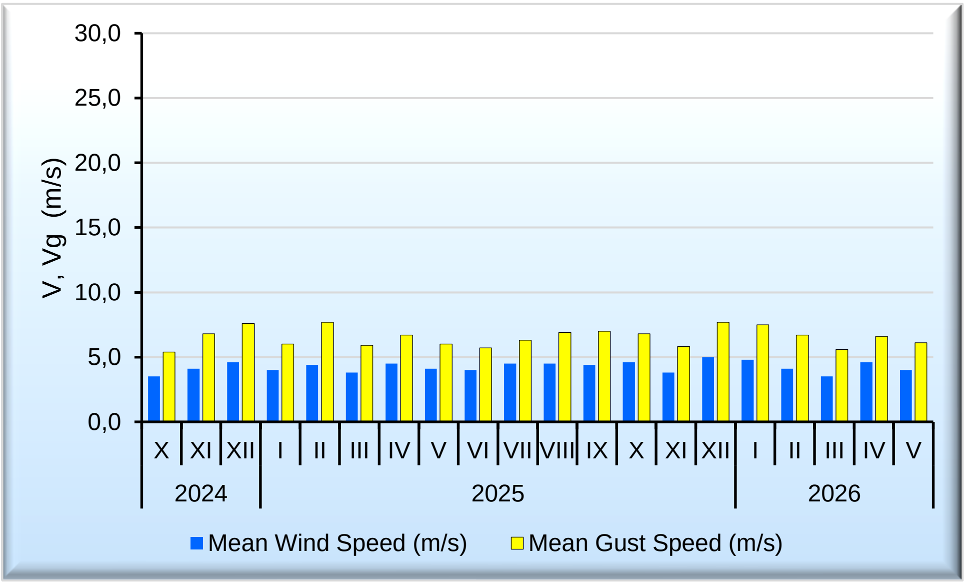


Fig.A5-6. Mean wind speed (V) and gust wind speed (Vg) in Pomorie (04.10.2024 - 14.06.2026)

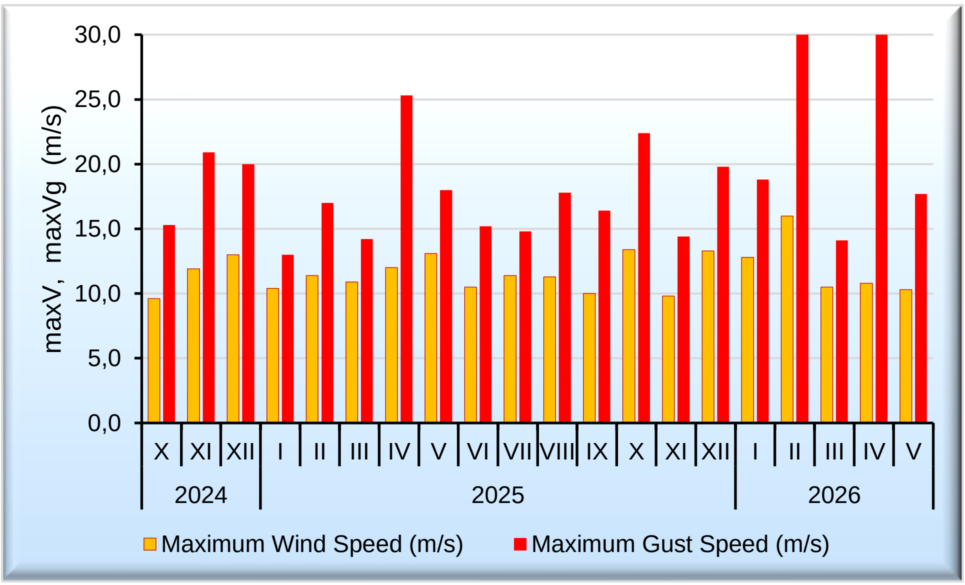


Fig.A5-7. Maximum wind speed (maxV) and gust wind speed (maxVg) in Pomorie (04.10.2024 - 14.06.2026)

Maximum monthly wind speeds exhibit a similar pattern, generally ranging between 9.6 and 13.4 m/s. The highest sustained wind speed observed during the entire monitoring period reached 16.0 m/s on 1 February 2026. In contrast, wind gusts displayed substantially greater variability. Monthly maximum gust speeds frequently exceeded 15 m/s and occasionally surpassed 20 m/s, reaching an absolute maximum of 30.0 m/s on 2 February 2026 and again during April 2026 (Figure A5-7). These results indicate that local wind hazard is associated primarily with short-lived gust events rather than with persistently high mean wind speeds.

The distinction between sustained wind speed and gust intensity is particularly important from a risk-assessment perspective. While the mean wind regime remains moderate, individual gusts may attain intensities capable of affecting coastal infrastructure, transportation, outdoor activities and exposed technical installations. Consequently, wind gusts constitute a more relevant indicator of potential damage than mean wind speed alone.

The directional distribution of the observed winds reveals a strongly organised circulation pattern (Table A5-3). Three directions dominate the local wind regime: west (26.6%), east (24.9%) and northwest (22.6%). Together, these directions account for approximately 74% of all observations, indicating a pronounced directional preference. In contrast, purely meridional airflow is comparatively rare, with northerly and southerly winds representing only 2.5% and 2.6% of observations, respectively.

Table A5-3. Wind direction distribution (October 2024 – June 2026)

Direction	Number of events/observations	Share (%)
N	720	2.5
NE	3174	10.8
E	7297	24.9
SE	1668	5.7
S	777	2.6
SW	1276	4.3
W	7798	26.6
NW	6626	22.6

The substantial contribution of westerly and northwesterly winds reflects the prevailing west-to-east atmospheric circulation over Bulgaria and southeastern Europe. These airflows are commonly associated with the passage of frontal systems and Atlantic-origin air masses that gradually lose part of their moisture content while crossing the European continent and the Bulgarian mainland before reaching the Black Sea coast. At the same time, the eastern sector (NE–E–SE) contributes approximately 41.4% of all observations, highlighting the significant influence of the marine environment on local wind conditions.

Taken together, these results indicate that the local wind regime is controlled by the interaction between two major factors: the regional-scale west-to-east atmospheric circulation and the direct influence of the Black Sea. The exposed coastal location of the monitoring station enables both circulation systems to be clearly expressed in the observed wind field, resulting in a distinctive bimodal directional structure characterised by strong contributions from both western and eastern airflow sectors.

Windstorm Occurrence and Severity

The analysis of windstorm occurrence reveals a substantial contrast between the general wind regime and the frequency of potentially hazardous wind conditions. Although mean wind speeds remained moderate throughout most of the observation period, elevated wind conditions occurred regularly and occasionally reached levels associated with significant hazard potential.

The frequency distribution of sustained wind speeds demonstrates that conditions corresponding to the Strong Wind class (10.0–14.9 m/s) were recorded during 466 individual 30-minute observations, while only two observations reached the Very Strong Wind class (15.0–19.9 m/s) (Table A5-4). No sustained wind speeds exceeded 20 m/s during the monitoring period. These results indicate that exceptionally strong mean wind conditions were relatively uncommon despite the exposed coastal location of the station.

Table A5-4. Frequency of wind-speed conditions by Beaufort-equivalent classes

Class	Threshold (m/s)	Observations
Strong Wind	10.0–14.9	466
Very Strong Wind	15.0–19.9	2
Storm	20.0–24.9	0
Severe Storm	25.0–28.9	0
Hurricane-force	≥29.0	0

A markedly different picture emerges when wind gusts are considered (Table A5-5). Gusts corresponding to the Strong Wind class (10.0–14.9 m/s) were recorded during 3380 observations, while 348 observations reached the Very Strong Wind category (15.0–19.9 m/s). Particularly noteworthy is the occurrence of 18 storm-force gust observations (20.0–24.9 m/s), one severe-storm gust observation (25.0–28.9 m/s), and two hurricane-force gust observations (≥29.0 m/s). The maximum recorded gust reached 30.0 m/s, representing a level capable of causing local damage to exposed structures, vegetation and coastal infrastructure.

Table A5-5. Frequency of gust-speed conditions by Beaufort-equivalent classes

Class	Threshold (m/s)	Observations
Strong Wind	10.0–14.9	3380
Very Strong Wind	15.0–19.9	348
Storm	20.0–24.9	18
Severe Storm	25.0–28.9	1
Hurricane-force	≥29.0	2

These findings clearly demonstrate that wind-related hazard in Pomorie is associated primarily with short-duration extreme gusts rather than with prolonged periods of exceptionally high sustained wind speed. Consequently, gust intensity represents a more relevant indicator of potential impacts than mean wind speed alone.

Application of the threshold-based methodology identified a total of 70 windstorm days, defined as days with at least one observation of mean wind speed equal to or exceeding 10 m/s (Table A5-6). These days were grouped into 42 individual windstorm episodes, indicating that most events were relatively short-lived. The longest episode persisted for nine consecutive days between 28 December 2025 and 5 January 2026, suggesting the influence of a prolonged period of enhanced synoptic-scale atmospheric activity. Additional notable episodes included a five-day event between 20 and 24 November 2024 and several three-day episodes during late 2024 and late 2025.

Table A5-6. Windstorm episodes (Wind Speed ≥ 10 m/s)

Indicator	Value
Number of windstorm days	70
Number of windstorm episodes	42
Longest episode	9 days
Period of longest episode	28 Dec 2025 – 5 Jan 2026

In contrast, severe windstorm conditions, defined by the occurrence of gusts equal to or exceeding 20 m/s, were considerably less frequent. Only 11 severe windstorm days were identified during the entire monitoring period, grouped into eight separate severe windstorm episodes (Table A5-7). The longest severe episodes lasted only two consecutive days and occurred during 2–3 October 2025, 1–2 February 2026 and 26–27 April 2026. Most severe events were limited to a single day, indicating that the most hazardous wind conditions tend to occur as short-lived but intense episodes.

Table A5-7. Severe windstorm episodes (Wind Gust Speed ≥ 20 m/s)

Indicator	Value
Number of severe windstorm days	11
Number of severe windstorm episodes	8
Longest episode	2 days

Taken together, these results suggest that windstorm hazard in Pomorie is characterised by relatively frequent occurrences of strong winds, accompanied by much rarer episodes of severe gust activity. While the overall wind climate remains moderate, the occasional occurrence of storm-force and hurricane-force gusts highlights the potential for high-impact wind events capable of generating disproportionate damage relative to their short duration. This distinction between background wind conditions and episodic extreme gust events represents one of the most important characteristics of the local wind hazard regime.

Wind Direction and Storm-Generating Circulation Patterns

While the general wind regime is dominated by westerly, easterly and northwesterly airflow, the directional distribution of strong and extreme wind events reveals a more complex relationship between prevailing circulation patterns and windstorm hazard (Table A5-8).

Table A5-8. Strong winds by direction

Wind Speed ≥ 10.0 m/s

Direction	Number of observations
N	0
NE	113
E	141
SE	14
S	0
SW	23
W	162
NW	15

Wind Gust Speed ≥ 20.0 m/s

Direction	Number of observations
N	0
NE	9
E	1
SE	0
S	0
SW	3
W	0
NW	8

Strong wind conditions (mean wind speed ≥10 m/s) were most frequently associated with westerly (162 observations), easterly (141 observations) and northeasterly (113 observations) airflow. Together, these three directions account for the vast majority of strong-wind observations, indicating that hazardous wind conditions generally develop within the same circulation sectors that dominate the overall wind regime. This result is consistent with the dual influence of regional atmospheric circulation and local marine exposure identified in the previous section.

The distribution of the most severe gust events, however, differs substantially from the general directional pattern. Gusts exceeding 20 m/s were concentrated primarily within the northeastern and northwestern sectors, which accounted for nine and eight observations, respectively (Table A5-8). In contrast, no gusts above 20 m/s were recorded from the southern, southeastern or westerly sectors. This finding demonstrates that the directions responsible for the strongest wind impacts are not necessarily those associated with the highest overall frequency of occurrence.

The predominance of extreme gusts from the northeastern sector is particularly noteworthy. Given the exposed position of the monitoring station on a coastal promontory extending into the Black Sea, northeasterly winds have a long unobstructed fetch over the marine surface before reaching the observation site. Such conditions favour the development of high wind speeds and powerful gusts, especially during storm situations affecting the western Black Sea basin.

The northwestern sector appears to represent a second important source of hazardous wind conditions. In the regional climatic context of Bulgaria, northwesterly airflow is frequently associated with the passage of cold fronts, post-frontal air-mass intrusions and intensified pressure gradients. These synoptic situations can generate strong and turbulent airflow, producing short-duration but potentially damaging gust events.

The observed contrast between prevailing winds and the directions responsible for the most intense gusts highlights an important characteristic of local wind hazard. The frequency of a given wind direction alone does not necessarily determine its risk significance. Instead, hazard potential is strongly influenced by the ability of particular circulation patterns to generate extreme gusts capable of affecting infrastructure, transportation systems, coastal facilities and outdoor activities.

From a risk-management perspective, the results suggest that particular attention should be paid to northeastern and northwestern storm situations. Although these directions do not dominate the overall wind climate to the same extent as the combined western and eastern sectors, they account for the majority of the most severe gust events recorded during the observation period and therefore represent the principal circulation patterns associated with elevated windstorm hazard in the Pomorie area.

Lightning Activity and Compound Wind–Lightning Hazards

Lightning activity represents an important component of severe weather hazard in coastal environments due to its potential impacts on human safety, critical infrastructure, tourism facilities, electrical systems and communication networks. The high-resolution observations reveal that lightning is a relatively frequent phenomenon in the Pomorie area, with a total of 7799 recorded lightning strikes during the observation period and lightning detected during 68 individual days (Table A5-9).

Table A5-9. Lightning activity characteristics (October 2024 – June 2026)

Indicator	Value
Total number of lightning strikes	7799
Observations with registered lightning	385
Lightning days	68
Maximum daily number of lightning strikes	1160
Date of maximum daily activity	23 May 2026
Mean lightning-strike distance	12.6 km
Minimum lightning-strike distance	1.0 km

The analysed data indicate considerable variability in thunderstorm intensity. The most active day occurred on 23 May 2026, when 1160 lightning strikes were recorded, highlighting the capacity of individual convective events to generate intense electrical activity over relatively short periods. The mean estimated lightning-strike distance amounted to 12.6 km, while the minimum recorded distance was only 1.0 km, indicating that some thunderstorms developed directly above or in the immediate vicinity of the monitoring station (Table A5-9).

Despite the relatively frequent occurrence of lightning, the analysis of compound wind–lightning events reveals that simultaneous occurrences of severe electrical and wind hazards are comparatively rare (Table A5-10). Only five days were 85haracterized by the simultaneous occurrence of lightning activity and mean wind speeds equal to or exceeding 10 m/s. Even fewer cases involved the coincidence of lightning activity and severe wind gusts. During the entire observation period, only one day combined lightning occurrence with gust speeds equal to or exceeding 20 m/s, while no cases were identified in which lightning activity coincided with gusts exceeding 25 m/s.

Table A5-10. Combined wind–lightning storm events

Combined Hazard Criterion	Observations	Days
Wind Speed ≥ 10 m/s + Lightning	6	5
Wind Gust ≥ 20 m/s + Lightning	2	1
Wind Gust ≥ 25 m/s + Lightning	0	0

These findings suggest that the strongest wind events and the most intense thunderstorm activity do not necessarily occur simultaneously. While thunderstorms constitute an important local hazard, many of the most severe wind episodes appear to be associated with larger-scale synoptic processes, including frontal systems and enhanced pressure gradients, rather than with local convective storms alone. Conversely, some thunderstorms may generate substantial lightning activity without producing exceptionally strong winds at the observation site.

The distinction between windstorm and thunderstorm hazards is important from a risk-management perspective. Although both phenomena may occur within the same climatic setting, their occurrence is often controlled by different atmospheric mechanisms and therefore requires separate consideration in local adaptation and emergency-planning strategies.

Implications for local risk assessment and monitoring

The combined analysis of long-term regional records and high-resolution local observations provides valuable insights into the nature of windstorm hazard in the Pomorie area. The long-term data indicate relatively stable wind and thunderstorm conditions at the regional scale, with only weak positive trends and no convincing evidence of substantial long-term change. In contrast, the local observations reveal the presence of short-lived but occasionally intense windstorm events, particularly in the form of extreme gusts reaching up to 30.0 m/s.

A key finding of the study is the distinction between the generally moderate background wind climate and the occurrence of infrequent but potentially damaging gust events. The results demonstrate that hazard levels are determined primarily by short-duration extremes rather than by sustained high wind speeds. This characteristic is particularly relevant for the management of coastal infrastructure, tourism facilities, transport systems and other exposed assets.

The location of the monitoring station on an exposed coastal promontory provides valuable information on marine and coastal meteorological conditions and enables effective identification of potentially hazardous wind situations affecting the shoreline environment. At the same time, the observed wind regime should be interpreted as representative of this highly exposed coastal setting rather than of the entire urban area of Pomorie.

For this reason, the establishment of an additional automatic meteorological station within the built-up urban environment of Pomorie would be highly beneficial. Such a monitoring configuration would allow direct comparison between coastal-exposed and urban meteorological conditions, improve the spatial representativeness of local observations, and provide a stronger evidence base for future climate-risk assessments and adaptation planning. Together, the existing coastal station and a complementary urban monitoring site would offer a more comprehensive understanding of local windstorm hazard and its implications for the municipality.

Overall, the windstorm hazard assessment shows that Pomorie's wind-related hazard is driven primarily by short-duration gust extremes rather than by sustained high mean wind speed. The CLIMAAX event-based workflow provides a useful storm-footprint layer for testing the potential impact of selected historical windstorm events, while the local observations show that the coastal monitoring site experiences a generally moderate but persistent wind regime, interrupted by occasional severe gusts reaching up to 30.0 m/s. The most relevant local hazard indicators are the occurrence of 70 windstorm days, 11 severe windstorm days, the concentration of severe gusts mainly from the northeastern and northwestern sectors, and the limited coincidence between severe gusts and lightning. These findings confirm that windstorm monitoring and preparedness in Pomorie should focus on gust intensity, wind direction, exposed coastal assets and the distinction between coastal and more sheltered urban wind conditions.

The main limitation of the hazard assessment is that the CLIMAAX workflow is based on selected historical events and not on a full probabilistic catalogue of local windstorm return periods. The local station is highly valuable but represents an exposed coastal promontory and may not describe wind conditions inside the built-up urban fabric. Additional monitoring within the urban area would improve spatial representativeness and support better distinction between coastal-exposed and urban wind conditions.

5.2. Risk assessment

The windstorm risk assessment combines the selected storm footprint with land-use exposure and vulnerability curves. The structural damage workflow uses maximum 3-second wind gust as the hazard variable. Exposure is represented by land-cover classes, each associated with maximum damage values. Vulnerability is represented by wind-damage curves that estimate the fraction of damage expected at different gust speeds for different construction or asset classes.

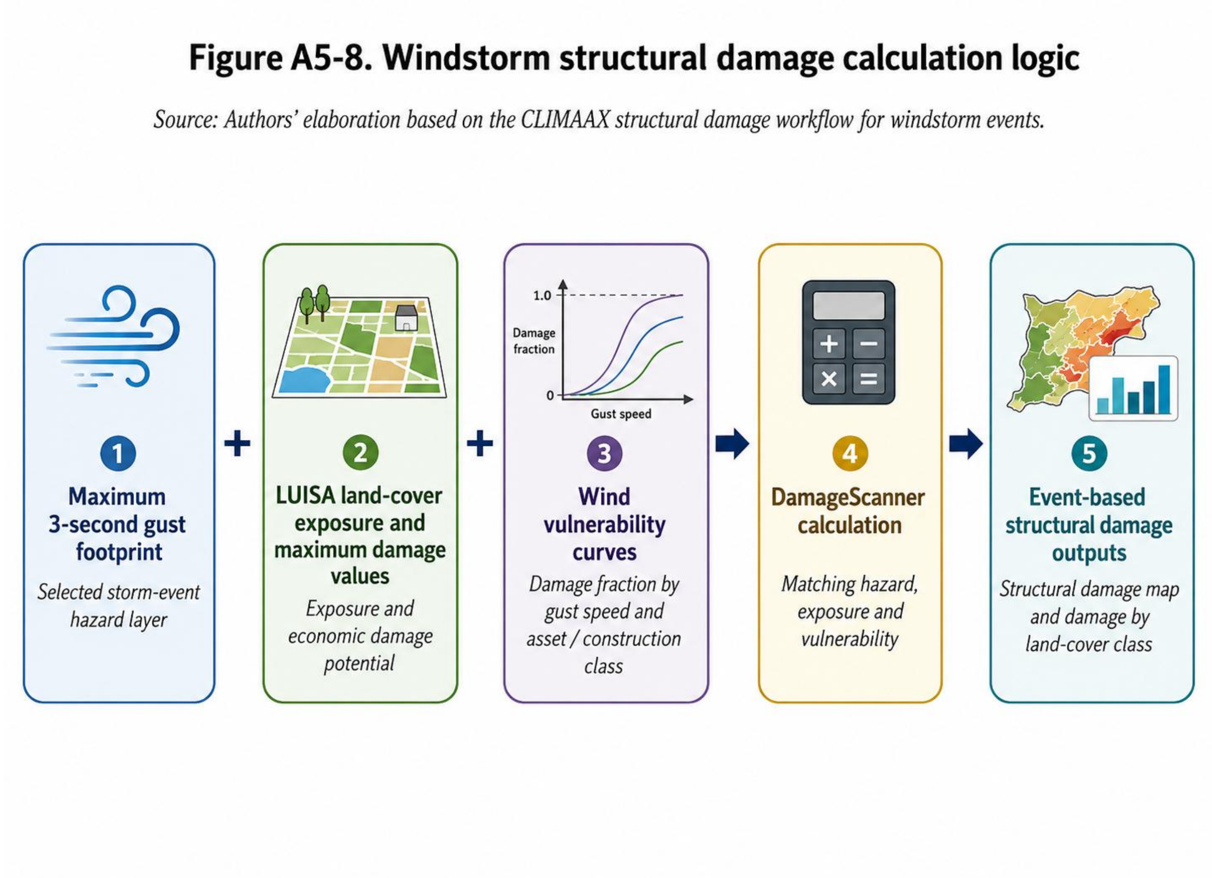


Figure A5-8. Windstorm structural damage calculation logic.

Source: Authors' elaboration based on the CLIMAAX structural damage workflow for windstorm events.

The uploaded structural damage workflow used LUISA land-cover data for the Pomorie bounding box. Maximum damage per land-cover class was derived from the LUISA damage information and JRC-based economic damage estimates. Vulnerability curves were adapted to fit the land-use classes by linking each class to a mixture of construction types. The hazard and exposure layers were reprojected and matched, and the DamageScanner approach was then used to estimate potential structural damage for the selected storm event.

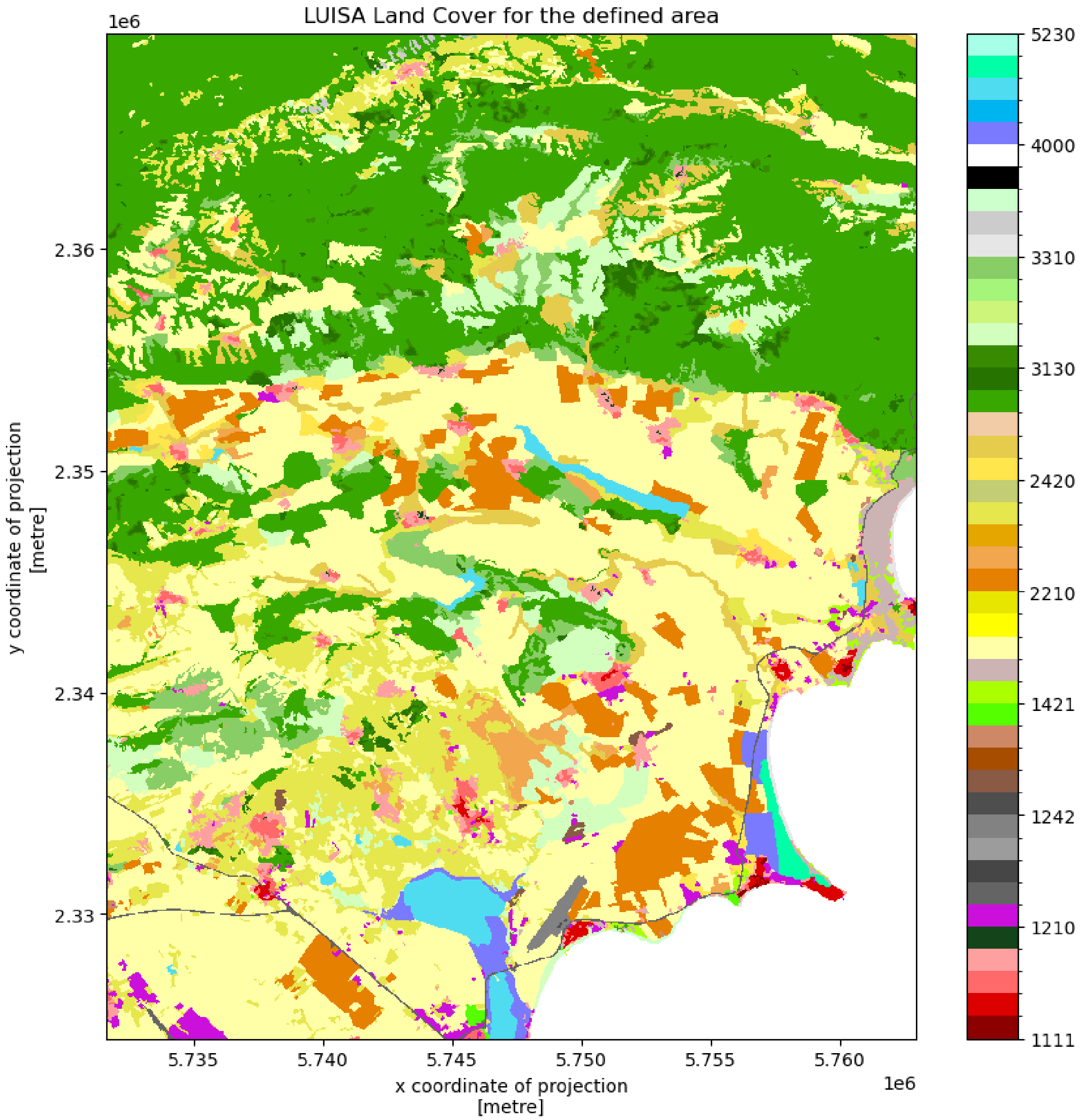


Figure A5-9. LUISA land-cover exposure and maximum structural damage potential for Pomorie.

Source: CLIMAAX structural damage workflow for windstorm events, based on LUISA land-cover data and JRC maximum damage estimates.

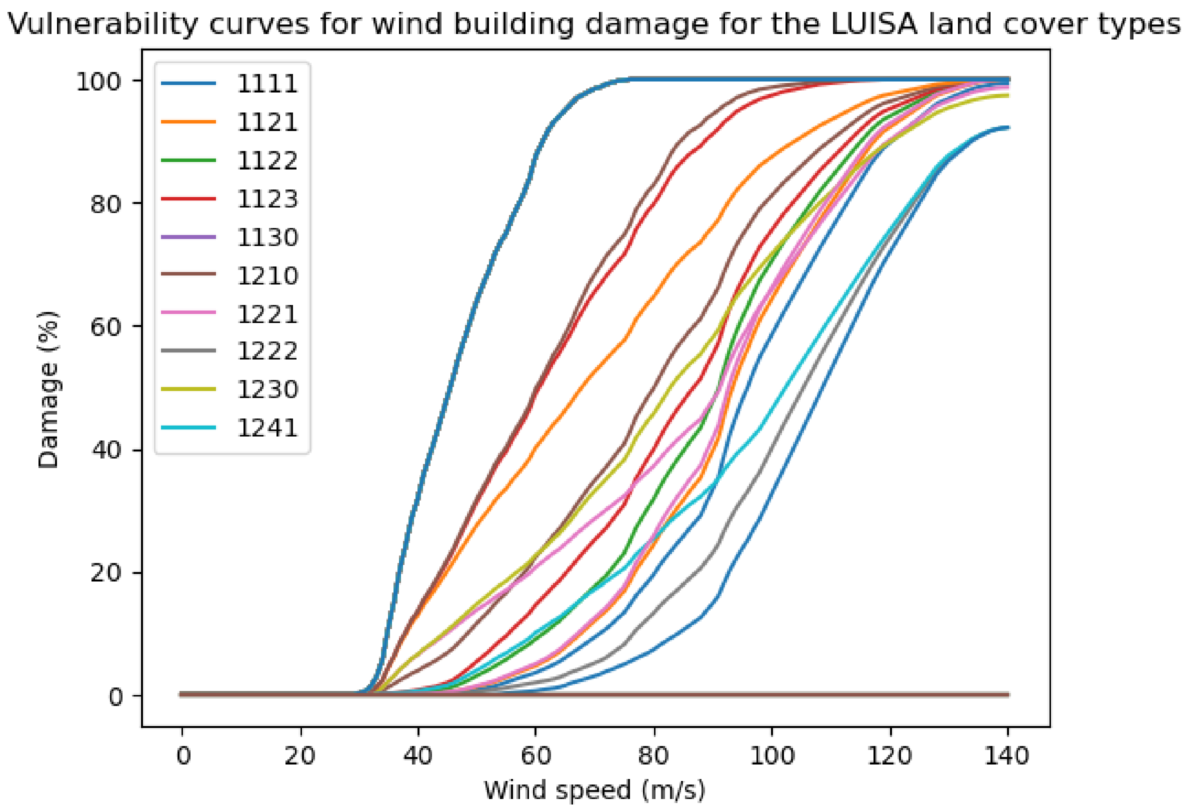
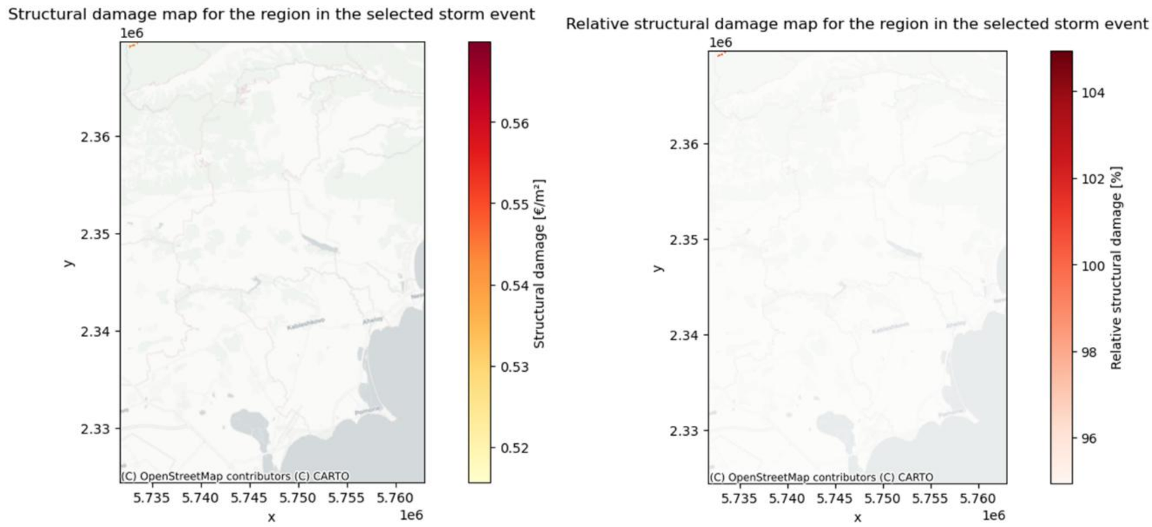


Figure A5-10. Wind vulnerability curves used in the windstorm structural damage workflow. *Source: CLIMAAX structural damage workflow, based on adapted Feuerstein/Koks-type vulnerability curves.*

The calculated damage for the selected storm event was low. Total estimated damage in the analysed Pomorie region was approximately €0.077 million. The damage was concentrated mainly in non-irrigated arable land and pastures, while many urban and infrastructure classes showed zero estimated damage for this specific event. This result should be interpreted carefully. It does not mean that urban assets in Pomorie are not vulnerable to windstorms. Rather, it means that under the selected historical storm footprint and model assumptions, damaging wind speeds did not overlap strongly with high-value urban asset classes in the processed damage calculation.



Figures A5-11. Event-based structural damage estimate for selected storm 1293 in the Pomorie area.

Source: CLIMAAX structural damage workflow for windstorm events.

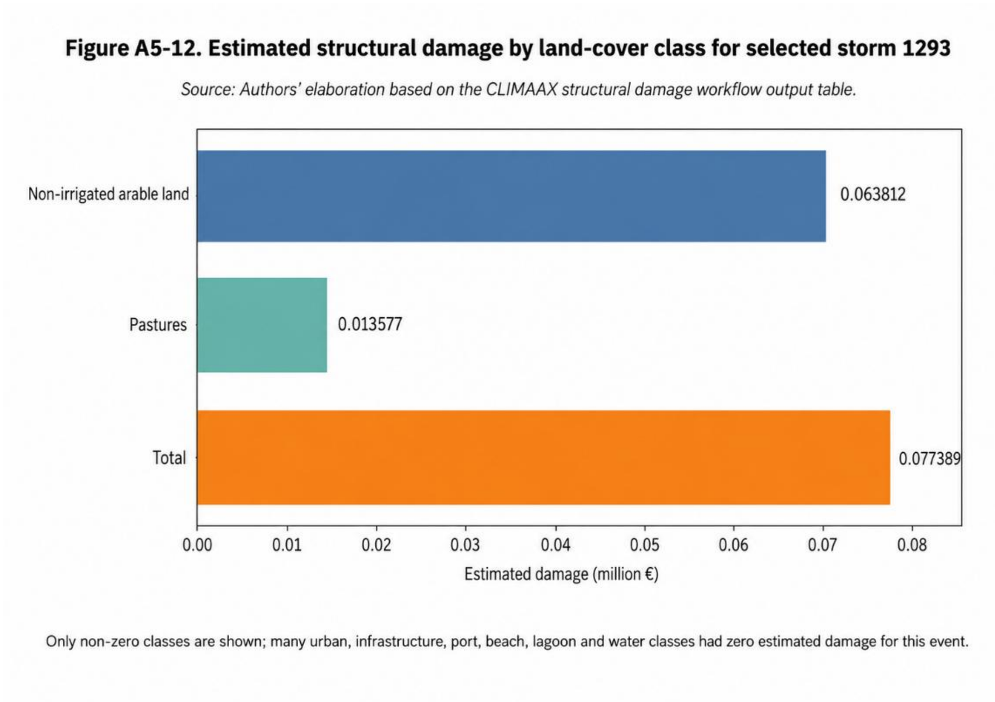


Figure A5-12. Estimated structural damage by land-cover class for selected storm 1293. *Source: Authors' elaboration based on the CLIMAAX structural damage workflow output table.*

From a local risk perspective, the event-based damage estimate should therefore be treated as an illustrative stress test. It demonstrates the workflow logic and provides a first-order indication of how storm footprints, land use and vulnerability curves can be combined. It does not replace local damage records, building inventories, roof-type information, infrastructure data or emergency-service records.

The local observations indicate that the main real-world windstorm risk pathway in Pomorie is likely to be associated with short-duration gusts. Gusts up to 30.0 m/s are capable of affecting temporary structures, roofs, trees, signs, street furniture, beach facilities, port and marina infrastructure, power and communication lines, agricultural structures and exposed tourism facilities. The risk is particularly relevant in coastal and open areas, where wind exposure is higher and where outdoor activities are concentrated during parts of the year.

The most exposed systems include the waterfront and promenade areas, the Old Town peninsula, port and coastal infrastructure, beaches and beach-service installations, roads and transport links, tourism facilities, open public spaces, agricultural land, orchards, vineyards, greenhouses, electricity and communication networks, and trees in urban and recreational areas. Windstorms may also increase risk for boats, small craft, coastal recreation and outdoor events.

Indirect impacts were considered qualitatively. Windstorms may cause disruption to transport, temporary closure of roads or public spaces, interruption of electricity and communications, damage to roofs and lightweight structures, fallen trees and branches, damage to agricultural infrastructure, reduced safety for tourists and residents, interruption of port or beach activities, and increased demand on emergency-response services. Windstorms may also interact with coastal flooding when strong onshore winds coincide with elevated sea levels, and with heavy rainfall or thunderstorms when frontal or convective systems produce multiple hazards.

The directional findings are important for risk management. Severe gusts were concentrated mainly from the northeastern and northwestern sectors. Northeastern storm situations are particularly relevant for exposed coastal infrastructure because of the marine fetch over the Black Sea. Northwestern situations are relevant because they may be linked to frontal systems and pressure-gradient winds. Monitoring, warnings and preparedness procedures should therefore pay special attention to forecasts involving these sectors.

The main limitations of the risk assessment are related to data and model assumptions. The structural damage workflow uses generalized land-cover exposure, maximum damage values and vulnerability curves. It does not include detailed local building footprints, roof types, building age, structural condition, tree inventories, overhead electricity-network data, port infrastructure, beach facilities, insurance claims or recorded past damage. The selected storm footprint is only one historical event and does not represent the full range of possible windstorm scenarios. Future socio-economic exposure and future storm climatology were not modelled quantitatively.

Overall, the Phase 2 windstorm assessment shows that Pomorie has a moderate but persistent coastal wind regime, with hazards mainly driven by short-lived gust extremes rather than sustained winds. The CLIMAAX event-based workflow provides a useful first demonstration of structural damage assessment, while the local observations provide stronger evidence for operational risk understanding. The results support the need for continued wind and gust monitoring, inclusion of gust-based thresholds in local warning procedures, assessment of exposed coastal and tourism infrastructure, collection of local wind-damage records, maintenance of trees and lightweight structures, and better integration of windstorm risk with coastal flooding, thunderstorm and emergency-response planning.