Deliverable Phase 2 – Climate risk assessment

BOMAAX – CLIMAAX for Bolzano

Italy, Trentino-Alto Adige/Bolzano

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

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101093864. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

Document Information

Deliverable Title	Phase 2 – Climate risk assessment
Brief Description	This deliverable presents the Phase 2 Climate Risk Assessment for the BOMAAX – CLIMAAX for Bolzano project. Building on the Phase 1 risk screening, it refines the assessment of heatwaves, extreme rainfall/urban flash flooding and river flooding through the integration of local datasets, climate projections, observed impact data and stakeholder input. The report provides spatially explicit risk evidence to support municipal adaptation planning, Nature-based Solution strategies, the selection of priority intervention areas and the preparation of Phase 3 activities.
Project name	BOMAAX
Country	Italy
Region/Municipality	Bolzano Municipality
Leading Institution	Bolzano Municipality
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Deliverable submission date	30/06/2026
Final version delivery date	29/06/2026
Nature of the Deliverable	R – Report
Dissemination Level	PU - Public

Version	Date	Change editors	Changes
1.0	30/06/2026	Bolzano Municipality	Deliverable submitted
2.0	…	CLIMAAX's FSTP team	Review completed
5.0	…		Final version to be submitted

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Abbreviations and acronyms

Abbreviation / acronym	Description
AIT	Austrian Institute of Technology GmbH
ASL	Above Sea Level
BOMAAX	CLIMAAX project for Bolzano Italy, Trentino-Alto Adige/Bolzano
CISMA	Consulting, Engineering, Development and Environmental Modelling
CLIMAAX	CLIMAte risk and vulnerability Assessment framework and toolboX
COC	Civil Protection Operational Center
CRA	Climate Risk Assessment
ER	Emergency Room
FSTP	Financial Support to Third Parties
GIS	Geographic Information System
GCM	Global Climate Model
IDF	Intensity-Duration-Frequency
JRC	European Commission’s Joint Research Centre
LAND	LAND Italia Srl
LST	Land Surface Temperature
NBS	Nature Based Solutions
NDVI	Normalized Difference Vegetation Index
P1D	Phase 1 Deliverable
PAESC	Piano di Azione per l’Energia Sostenibile e il Clima
PZP	Hazard Zoning Plan
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SECAP	Sustainable Energy and Climate Action Plan
UHI	Urban Heat Island

Executive summary

This deliverable presents the Phase 2 Climate Risk Assessment (CRA) for BOMAAX – CLIMAAX for Bolzano. Building on the Phase 1 screening, which identified heatwaves, extreme rainfall/urban flash flooding and river flooding as the main climate-related risks, Phase 2 refines the assessment through local data and spatially explicit outputs. The work adapted the CLIMAAX workflows to the Bolzano context by integrating bias-corrected and downscaled climate data, municipal population data, local meteorological records and observed impact data, including ambulance interventions during extreme heat and fire brigade interventions during rainfall events. The assessment provides a more operational understanding of where risks occur, who or what is exposed, and which interventions are most relevant. For the heatwave hazard, Phase 2 combined future projections for heatwaves, hot days and tropical nights with 50 m overheating maps, population vulnerability data and commuter exposure. Results show that heat risk is already relevant across much of the built-up area, especially in dense residential districts, the historic centre, highly used public spaces and the industrial area, where high temperatures overlap with worker exposure. Ambulance intervention data for cardiovascular problems during extreme heat provide additional evidence that the mapped risk pattern corresponds to observed health impacts. Future projections indicate that heatwave exposure is expected to increase, making heat risk the main priority for immediate and spatially targeted adaptation.

For the extreme rainfall hazard, Phase 2 used fire brigade intervention data to understand which rainfall events produce impacts in the city. The analysis indicates two relevant situations: short-duration, high-intensity rainfall events that can generate urban flash flooding, and longer rainfall events lasting more than 48 hours that can affect buildings, streets and drainage systems. For river flooding, the assessment was updated using municipal flood maps, 50 m population data and building-level exposure information. Compared with Phase 1, local data reduce the apparent flood extent and estimated damages, while making the interpretation more precise for local planning.

The Key Risk Assessment linked technical outputs with the selection of blueprint areas for intervention. Heatwave and extreme-rainfall risks were discussed through a participatory workshop, where maps, personas and solution cards connected risk evidence with local knowledge and public-space use. The workshop confirmed that heat-risk priorities should include residential vulnerability, public spaces, industrial and work areas, walking routes, schools, playgrounds, bus stops and squares where temporary exposure is high. For rainfall risk, participants emphasised drainage capacity, maintenance, road safety, slippery surfaces and rainwater management in public-space design.

The main conclusion of Phase 2 is that local data substantially improve the usefulness of the CRA for decision-making. Heat risk emerges as the most urgent priority because it is already visible, affects public health and is expected to intensify. Extreme rainfall requires integrated stormwater-management measures, while river flooding should be addressed through targeted interventions in exposed areas and in coordination with existing flood-risk and civil-protection procedures. Remaining difficulties concern data scale, completeness and suitability, especially regarding drainage capacity, short-duration rainfall, public-space use and future monitoring indicators. In Phase 3, the results will be translated into city-wide adaptation guidelines, and a set of adaptation solutions, including Nature-based Solutions. The final outputs will support the Municipality of Bolzano in moving from climate risk assessment toward actionable adaptation measures.

1 Introduction

1.1 Background

Bolzano is increasingly exposed to climate-related pressures that affect public health, infrastructure, mobility, water management and the quality of urban spaces. Previous project Phase 1 identified heatwaves, heavy rainfall and river flooding as the three main hazards requiring further assessment. Phase 2 of BOMAAX builds on this initial screening by refining the analysis with local data and by translating risk evidence into information that can support adaptation planning, Nature-based strategies and the selection of 'blueprint' areas: priority areas requiring urgent action as they are particularly exposed to climate risks, and which can serve as pilot sites for testing and subsequently scaling up climate adaptation strategies.

1.2 Main objectives of the project

Phase 2 of the BOMAAX project aims to refine and localize the climate risk assessment developed in Phase 1, maintaining the focus on heatwaves, heavy rainfall and river flooding as the main climate risks for the Municipality of Bolzano. Building on the CLIMAAX framework and the initial risk screening, this phase seeks to produce a more detailed and locally relevant understanding of how these hazards interact with the city's urban morphology, exposed population, infrastructure and planning priorities.

More specifically, Phase 2 pursues the following objectives:

Refinement of climate risk assessments for heatwaves, heavy rainfall and river flooding, by adapting the CLIMAAX workflows to the Bolzano context and improving the interpretation of hazard, exposure and vulnerability at the urban scale.

Integration of local data and models into the CLIMAAX framework, including municipal population data, local meteorological records, updated flood maps, ambulance intervention data, fire brigade intervention data and additional spatial information. This allows the assessment to move beyond coarse regional datasets and better identify where climate risks are already producing impacts.

Identification of priority risk areas and intervention needs, by analysing key risk assessment findings, assessing severity and urgency, and distinguishing between areas requiring immediate action, targeted intervention or further monitoring.

Strengthening of stakeholder engagement and shared risk understanding, by using technical results as a basis for discussion with municipal departments, local experts and stakeholders, and by refining the selection of blueprint areas according to local knowledge, perceived exposure and feasibility of intervention.

Support for municipal decision-making and adaptation planning, by producing risk maps, indicators and spatially explicit outputs that can inform city-wide adaptation guidelines, Nature-based strategies, emergency planning and future planning instruments.

Preparation of the analytical basis for Phase 3, ensuring that the results of the risk assessment can be translated into concrete solution bundles for typical high-risk urban situations, including Nature-based Solutions, best practices, cost considerations and expected socio-economic benefits.

The use of the CLIMAAX Handbook and toolbox provides a clear and harmonized methodological structure for the assessment, while the inclusion of local datasets and models makes the results more relevant for Bolzano's specific urban and climatic conditions. In this way, Phase 2 contributes both to a comparable European climate-risk assessment process and to decision-ready information that can support practical adaptation actions in the Municipality of Bolzano.

1.3 Project team

The BOMAAX project is implemented by a specialised consortium supporting the City of Bolzano in climate risk assessment, adaptation planning and urban resilience. **Municipality of Bolzano**: oversees the project, ensures alignment with city strategies, and facilitates stakeholder cooperation; **LAND Italia Srl**: coordinates the subcontracted team and integrates project outputs into climate adaptation guidelines; **Studio Calas GbR**: supports sustainable urban planning and research by integrating eco-social practices at every stage of the work; **AIT Austrian Institute of Technology GmbH**: provides expertise in climate adaptation, digital workflows and urban-scale risk analysis; **CISMA Srl**: contributes climate downscaling, hydrology, meteorology and local climate-impact modelling.

1.4 Outline of the document's structure

The document follows the template guidelines provided by the CLIMAAX Project team and is organised into seven main sections.

Section 1 introduces the BOMAAX project, the local background, the main objectives of Phase 2, the project team and the structure of the report.

Section 2 presents the Climate Risk Assessment of Phase 2. It includes the scoping of the assessment, the risk exploration process, and the regionalised risk analysis for heatwaves, heavy rainfall, river flooding and additional local assessments based on municipal data and models. The section then presents the Key Risk Assessment Findings, including the collection of risk-analysis outputs, severity, urgency, resilience capacity, risk prioritisation and adaptation strategies. It concludes with Monitoring and Evaluation and the work plan for Phase 3.

Section 3 summarises the main conclusions of Phase 2, including the key findings, challenges addressed, remaining gaps and implications for the next project phase. It develops a preliminary adaptation strategy that describes a systematic approach to the urban environment and its response to the adaptation measures. This strategy is to be develop further in the Phase 3.

Sections 4 and 5 report on progress evaluation pointing out the milestones and using KPIs, and including supporting documentation, relevant outputs, datasets, maps, workshop material and workflow documentation.

Section 6 provides the references used in the report.

Compared with Phase 1, which provided the initial screening of climate-related hazards and the selection of the main risks for Bolzano, Phase 2 focuses on the refinement, localisation and operational interpretation of the assessment. The added value of this phase lies in the integration of local datasets, observed impact information and stakeholder knowledge into the CLIMAAX workflows, to improve the spatial accuracy and practical relevance of the results. This makes it possible to move from a general understanding of climate hazards to a more detailed identification of exposed areas, vulnerable groups, critical urban conditions and possible adaptation priorities.

In this sense, the Phase 2 assessment acts as an intermediate step between risk screening and adaptation planning. It provides the technical and interpretative basis for the development of Phase 3 outputs, including city-wide adaptation guidelines, Nature-based Solution bundles and spatially explicit pilot-area proposals. The results are therefore intended not only as analytical outputs, but also as decision-support material for municipal departments, local stakeholders and future planning or design processes.

2 Climate risk assessment – phase 2

Phase 2 builds on the Phase 1 risk screening and focuses on refining the assessment for the three priority hazards identified for Bolzano: heatwaves, extreme rainfall/urban flash flooding and river flooding. The analysis applies the CLIMAAX framework together with local datasets, local models and observed impact information, to produce more detailed, spatially explicit and decision-oriented results.

The purpose of this section is to describe how the selected risks were regionalised, analysed and prioritised during Phase 2. It presents the scoping of the assessment, the risk exploration process, the regionalised risk analysis, the key risk assessment findings, the monitoring and evaluation approach, and the work plan for Phase 3.

2.1 Scoping

The scoping phase defines the purpose, boundaries and expected use of the Climate Risk Assessment. In Phase 2, the scope is focused on refining the three priority risks identified in Phase 1: heatwaves, extreme rainfall/urban flash flooding and river flooding. The assessment aims to move from a broad screening of hazards toward a more detailed and locally relevant understanding of where risks occur, who or what is exposed, and which areas are most suitable for adaptation interventions.

The scoping also clarifies how the CRA should support local decision-making. The results are intended to inform municipal adaptation planning, Nature-based Solution guidelines, the selection of blueprint areas and the preparation of Phase 3 solution bundles. The process combines the CLIMAAX framework with local datasets, local expert knowledge and stakeholder input, while also documenting data gaps and methodological limitations that affect the interpretation of the results.

The following subchapters describe the objectives of the CRA, the local and governance context, the organisation of risk ownership, the application of CLIMAAX principles and the stakeholder engagement process.

2.1.1 Objectives

The Climate Risk Assessment provides spatially explicit and decision-oriented evidence on the three priority risks identified in Phase 1: heatwaves, extreme rainfall/urban flash flooding and river flooding. The CRA aims to:

- identify where the selected climate risks occur in Bolzano and which urban areas, people, buildings and infrastructures are most exposed;
- explain why specific areas are more critical by combining hazard, exposure, vulnerability and observed impact data;
- support the prioritisation of risk areas according to severity, urgency, resilience capacity and intervention potential;
- provide evidence for municipal adaptation planning, including Nature-based Solution guidelines, public-space redesign, stormwater management and targeted flood-risk measures;
- support the selection of blueprint areas and the preparation of Phase 3 solution bundles;

- document the main data and methodological limitations, including coarse climate datasets, incomplete metadata, limited information on short-duration rainfall, drainage capacity, detailed public-space use, future river-discharge scenarios and monitoring indicators;
- improve the practical usefulness of the CLIMAAX workflows by integrating local datasets such as municipal population data, meteorological records, updated flood maps, ambulance intervention data and fire-brigade intervention data.

The expected outcome is a set of spatial and interpretative outputs that can support adaptation-related decision-making by the Municipality of Bolzano. These outputs are intended to inform city-wide adaptation guidelines, the prioritisation of blueprint areas, the selection of suitable Nature-based Solution measures, and the integration of climate-risk evidence into public-space design, stormwater management, emergency planning and future municipal investment priorities. The assessment also provides the basis for Phase 3, where the identified risks and intervention needs will be translated into more operational solution bundles and pilot-area proposals.

2.1.2 Context

2.1.2.1 Geographical Setting

Bolzano is the capital of the Autonomous Province of Bolzano – South Tyrol and has approximately 100,000 inhabitants. The city is located at the bottom of a wide Alpine basin, at the junction of the Isarco/Eisack, Adige/Etsch and Sarentino/Sarntal valleys. This setting strongly influences its climate-risk profile: valley morphology limits air circulation, supports summer heat accumulation and concentrates urban development within a constrained area (*Eurac Research et al., 2021*)[4].

From a hydrographic perspective, Bolzano lies at the confluence of the Talvera/Talfer stream and the Isarco/Eisack River, which joins the Adige/Etsch River south of the city. The surrounding valley sides and river system make hydrological risk, surface runoff and flood management important components of local planning. These risks are already addressed through provincial hazard-zone planning instruments, which identify floods, landslides, debris flows and avalanches and influence spatial planning and building regulation (*Eurac Research et al., 2018*)[1].

Bolzano has a diversified economy, with relevant sectors including public services, tourism, commerce, research and high-tech activities, transport, agriculture and industry. Several of these sectors are climate sensitive. Public health is affected by heatwaves; mobility and infrastructure can be disrupted by heavy rainfall and flooding; agriculture and tourism are exposed to changing seasonal and water conditions; and urban planning must increasingly address heat, runoff, flood exposure and the protection of vulnerable groups (*Eurac Research et al., 2018*)[1].

2.1.2.2 Climate hazards, impacts and previous risk assessment

Climate hazards and impacts in Bolzano and South Tyrol have so far been addressed through a combination of municipal climate planning, provincial climate monitoring, hazard-zone planning and sectoral studies. At municipal level, the PAESC of the City of Bolzano includes measures for climate-change adaptation and emission reduction and provides an existing planning basis for local climate action[3]. At provincial level, South Tyrol has developed climate-monitoring and risk-assessment work through the Klimarisiken und Anpassung platform, which builds on the South Tyrol Climate Report and provides updated indicators and sectoral knowledge on climate impacts[1]. The main problem addressed by BOMAAX is that existing regional and municipal assessments provide an important basis, but do not always give sufficient spatial detail for operational urban adaptation. For example, city-scale heat exposure, public-space use, commuter exposure, short-duration rainfall impacts and building-level flood exposure require more detailed local data than is available in broad regional assessments. The CRA therefore aims to bridge the gap between strategic climate planning and site-specific intervention planning.

2.1.2.3 Governance and policy context

The CRA is framed within municipal, provincial, national and European climate-adaptation policies. At municipal level, the PAESC of Bolzano and the ClimaBZ process provide the local basis for climate action and participatory planning (*Comune di Bolzano, 2024*)[3].

At provincial level, the Klimaplan Südtirol 2040, the South Tyrol adaptation-strategy work and the Hazard Zone Plan system define the broader strategic and regulatory framework for climate adaptation, natural-hazard planning and flood-risk management[5].Provincia Autonoma di Bolzano – Piano delle zone di pericolo / Hazard Zone Plan, https://pericoli-naturali.provincia.bz.it/it/piano-delle-zone-di-pericolo-pzp At national level, the Italian National Plan for Adaptation to Climate Change provides the wider policy framework, while at European level the CLIMAAX project and the EU Mission on Adaptation to Climate Change support regions and municipalities in strengthening climate-risk assessment and resilience planning (*CLIMAAX, 2023*)[6]. Within this framework, BOMAAX adds value by connecting existing policies and initiatives with more detailed spatial evidence on heat exposure, rainfall impacts, river-flood exposure and vulnerable urban conditions.

2.1.2.4 Possible adaptation interventions

The broader adaptation palette for Bolzano includes Nature-based Solutions, grey or technical measures, digital and data-driven tools, governance and planning measures, and communication or stakeholder-engagement actions. In Phase 2, however, the preliminary solution bundle was developed primarily around Nature-based Solutions, while complementary measures for a broader adaptation strategy will be explored and integrated in Phase 3 including grey / technical / engineering measures, digital and data-driven tools, governance and planning measures, communication, awareness and stakeholder-engagement actions.

Heat-related interventions may include tree planting, soil de-sealing, shaded public spaces, cool materials and improved access to green areas. Extreme rainfall and urban flash-flooding measures may include permeable surfaces, rain gardens, bioswales, detention and retention areas, and local drainage improvements. River-flood adaptation should remain coordinated with existing hazard-zone planning and civil-protection procedures, focusing on exposed buildings, access routes, critical infrastructure and vulnerable users.

2.1.3 Participation and risk ownership

The Climate Risk Assessment was developed as a technical and participatory process. Stakeholder involvement helped complement spatial analysis with local knowledge on perceived risks, operational responsibilities and possible adaptation priorities, especially for heatwaves and extreme rainfall, where impacts depend on public-space use, mobility, vulnerable groups, maintenance and infrastructure conditions. Risk ownership in Bolzano is shared across several actors. Heat-related risks are mainly linked to municipal responsibilities for public space, green infrastructure, urban planning and communication with vulnerable users, in coordination with health and social actors where relevant. Extreme rainfall and urban flash flooding require coordination between municipal technical services, drainage and utility operators, emergency services and civil-protection actors. River flooding is more directly connected to provincial hazard-zone planning, flood-risk management and civil protection, while the Municipality remains responsible for integrating this information into local planning, exposed buildings, public spaces and emergency access.

The participatory process confirmed that climate risks cannot be addressed by a single actor or sector. Adaptation requires coordination between planning, environment, infrastructure, emergency management, health, mobility and social-policy responsibilities. The outcomes of Phase 2 will support Phase 3, where the identified risks and preliminary adaptation directions will be translated into spatially explicit adaptation solutions and implementation priorities.

2.1.4 Application of principles

The Phase 2 CRA applied the CLIMAAX principles by combining methodological consistency, local relevance and transparency. The assessment started from the standard CLIMAAX workflows and adapted them to the Bolzano context through the integration of local datasets, municipal information and observed impact records.

Quality, rigour and transparency were supported by documenting the datasets, assumptions and limitations used in the analysis, including the scale of climate data, the use of local impact records and the uncertainty related to incomplete or non-homogeneous sources. This allows the results to be interpreted with the necessary caution and makes clear where further data improvements are needed. The assessment also followed a participatory and actionable approach. Stakeholder input helped connect technical outputs with local knowledge, perceived risks and possible adaptation priorities. In this way, the CRA was not limited to hazard mapping, but was used as a basis for decision-making, future monitoring and the development of adaptation solutions in Phase 3.

2.1.5 Stakeholder engagement

Stakeholder engagement was structured around an information session and a half-day participatory workshop that combined local risk perception with the co-design of nature-based adaptation solutions for selected urban areas at different scales. Nature-based Solutions were used as the main discussion focus because they are tangible, spatially understandable and closely linked to how people experience streets, squares and public spaces, while technical and governance measures will require further expert assessment in the next phase. The workshop took place in Bolzano and focused on heatwaves and extreme rainfall in various neighbourhoods and public spaces, with the aim of integrating everyday experiences of climate risk into the Climate Risk Assessment process.

2.1.5.1 Participants and stakeholder groups

Participants were organised into three thematic tables and represented different urban users, responsibilities and areas of expertise exposed to climate risks. The discussion used representative personas to address vulnerable and exposed groups, including older people, children, outdoor workers, people with health conditions, office workers and families with small children.

2.1.5.2 Forms of engagement and communication of project goals

The main engagement format was an in-person workshop divided into two sessions for each table:

- Session 1 on local risk perception – using maps, post-its and facilitated discussion to identify vulnerability among users and everyday impacts of heatwaves and extreme rainfall.
- Session 2 on blueprint co-design - on a range of potential blueprint areas using solution cards for nature-based measures to co-design potential interventions.

Project goals and intermediate results were introduced through a short presentation linking the CLIMAAX climate-risk-assessment framework to concrete neighbourhood conditions. Personas, maps and solution cards helped translate technical adaptation options into tangible solutions that participants could discuss, combine and relate to comfort, accessibility and public-space quality.

2.1.5.3 Reception of results and feedback

The workshop showed clear convergence on the need for more shade, trees, de-sealing, blue measures, shaded seating and cooler walking routes under heatwave conditions. For extreme rainfall, participants emphasised stormwater retention, drainage and maintenance, safer pedestrian routes and improved communication and awareness-raising in public space.

Participants also expressed a strong preference for multifunctional nature-based solutions able to provide shade, manage water, improve public-space quality and support biodiversity. Temporary and tactical interventions, such as trees in planters, pilot greening or temporary pergolas, were considered useful to test solutions before permanent redesign.

2.1.5.4 Use of outcomes by participants

The workshop outcomes provide a shared set of priorities for future climate-adaptation actions in Bolzano, especially the integration of blue-green infrastructure, shaded and connected public spaces and improved stormwater management in ongoing planning and design processes. The co-designed blueprints for specific streets and squares can inform feasibility studies, project briefs and tactical interventions, while the focus on vulnerable personas supports the integration of human-related climate risks into planning and communication activities.

2.1.5.5 Difficulties encountered in stakeholder engagement

Main challenges emerged during the engagement process:

- Complexity of simultaneous hazards need multifunctional and adaptable solutions
- Working with highly exposed yet technically constrained spaces (e.g. historic squares with underground infrastructure) made it necessary to balance ambitious ideas with feasibility concerns, which sometimes limited the range of immediately implementable proposals
- Awareness-raising measures among the local population along technical solutions

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

Heatwaves, heavy rainfall and river floods were identified in Phase 1 as the most significant hazards for the municipality of Bolzano using the available sources (e.g., data, analysis, Copernicus Climate Atlas, etc.) and stakeholder local insights and feedback. In Phase 2, no new relevant hazards have been identified and added, as there were no foreseen changes in climate situation for Bolzano nor any other hazard events occurring since Phase 1. The initial reasoning for the selection of the three hazards can be found in Phase 1 deliverable (P1D).

The CRA for these hazards then moved forward by refining the analysis with high-quality, local data sets that allowed to improve on accuracy and better identify exposure and vulnerability of the city and population:

- Data on ambulance interventions for cardiovascular problems due to extreme heat, which were used to assess and map the most impacted areas of the city,
- Data on fire brigade interventions due to intense precipitations (rain fall), which allowed to identify critical impact-based rain thresholds for floods in streets and in buildings,
- Hazard maps from the Hazard Zoning Plan (PZP) of Bolzano allowed to refine, assess and investigate the city areas at risk of river flooding.

In addition, the accurate census population data with the distribution by age and gender provided by the municipality of Bolzano was used along with satellite images from the Sentinel-2 data set (maximum air temperature above the surface and NDMI index) to obtain information about the spatial distribution of the climatic risks. The CLIMAX workflows were then adapted and extended in order to fit the output of the analysis to the local characteristics and needs of the study area.

2.2.2 Choose Scenario

Phase 2 followed the CLIMAAX climate-scenario framework, using historical reference conditions and future projections for 2041–2070 under RCP4.5 and RCP8.5. These scenarios were selected to represent moderate and high levels of future climate pressure and to verify whether the direction of change remains consistent under different emission pathways.

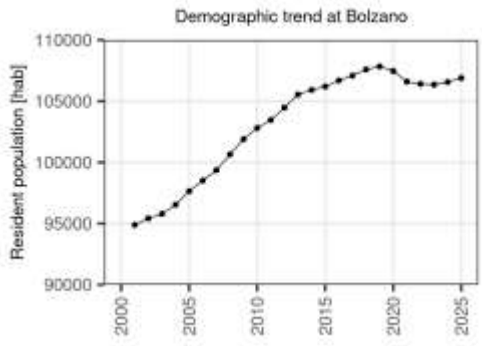

Figure 2-1 Demographic trend of the resident population at Bolzano. Data from ISTAT [1]

In *Figure 2-1* population and demographic structure were treated as broadly stable for the short-term planning horizon, with only moderate medium-term growth considered in the interpretation of exposure. Exposure and vulnerability were therefore assessed using the most recent municipal population data, current urban conditions, building information and land-use patterns. This approach is consistent with the objective of Phase 2, which is to understand how projected climate changes may affect the current urban system and its vulnerable areas.

The scenarios support the assessment of future changes in heatwaves, hot days, tropical nights and extreme rainfall. River-flood exposure was mainly assessed through updated municipal flood maps and current exposure data. Short- and medium-term planning horizons remain relevant because adaptation measures such as de-sealing, greening, drainage improvement and public-space redesign need to be implemented in the coming years to reduce future risk.

[1] https://www.istat.it/en/

2.3 Regionalized Risk Analysis

In Phase 1 the spatial representativeness of the climate datasets was found inadequate to properly capture processes at the city scale. The scale mismatch is particularly relevant for temperature and precipitation projections and their derived indices (native resolution of 12 km) and has directly informed the methodological choices adopted in Phase 2. Bolzano falls almost entirely within a single grid cell, also containing the reference meteorological station. This cell was therefore selected as the representative unit, to ensure consistency and facilitate bias correction and downscaling where applicable, while the hazard was assumed to be spatially uniform across the urban area. Considering (river) flooding scenarios and hazard, in Phase 1 the flooding maps (extent and depth) for return periods of, e.g., 50, and 500 years as provided/calculated by the European Commission's Joint Research Centre were used. Although an excellent data set for a first assessment, it has its limitations, such as overestimating flood-prone areas *(Dottori et al. 2022)*[13], which is the case for Bolzano as well. The following subsections describe how each selected workflow was adapted to the Bolzano context by combining CLIMAAX datasets with local observations, municipal data and observed impact records. The interpretation of the results considers the different spatial and temporal resolutions of the available datasets and the need to connect model outputs with locally observed risk patterns. Dataset-specific assumptions and limitations are described within each hazard assessment, where they directly affect the interpretation of results. A detailed overview of all datasets used for the three workflow is provided in the "**Att.1_Data overview regionalised risk analysis**" supporting documentation.

2.3.1 Heatwaves - fine-tuning to local context

2.3.1.1 Hazard assessment

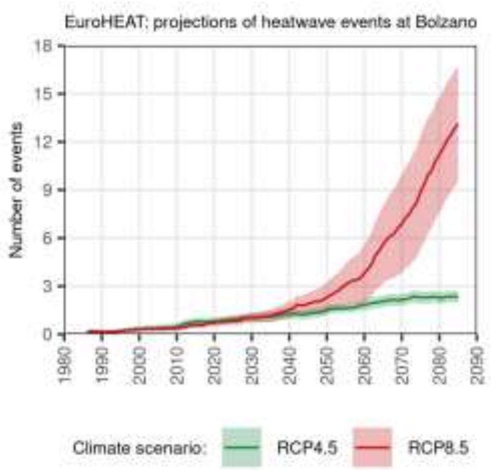

Figure 2-2 Climate projections of heatwave events at Bolzano under the RCP4.5 and RCP8.5 scenarios according to the EuroHEAT methodology.

The hazard assessment considered heatwaves, hot days and tropical nights. Both the EuroHEAT and Xclim methodologies were applied over the historical (1976–2005) and future (2041–2070) periods under the RCP4.5 and RCP8.5 scenarios.

EuroHEAT yielded heatwave trends from the dataset "Climate indicators for Europe derived from reanalysis and climate projections", built from EURO-CORDEX scenarios, in which heatwave episodes are computed as ensemble values of the bias-corrected scenarios under several definitions, including Italy's. The dataset spans 1986-2085 - the full future reference period but not the first ten years of the historical one (*Figure 2-2*). As a reliability check, modelled heatwave days over 2015–2025 showed fair agreement with local observations, confirming the dataset's suitability.

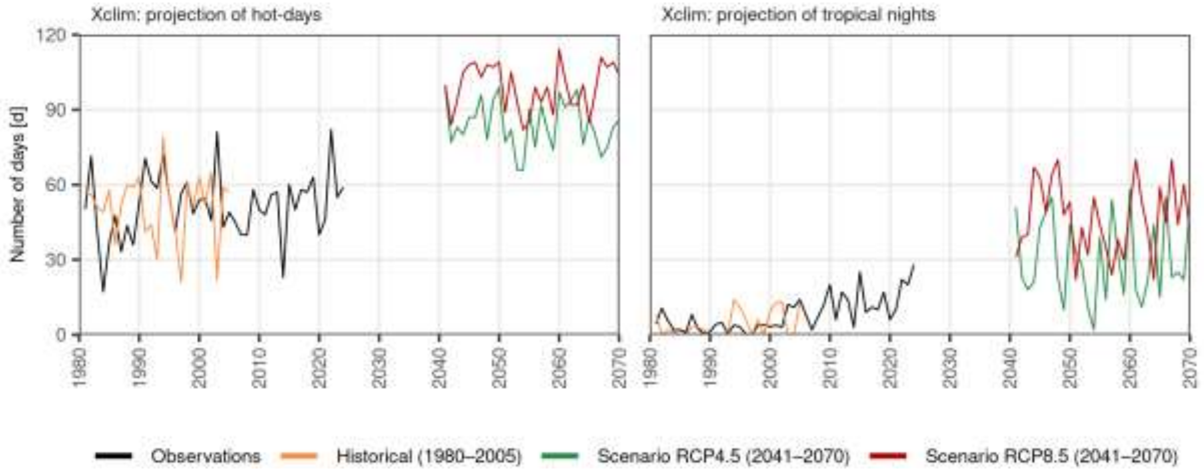

Figure 2-3 Climate projections of hot days and tropical nights at Bolzano under the RCP4.5 and RCP8.5 scenarios according to the Xclim methodology.

The Xclim methodology retrieved the daily minimum and maximum temperatures needed to compute hot-day and tropical-night trends. Its workflow was adapted to download these series from the EURO-CORDEX dataset (European domain) for the Bolzano grid cell. Only GCM-RCM combinations supplying data for both periods and both scenarios were retained, yielding five [2]. These series were bias-corrected with the Cumulative Distribution Function transform (CDFt) (*Vrac, M. et al., 2012)* [9] (*Michelangeli, P.A. et al., 2012)*[10] (*Weedon, G. P. et al., 2014)* [11]43 - the same algorithm used to bias-correct the EuroHEAT temperature data. Annual trends were then computed, and comparison with local observations (to 2025) identified ipsl-cm5a-mr_smhi-rca4 as the reference model for the hazard assessment (*Figure 2-3*).

Table 2-1 Average number per summer of heatwave days, hot days and tropical nights

Extreme heat index	Observations	Historical	Future RCP4.5	Future RCP8.5
Heatwave days	27 (2015-2025)	8 (1981-2005)	54(2041-2070)	136 (2041-2070)
Hot days	51 (1981-2005) 52 (2006-2025)	51 (1981-2005)	84 (2041-2070)	100 (2041-2070)
Tropical nights	4 (1981-2005) 13 (2006-2025)	5 (1981-2005)	30 (2041-2070)	47 (2041-2070)

[2] ichec-ec-earth_knmi-racmo22e, ipsl-cm5a-mr_ipsl-wrf381p, ipsl-cm5a-mr_smhi-rca4, mpi-m-mpi-esm-lr_smhi-rca4, mpi-m-mpi-esm-lr_mpi-csc-remo2009

Values in the table are evaluated from local data and for the modelled (bias-corrected) trends for the historical period and future climate scenarios. Reference periods are reported close to each value.

2.3.1.2 Risk assessment

Exposure to heat. Maximum near-surface air temperature maps at 50 m resolution for summer 2025, from the Sentinel-2 Land Surface Temperature Monitoring dataset, were used to identify the areas of Bolzano contributing most to the UHI. Because these maxima reflect surface temperature more than air temperature, a bias correction was applied that preserves the city's warming pattern while rescaling values to air temperature. The bias was computed at the Bolzano Ospedale weather station as the difference between the remotely sensed temperature and the measured temperature (summer 2025 average) there, then subtracted from the Sentinel-2 maps. In the resulting distribution *("max_LST_2025.tif" file on Zenodo, see Ch.5* **Workflow datasets***)* almost the entire built-up area shows air temperatures above 30 °C, with hotspots in the Industrial Zone where they can exceed 35°C.

Vulnerability to heat. The vulnerability was assessed by considering both the most vulnerable age groups — children (< 5 years) and the elderly (> 65 years) — and the working-age population. Children and the elderly are typically the most susceptible to heat stress. Since their daily travel radius is more limited, largely confined to their place of residence, the resident-population map is a good proxy for their exposure. The working-age population, on the other hand, is more mobile. During the day — when extreme heat peaks — they are typically not at home but in workplaces such as industrial and commercial zones, i.e. areas with low residential population. Moreover, in cities such as Bolzano, commuting must also be accounted for: the non-resident population that travels into the city each day and is exposed to extreme heat during its stay. Within the BOMAAX project, the distribution of the vulnerable age groups (under 5 and over 65) was provided by the Bolzano Municipal Statistics Office, while the exposure of the working-age population (including commuters) was assessed by evenly distributing 22000 people across the industrial areas. The number of workers employed in the industrial zone was taken from a report by the Institute for Economic Research of the Chamber of Commerce of Bolzano *(IER, 2020)*[12]

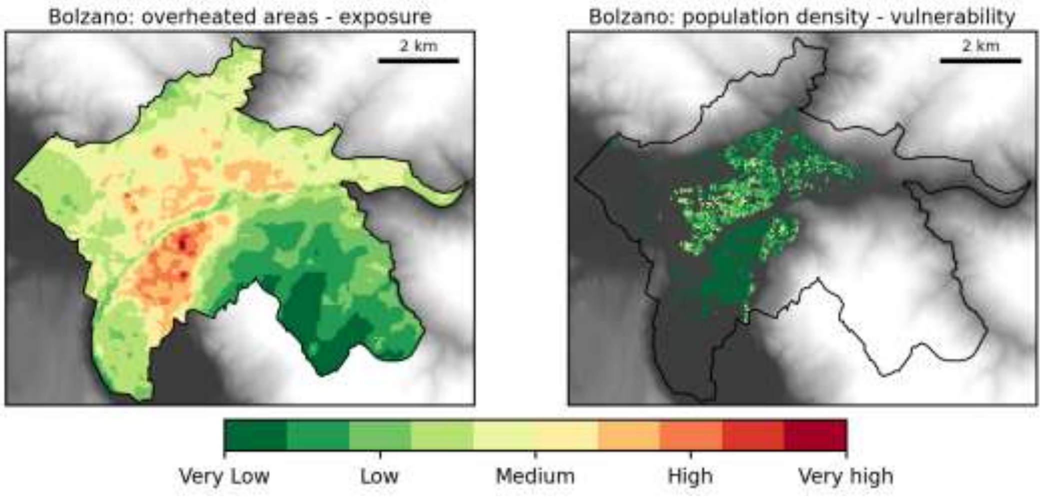

Figure 2-4 Levels of exposure (left) and vulnerability (right) computed according to the CLIMAAX workflow from the map of air temperature and population distribution, respectively.

Current risk. The exposure and vulnerability maps were produced with the CLIMAAX workflow. In line with the temperature maps, the exposure map (*Figure 2-4* left) shows higher average heating levels in built-up areas, with significant hotspots in the Industrial Zone. The vulnerability map (*Figure 2-4* right) - obtained by adding commuters to the heat-sensitive resident population - shows low-to-medium vulnerability across the city's residential areas and lower levels in the industrial zone.

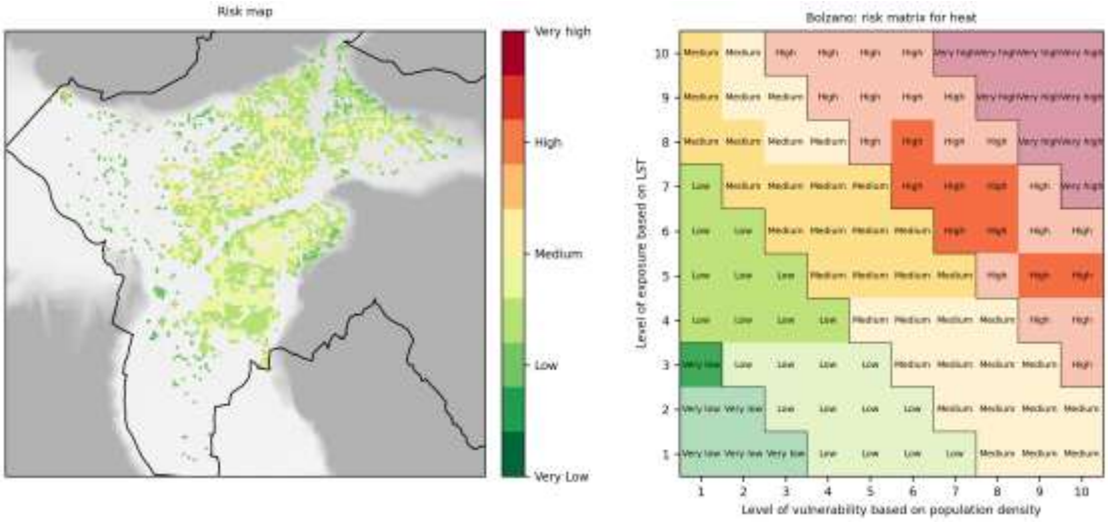

Figure 2-5 Risk map (left) and risk matrix (right). The cells in the matrix that are highlighted in colour correspond to the risk levels shown on the map.

The risk matrix was then used to define risk levels and produce the extreme-heat risk map for Bolzano. shows this map on the left and the risk matrix on the right, with the cells where a risk is identified highlighted. Across the built-up area, the population faces, on average, a moderate risk of extreme heat. More critical zones appear within residential areas, linked to the higher density of the most vulnerable groups (children and the elderly). Conversely, in the Industrial Zone, despite its low population density (commuters spread across the buildings), risk levels are comparable to those in the historic centre, owing to the high temperatures that can be reached there. Risk levels are, however, low or very low in the city's outlying areas, near the hillsides.

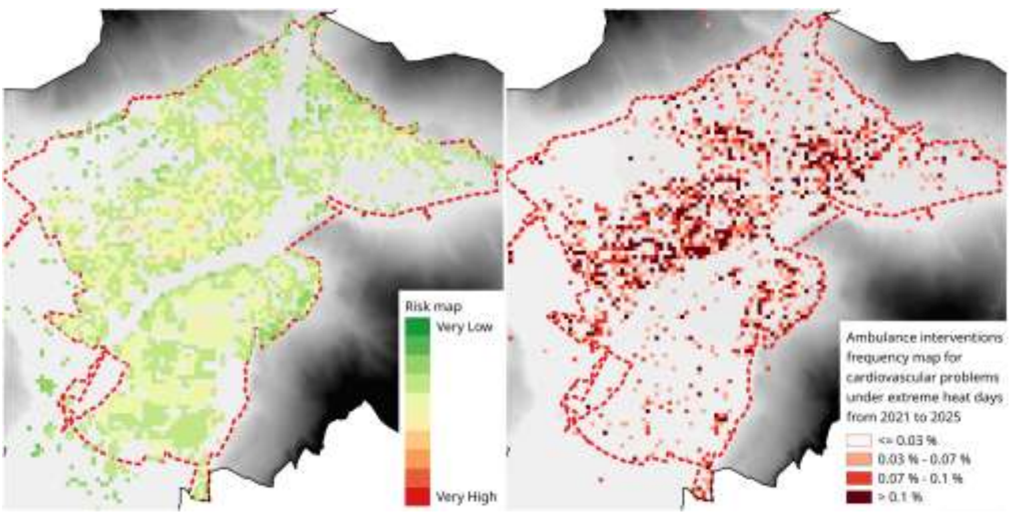

Figure 2-6 Risk map for extreme heat (left) and frequency distribution of ambulance interventions for cardiovascular problems under extreme heat conditions from 2021 to 2025 (right)

The *Figure 2-6* compares the extreme-heat risk map with the distribution of ambulance interventions for cardiovascular problems during extreme heat between 2021 and 2025 - a direct reflection of its impact on the population. This comparison offers validation-like evidence for the calculated risk map: most emergency responses are concentrated in the parts of the city where risk levels are highest.

Future risk. BOMAAX adopts the short-to-medium term as its reference scenario, in line with local planning horizons and the SECAP framework (Section 2.2.2). As already noted, current demographic trends suggest that the population - and its distribution by age group and gender - is likely to remain stable over this period (2040–2070). The hazard analysis indicates that Bolzano may face more frequent extreme-heat episodes in the near future, particularly tropical nights and heatwaves (*Table 2-1*). On this basis, and absent effective localised measures to mitigate surface warming, exposure to extreme heat is likely to rise across the whole city - intensifying where overheating is already significant, namely the industrial zone and parts of the residential areas - with a corresponding increase in risk.

2.3.2 Heavy Rainfall - finetuning to local context

The data set of fire brigade interventions due to adverse weather, analysed preliminary in Phase 1 (see P1D), was examined in greater detail in Phase 2 (Section **Errore. L'origine riferimento non è s tata trovata.**). Results show that heavy rainfall damages buildings and streets through flash floods. This damage arises from two rainfall types: short-lived (15–30 minutes), high-intensity events and low-intensity precipitation lasting more than 48 hours. The short-lived events are typical of summer, developing at the end of very warm periods, so their frequency and intensity are exacerbated by extreme-heat events (Section 2.3.1). The dataset enabled the development of a hazard–impact database and the identification of critical-impact rainfall thresholds. The impact of climate change on short-duration rainfall is a critical point in applying the CLIMAAX workflow for extreme rainfall: the reference reanalyses and projections (EURO-CORDEX) provide cumulative precipitation fields at a three-hourly resolution, so the annual precipitation maxima needed for statistical rainfall analysis can only be derived for durations of 6 hours or more. Phase 2 addressed this issue to assess the climate-driven shift in hazard - i.e. in the critical-impact rainfall thresholds (Section 2.3.2.1). The city elements most vulnerable to extreme rainfall are buildings and roads. Impervious surfaces alter the city's exposure to flooding, so a risk map was produced to identify potentially critical areas (Section 2.3.2.2). This map was then compared with the urban drainage network and the locations of fire-brigade interventions, as validation-like evidence for the patterns identified.

2.3.2.1 Hazard assessment

The hazard assessment was performed once defined: (1) the statistical framework for analysing precipitation (modelled and observed); (2) the criteria for selecting the most appropriate combination of GCM and RCM from the EURO-CORDEX dataset for the analyses; (3) the bias-correction approach, which aligns modelled precipitation with local patterns, including sub-hourly durations. The procedure returns a NetCDF file containing the coefficients of the intensity-duration-frequency curves for several return periods (**T** = 2, 3, 5, 10, 20, 30, 50, 100, 200 and 300 years) and for each available dataset: observed data for 1976-2005, and modelled data before and after bias correction for both the historical (1976-2005) and future (2041-2070) periods under the RCP4.5 and RCP8.5 scenarios. These coefficients were then used to evaluate the frequency and precipitation shift of intense rainfall due to climate change. The analysis of fire-brigade interventions for the climate risk assessment (Section **Errore. L'origine riferimento non è stata t rovata.**) made it possible to identify the impact-based rainfall thresholds: one for short-duration, high-intensity events and one for long-duration, low-intensity events. *Figure 2-7* reports the frequency and precipitation shift of these thresholds due to climate change.

			Frequency shift				Precipitation shift			
Threshold		Actual climate	Future – RCP4.5		Future – RCP8.5		Future – RCP4.5		Future – RCP8.5	
short-duration high-intensity	Duration	30 min								
	Return period	10 years	4 years	[-59.5%]	2 years	[-77.8%]				
	Precipitation height	22.04 mm					25.38 mm	[+15.1%]	30.92 mm	[+40.3%]
long-duration low-intensity	Duration	48 hours								
	Return period	30 years	12 years	[-59.8%]	13 years	[-57.1%]				
	Precipitation height	112.70 mm					128.73 mm	[+14.2%]	130.22 mm	[+15.5%]

Figure 2-7 Impact-based rainfall thresholds derived from the analysis of fire brigade interventions and their frequency and precipitation shift due to climate change.

The results can be summarised as follows: (1) Regardless of event duration, climate change tends to affect the frequency (return period) more than the amount of precipitation; this is clearer for the long-duration, low-intensity threshold. (2) Climate change is expected to increase event frequency: current return periods shorten by just over half under future scenarios. (3) Differences between RCP scenarios are significant for short, high-intensity events but almost negligible for longer-duration, lower-intensity ones. A more detailed procedure can be found in the supporting document "**Att.2_Heavy rainfall technical document**".

2.3.2.2 Risk assessment

The limited extent of the BOMAAX study area precludes any assessment of the spatial variability of extreme precipitation, whether under current conditions or under climate-change scenarios. The shift in critical-impact thresholds determined in Section 2.3.2.1therefore applies to the whole city. Nevertheless, it remains useful to identify the areas potentially most exposed and vulnerable to extreme-rainfall damage, even assuming a uniform precipitation distribution and hazard level. In Phase 2, a risk map was produced to identify these areas. The distribution of artificial surfaces and their degree of impermeability determine the city's exposure and vulnerability. As a proxy, high-resolution annual-average maps of the NDMI from Sentinel-2 were used. The NDMI (Normalised Difference Moisture Index) quantifies the water stress of vegetation, ranging from −1 (arid, bare soil) to +1 (vegetation without water stress). In an urban context, the inverse of the NDMI therefore serves as a proxy for soil permeability and, hence, for the degree of surface imperviousness.

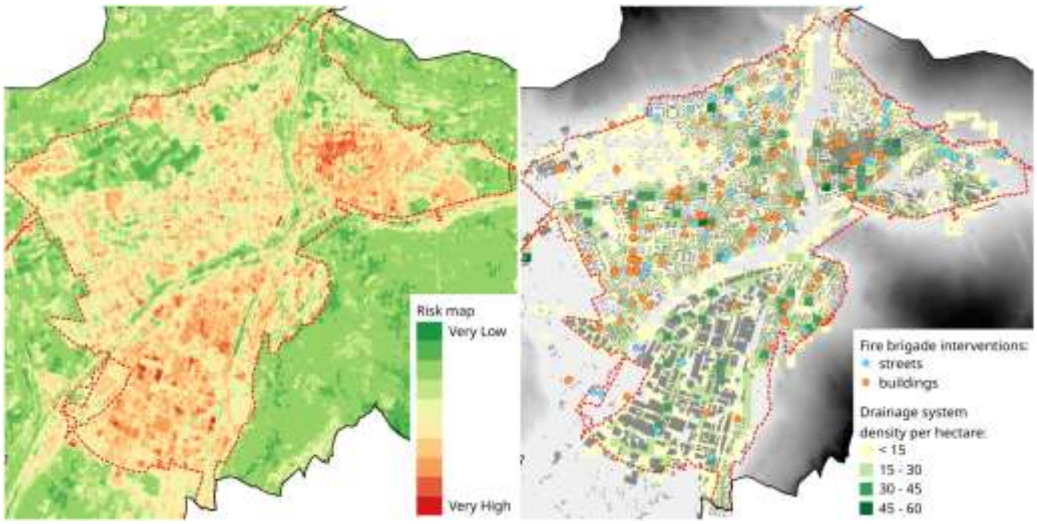

Figure 2-8 Risk map for extreme precipitation (left) and distribution of fire brigade interventions superimposed on the density of public drainage network system (right).

The resulting map (*Figure 2-8* left) shows that the areas potentially most at risk from extreme rainfall are those with the highest degree of surface sealing — notably the historic centre and the industrial area. To validate these patterns, the right-hand map shows the distribution of fire-brigade interventions, categorised by impact on open areas (roads) or on buildings, overlaid on the density of the public drainage network per hectare. This network excludes private drainage systems and is itself risk-mitigation infrastructure. Even so, a clear correlation between the degree of soil sealing and fire-brigade interventions is evident, particularly in the historic centre.

2.3.3 River floods - finetuning to local context

2.3.3.1 Hazard assessment

To conduct river flooding hazard and risk assessment for Phase 2, The "River & Costal Floods - River flood" workflow, provided by the CLIMAAX project team, was implemented. The relevant code parts of the workflow were adapted to accommodate the improvements evolving around the new, localized data. In Phase 1 of the river flooding hazard assessment, data from the EC the Joint Research Center (JRC) were used. These data indicated extensive flooding, affecting large portions of the city, likely due to multiple converging rivers and rivulets, complex terrain and existing local flood protection structures. The estimated depth and extent suggested a high risk to the population. For the Phase 2 the Bolzano municipality provided improved and better resolved flood maps, which are expected to be more realistic, incorporating local details that affect the flooding.

Figure 2-9 Improved flooding maps for the 3 selected return periods, established by the Municipality of Bolzano. The water extent (and surface) is shown in blue colour.

These maps differ significantly from the Phase 1 data, showing a smaller extent and reduced flood depths within Bolzano (*Figure 2-9*). On the other hand, zooming in on one area with significant vulnerable population (e.g., elderly; *Figure 2-11*), it can be observed that the data are more detailed (due to the better resolution), and that there is a presence of a risk, as opposed to Phase 1 hazard assessment for this particular selection of location. This directly affects the risk assessment, providing a more realistic evaluation. The hazard, however, remains real, with assessments conducted for three return periods: 50, 100, and 200 years.

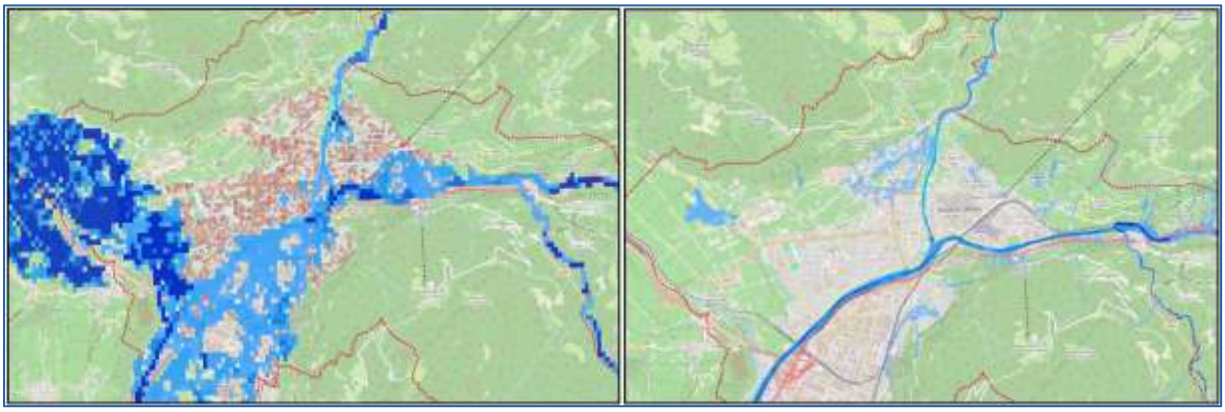

Figure 2-10: Comparison of 100-year return period flooding maps used in Phase 1 and Phase 2 shows significant differences. Left: maps produced by JRC (Phase 1). Right: maps produced by the Bolzano Municipality (Phase 2).

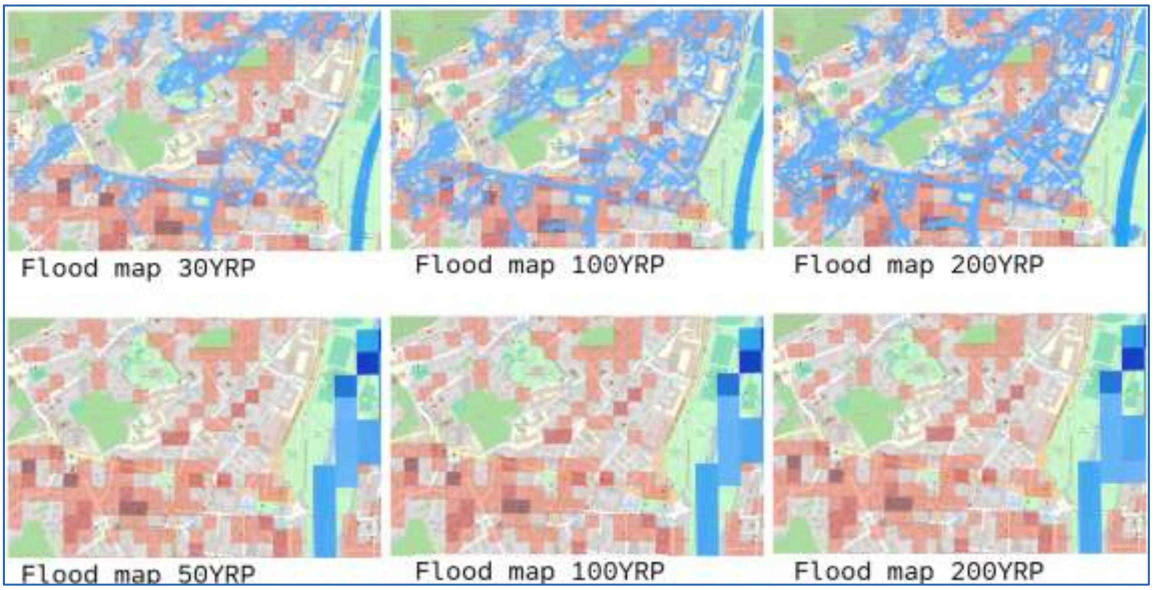

Figure 2-11: Flooding extent differences between JRC data and Municipality of Bolzano data

2.3.3.2 Risk assessment

Population exposure to the river flooding hazard

Exploiting the new and improved flooding maps, a more accurate risk assessment was performed, especially in combination with the improved population/demographics dataset. Where the *WorldPop* datasets was used in Phase 1, which are numerical estimates spatially distributed with the resolution of ca. 100 meters and categorized into several vulnerable age groups (see P1D), the official census data prepared by the Municipality of Bolzano was used. The dataset is highly resolved (50 meters) and contains several vulnerable categories (across sex and age). All these data were prepared for integration into the CLIMAAX workflow from Phase 1. With slight adaptations, the risk maps were produced, highlighting the areas and locations of interest for potential adaptations measures.

An example output is show in *Figure 2-12*. It shows the selected vulnerable population group of *elderly above 66 years of age* (both sexes included), how they are distributed in the city, and how they would get affected in case of a 30-year return period flood, i.e., where would they be most exposed (the middle figure), and how many of this group would get displaced (the figure on the right showing the displaced for all three return periods). Similar maps and graphs are established for all vulnerable groups and available in Zenodo. Comparison to Phase 1 results, the numbers are significantly lower, as expected considering the flooding extent and depth differences using the improved flooding maps (see discussions above).

Figure 2-12 Left: Distribution of population of age 66 and above shown in orange. Middle: For a 30-year return period river flooding event, the calculations show the exposed/affected part of this vulnerable group, mostly within the red ovals, while the estimated number of displaced populations for 3 selected return periods (including 30-year return period), is shown on right.

Regardless of a seemingly/potentially not very high risk, and that one life affected is one life too many, the areas and locations at most risk for the (selected) population, and that could be considered for future mitigation and adaptation measures, were identified. These are in three major locations, as can be observed in *Figure 2-13*. Any further assessment and implementation of measures should focus on these locations, prioritising those with the highest potential impact and supporting them with more detailed analysis.

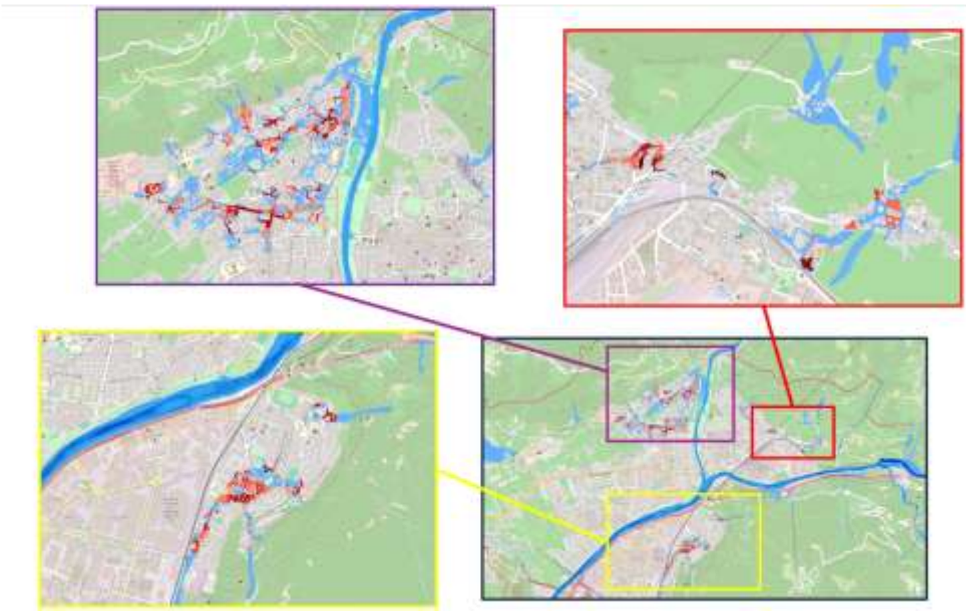

Figure 2-13 Most exposed and impacted locations considering population distribution and areas for river flooding.

Building exposure to the river flooding hazard

The updated flood hazard maps allowed a more accurate assessment of building exposure and potential economic damage. In Phase 2, the workflow used municipal building data, with more precise footprints and categories than the OSM data used in Phase 1. Flood depths were combined with building information, reconstruction costs and content values to estimate building-level damage. Results show a lower overall impact than in Phase 1, mainly due to smaller flood extents and reduced flood depths in the municipal maps. For the 30-year return period, estimated building damage is approximately ten times lower than in Phase 1, with similar reductions for the other return periods.

The risk is therefore more spatially specific rather than negligible, supporting targeted adaptation or protection measures for exposed buildings and areas.

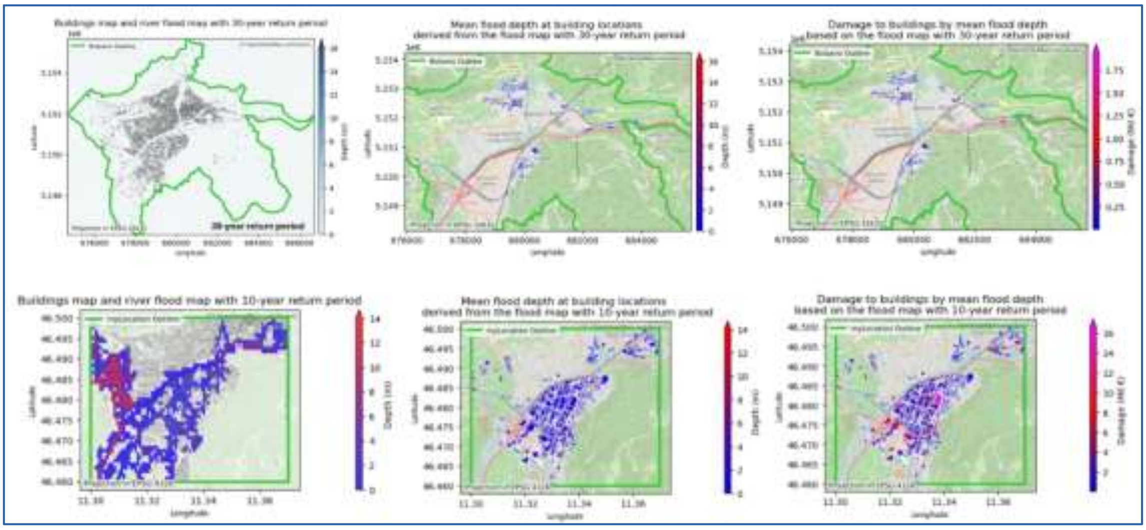

Figure 2-14 Risk assessment and estimated damage costs for river flooding affecting buildings and infrastructure. Phase 2 results (top row) based on more accurate flood maps and building data provided by the Municipality of Bolzano; Phase 1 (bottom row) using JRC flood maps and OSM building data.
Note that different flood return periods are used (30-year for Phase 2 and 10-year for Phase 1).

2.3.4 Additional assessments based on local models and data

Analysing local datasets and integrating the results into the workflows improved the alignment of the modelled scenarios with the characteristics of Bolzano, as described below:

- Analysing ER calls for cardiovascular problems made it possible to map the distribution of the impact of extreme-heat periods on public health across the city.
- Analysing fire-brigade interventions for rainfall-related damage made it possible to classify the damage, identify critical impact thresholds in terms of event duration and frequency, and map the distribution of these interventions across the city.
- Data on river floods for the whole Province of Bolzano are held in the ED30 registry, managed by the Civil Protection Agency since 1998 (P1D). The registry records flood and debris-flow events together with associated metadata (event location, weather conditions, damage and photographic documentation). For the Municipality of Bolzano, ED30 shows no river flooding — some occurred nearby but not within the city — only some damage from debris flows or sediment transport from small creeks; these fall outside the scope of the river-flood workflow and are therefore not considered. As ED30 is not useful for Phase 2, the PZP maps were used instead to extract the necessary information at the local scale. The PZP is not observed data but the output of high-resolution numerical modelling of potential flood scenarios across a range of return periods.

2.3.4.1 Heatwave

ER calls for cardiovascular problems since 2006, provided by Bolzano Hospital, were analysed. Each record gives the date and time of the call and the location of the intervention. After a preliminary screening, only the summer period (May–September) was retained. The correlation between ER calls and hot days, tropical nights and heatwaves was not statistically significant: at this level of detail the data are too noisy, not having been collected for this purpose. Interventions over the last five summers (2021-2025) were therefore gridded at 50 m resolution onto the population-distribution map - for the whole summer and for extreme-heat days alone (*Figure 2-15*). In both cases, the interventions cover the residential areas.

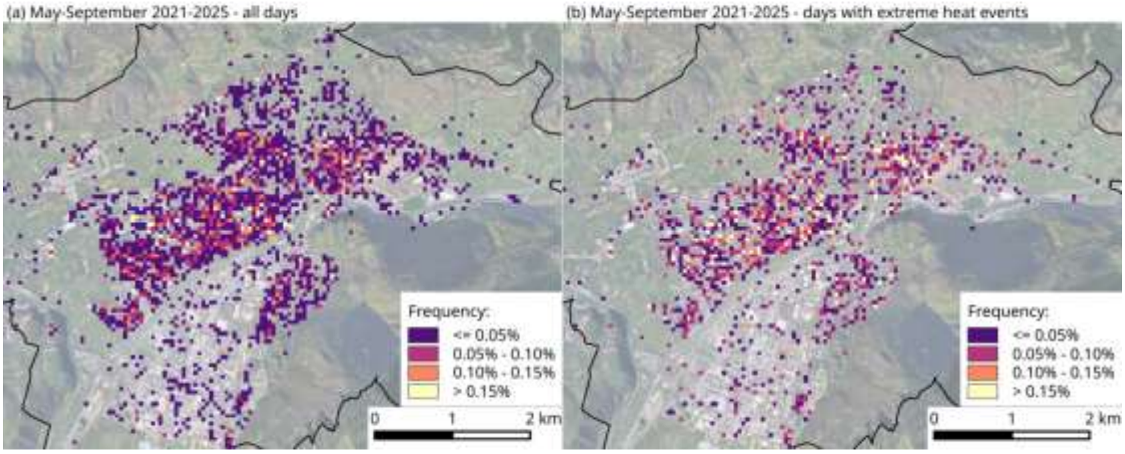

Figure 2-15 Frequency maps of ER calls for cardiovascular issues at 50 m resolution considering all days in the summer period and days under extreme heat conditions (hot days, tropical nights, heatwave).

2.3.4.2 Heavy Rainfall - Extreme Precipitation

Fire-brigade interventions for rainfall since 2018 were analysed to build the hazard–impact database and the impact-based rainfall thresholds required by the 'extreme precipitation' workflow. A detailed description of the analysis can be found in the supporting document "**Att.2_Heavy rainfall technical document**", while the main findings are drawn below.

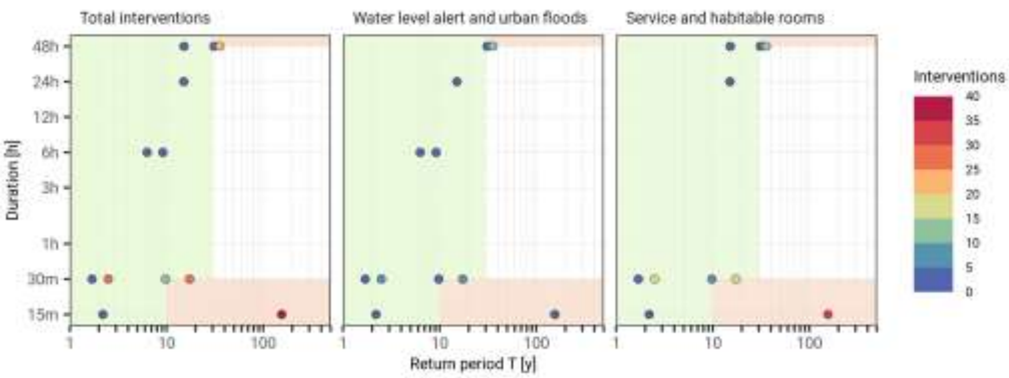

Figure 2-16 Intervention distributions by return period and duration of the precipitation and by impacted area. Red areas identify precipitation events with "high risk" of damages, while green areas identify precipitation with ""low risk" of damages.

The precipitation impact thresholds were identified from the graphs in *Figure 2-16* which plot the distribution of fire-brigade interventions against the duration and return period of the triggering precipitation. Interventions are shown both in total and aggregated by impact area (open areas and buildings). They split into two groups with event duration, reflecting the dual precipitation regime (convective and orographic). These distributions identify two precipitation thresholds separating high-risk from low-risk events: (1) events lasting more than 48 hours with return periods above 30 years; (2) events shorter than 30 minutes with return periods above 10 years. No threshold could be defined for intermediate-risk events, given the limited size of the fire-brigade intervention dataset. The procedure could, however, be repeated in future to improve the statistical significance of the analysis.

2.4 Key Risk Assessment Findings

2.4.1 Mode of engagement for participation

The key risk assessment evaluation following the CLIMAAX Risk Evaluation Protocol for Key Risk Assessment”[3] combined the technical outputs of the Regionalized Risk Analysis with stakeholder input collected during the Phase 2 participatory workshop. The engagement focused mainly on heatwaves and extreme rainfall/urban flash flooding, as these risks are strongly linked to everyday use of public spaces, mobility, vulnerable users and local maintenance conditions.

Workshop participants discussed risk maps, exposed users and preliminary adaptation solutions, helping to complement the technical results with local knowledge on perceived impacts, feasibility and intervention priorities. This input supported the qualitative assessment of severity, urgency, resilience capacity and risk priority. River flooding was included in the Key Risk Assessment, but it was not selected as a central workshop topic. This reflects the Phase 2 results, which show a more localised and lower-priority risk compared with heatwaves and extreme rainfall. River-flood risk was therefore assessed mainly through technical outputs, municipal flood maps, exposure data and institutional knowledge related to flood-risk management and civil-protection responsibilities.

2.4.2 Gather output from Risk Analysis step

The risk evaluation in Phase 2 builds on the results and outputs produced during the Risk Analysis Step described in earlier sections, which provides insights into all three relevant hazards, the exposure elements/components and their assessments, and both current risk and potential future risk impacts derived from climate projections. This provides the basis for assessing severity, urgency and resilience capacity, and thereby for establishing the overall risk priority for the Municipality of Bolzano.

2.4.3 Assess Severity

Following the CLIMAAX Key Risk Assessment Protocol, the severity of the climate-related risks was assessed for both current and future projected conditions. Severity was evaluated qualitatively and categorized as limited, moderate, substantial or critical, in line with the four categories defined in the protocol. Each categorization was based partly on the quantitative assessments and model outputs produced in the earlier Risk Analysis steps, together with the interpretation of those results in the local context. In addition, these quantitative outputs were integrated with the qualitative perceptions and expertise of local stakeholders gathered during the

[3] https://handbook.climaax.eu/_downloads/84739fdde14e02d84e111852f1d53fa4/key_risks_protocol_easy.pdf

participatory workshops, drawing on contextual information relevant to the Municipality of Bolzano and on its environmental, social and economic conditions.

2.4.3.1 Heatwaves

Extreme heat is the most critical hazard for Bolzano - a conclusion that also emerged from the participatory stakeholder workshops. Comparing the historical period (1976-2005) with the potential mid-term impacts (2041-2070) under the RCP4.5 and RCP8.5 scenarios reveals a significant increase in heatwaves and tropical nights. The associated risk can harm human health - causing heat-related morbidity and, among the most vulnerable groups (children and the elderly), mortality - while straining the healthcare system during heat peaks and subjecting the city's green areas and biodiversity to combined heat and water stress. However, adding the trend observed over 2015-2025 shows that current climate conditions are already approaching those expected under RCP4.5. **Extreme heat is therefore assessed as critical both now and in the future: the city already experiences critical-severity conditions, which are expected to persist or intensify (Severity: Critical - Critical)**.

2.4.3.2 Heavy Rainfall - Extreme Precipitation

Extreme precipitation in Bolzano falls into two categories: summer thunderstorms and orographic rainfall. Summer thunderstorms are intense but short-lived (30–60 minutes). Their frequency and intensity are expected to rise in the near future, as they are fuelled by periods of abnormal heat. They are frequent and mainly cause flooding on roads and in building service areas and, in the most intense cases, even inside homes. They also bring down branches and trees, block traffic and damage buildings and the businesses they house. Orographic rainfall is low-intensity but lasts several days, typically triggering river-level alerts and flooding in building service areas (partly from rising groundwater). Climate projections show a slight increase in these events, with no significant change in intensity. The resulting impacts are recurrent and spread across the urban area, but largely material and economic rather than irreversible. The impact on human health is also less direct than that of extreme heat. In line with this, the stakeholder workshop framed extreme precipitation as a manageable urban-water and public-space challenge - prioritising drainage, retention, multifunctional greening and improved communication and awareness-raising - rather than as a severe threat. Therefore, **extreme rainfall in Bolzano is considered to have a substantial level of severity (Severity: Substantial – Substantial)**.

2.4.3.3 River Floods

The severity of river flooding in Bolzano was assessed by interpreting the Phase 2 hazard and risk outputs, which are based on the improved, locally resolved flood maps and the official population census data and building data provided by the Municipality. Compared with the Phase 1 JRC-based assessment, these data show quite a smaller flood extent and reduced flood depths within the city, with population exposure and estimated building damage substantially lower. For example, the estimated damage for a 30-year return period is approximately ten times lower than was estimated in Phase 1, while exposed numbers of vulnerable residents at the most critical locations remain limited. The risk is there, but spatially concentrated rather than systemic, with a few clearly identifiable streets, buildings and groups of vulnerable residents might be affected, without evidence of large-scale, irreversible or cascading consequences such as widespread human loss or destruction of strategic economic or ecological assets. From the stakeholders' perspective, river flooding was not perceived as the dominant hazard for Bolzano, in contrast to extreme heat and rainfall, especially as there were no significant episodes of river flooding for a long time. On this basis, **river flooding is assessed at limited severity for both the current and future periods (Severity: Limited - Limited).**

2.4.4 Assess Urgency

The urgency of all three hazards (extreme heat, extreme precipitation and river flooding) was assessed by combining the temporal characteristics of each hazard with the Phase 2 risk results and the perceptions gathered from stakeholders during the workshop. The resulting assessment for each hazard is presented below.

2.4.4.1 Heatwaves

Extreme heat is a slow-onset, recurring hazard that returns every summer and persists over multiple consecutive days, which extends the population's exposure and amplifies its impact on public health. The assessed climate projections show a marked worsening in the near future, i.e., under the RCP4.5 and RCP8.5 scenarios, heatwave days are projected to rise from 8 in the historical period to 54 and 136 respectively by 2041–2070, with comparable increases in hot days and tropical nights. Importantly, the observed trend for 2015–2025 with its 27 heatwave days already exceeds the historical baseline and approaches the RCP4.5 projection, indicating that the severity changes from current to future risk is significant and already underway. This implies that action is needed now to minimise damages, since the absence of localised mitigation measures would otherwise lead to a steady intensification of risk in areas that already overheat today. The stakeholder perspective reinforced this, with extreme heat emerging as the most critical hazard for Bolzano and older people, children, outdoor workers and people with health conditions identified as the most exposed and least able to cope. **On this basis, extreme heat is assessed as requiring immediate action (Urgency: Immediate action needed).**

2.4.4.2 Heavy Rainfall – Extreme Precipitation

Heavy rainfall in Bolzano is a sudden-onset hazard, with damage to buildings and streets caused mainly by short-lived (15–30 minutes), high-intensity summer events as well as by long-duration, low-intensity precipitation. The short-duration events are particularly relevant because they tend to develop at the end of very warm periods, so their frequency and intensity are intensified by extreme heat, linking this hazard closely to the most critical risk for the city. Climate projections show a clear worsening in the near future, i.e., under both RCP4.5 and RCP8.5, these events become about twice as frequent, while their intensity changes little, the effect being most pronounced for short, high-intensity rainfall. This indicates a significant change in severity from current to future risk that is already underway, requiring action now to minimise damages, particularly in the most sealed parts of the city such as the historic centre and the industrial area. The stakeholder perspective reinforced this by highlighting drainage capacity, maintenance and road safety as concerns, with roads, parking areas and narrow pedestrian spaces seen as particularly problematic during heavy rain. **Extreme precipitation is thus assessed as requiring more action, given a worsening and recurring hazard whose impacts are closely tied to extreme heat and already felt across the most impervious areas of the city (Urgency: More action needed).**

2.4.4.3 River Floods

River flooding in Bolzano is a sudden-onset hazard tied to defined return periods (50, 100 and 200 years) rather than a slow-onset process, which means that when an event occurs its impacts are immediate, but the overall probability in any given year remains comparatively low. The Phase 2 assessment does not indicate a significant change in severity from current to future conditions, and the improved local flood maps show a smaller, more concentrated risk than previously estimated in Phase 1, partly reflecting the existing local flood-protection structures. Similar to Severy assessment, the risk is there justifying monitoring, and targeted, planned interventions rather than emergency action. From the stakeholders' perspective, river flooding was not seen as the most pressing hazard for Bolzano compared with extreme heat and rainfall, which supports a measured rather than immediate response. **Based on that, river flooding is assessed as a Watching Brief level, with the region able to plan and act on targeted measures within the coming years, in case the trend changes (Urgency: Watching Brief)**.

2.4.5 Understand Resilience Capacity

2.4.5.1 Heatwaves

For heatwave risk, resilience capacity of Bolzano is substantial, but with clear implementation gaps. Existing municipal and provincial planning instruments, including the PAESC/SECAP, the Piano del Verde, the Klimaplan Südtirol 2040 and ongoing initiatives such as JUSTNature, provide a strong basis for heat-risk reduction through urban greening, de-sealing, green roofs, shaded public spaces and biodiversity-oriented interventions. However, the risk maps show that the existing urban fabric still contains extensive sealed and overheated areas, particularly in the most exposed public spaces, dense residential areas and the Industrial Zone. Resilience capacity is therefore limited not by lack of awareness, but by the need to translate strategic plans into site-specific interventions on the ground. The planned or already initiated interventions framed around urban greening, Nature-based Solutions, de-sealing, green roofs and public-space cooling, confirm a valuable and improving capacity, nonetheless leaves space for improvement. **Thus, the Resilience Capacity were categorized as Substantial**.

2.4.5.2 Heavy Rainfall – Extreme Participation

The existence of fire brigade intervention records, local rainfall data, municipal drainage-related knowledge and the PAESC/SECAP adaptation framework provides a basis for identifying problematic areas and planning local runoff-reduction measures. The analysis, however, also shows that the most damaging events include very short rainfall durations that are not well represented in standard EURO-CORDEX precipitation data. This means that local monitoring, impact databases and drainage-network information are essential for planning. Capacity should be strengthened through systematic recording of damage locations, drainage bottlenecks, basement flooding, surface runoff paths and performance of existing drainage infrastructure during intense events. Planned or relevant interventions include de-sealing, permeable surfaces, rain gardens, bioswales, retention areas and improved maintenance of drains, gutters and catch basins, in line with green-infrastructure and Nature-based Solution approaches promoted in local adaptation planning. Based on this, **the Resilience Capacity for heavy rainfall is assessed as Medium**.

2.4.5.3 River Flooding

Considering the current measures of the Municipality, the availability of municipal flood maps and building data improve the assessment substantially compared with Phase 1 and enables targeted and location-specific planning. Planned or relevant measures include coordination with existing flood zoning, civil-protection procedures, building-level protection, protection of critical infrastructure, emergency access planning and continued updating of hazard and exposure information. Overall capacity is therefore substantial considering the *understanding* the river flooding hazard, however, it still requires development in intervention planning and implementation **(Resilience Capacity: Medium–Substantial)**.

2.4.6 Decide on Risk Priority

Risk Workflow	Severity		Urgency	Capacity	Risk Priority
	C	F		Resilience/ CRM	
River flooding	1	1	2	3	Low
Heavy rainfall	3	3	3	2	High
Heatwaves	4	4	4	2	Very high

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

Figure 2-17 Key Risk Assessment through risk ranking for the Municipality of Bolzano. Three hazards/risks are assessed through evaluation of Severity (C: current; F: future), Urgency and (resilience) Capacity, based on qualitative judgement. The overall outcome suggests risk prioritization indicating key and less urgent risks.

The Risk Priority was assigned by qualitatively integrating the three sub-evaluations, Severity, Urgency and Resilience Capacity, following the logic of the CLIMAAX Key Risk Assessment evaluation dashboard, where high severity and urgency raise the priority and low resilience capacity increases it further. The output is provided in Figure xx, and description of the assessment and decision process in the following paragraphs.

Heatwave risk is assigned the highest priority for Bolzano. Its severity is rated critical for both periods; most of the built-up area is already exposed to elevated summer temperatures, with the highest-risk conditions in dense residential areas, the historic centre and the Industrial Zone, while the validation against cardiovascular ambulance interventions confirms heat as a public-health risk, heightened by the concentration of vulnerable residents, commuters and workers. Urgency is immediate, since heatwaves, hot days and tropical nights are projected to rise sharply, and the observed trend is already underway. Resilience capacity is substantial, with strong planning instruments in place but still constrained by the need to translate them into site-specific interventions. Jointly, **these result in a very high overall risk priority**.

Considering Heavy Rainfall, a high priority was assigned. As described earlier, the severity comes primarily from sudden, localised impacts on streets, buildings, mobility and drainage systems, concentrated in the historic centre and the Industrial Zone. The fire-brigade data reveal two high-risk regimes/situations, forcing the city to prepare for both fast convective downpours that overwhelm drainage and for prolonged rainfall that affects buildings and infrastructure. Urgency is rated as *more action needed*, since these events are projected to become about twice as frequent and are closely tied to extreme heat. Resilience capacity is medium, since very short events are poorly captured in standard data and local monitoring. **Together, these give a high overall risk priority**.

To complete the risk analysis for the Municipality of Bolzano, River Flood risk was assessed as low, depending on the exposed receptor. The Phase 2 results reduce the overall severity compared with Phase 1, as the updated municipal flood maps show smaller flood extents and lower expected damages than the earlier JRC/OSM-based assessment. The risk is real but spatially concentrated at a few identifiable locations and groups of vulnerable residents, without evidence of systemic or cascading consequences. Urgency is therefore rated as a watching brief, while resilience capacity is rated as between *medium* and *substantial*. **Together, these give a low overall risk priority, justifying continued monitoring and targeted, planned interventions rather than emergency action.**

2.5 Adaptation strategy: approach and methodology

Although this chapter is not explicitly required by the CLIMAAX project template, it has been included to document the preliminary adaptation work developed during Phase 2 and to clarify how the Climate Risk Assessment and Key Risk Assessment findings started to inform possible adaptation directions for Bolzano.

Adaptation solutions are understood broadly, including Nature-based Solutions, grey or technical measures, digital and data-driven tools, governance and planning measures, and communication, awareness and stakeholder-engagement actions. In **Phase 2, the focus is placed primarily on Nature-based Solutions** and their relationship with the urban context, municipal planning instruments, local constraints and intervention opportunities. Other types of measures will be considered in more detail in Phase 3, where the full definition, validation and spatial development of the adaptation solutions will be carried out.

2.5.1 Preliminary logic for the definition of adaptation solutions

The preliminary definition of adaptation solutions in Phase 2 was based on the overlay of hazard, exposure and vulnerability maps, Key Risk Assessment findings, urban morphology, land-use patterns, public-space conditions, flood-prone areas and the main urban-planning and sectoral documents consulted for Bolzano. This planning-oriented reading helped identify where adaptation solutions may be more relevant, how they could respond to the main risk patterns and how they could be aligned with existing planning frameworks.

The logic was differentiated by risk. For heat-related risks, attention was given to areas where overheating overlaps with vulnerable users, public-space use, mobility routes or work-related exposure. For extreme rainfall and urban flash flooding, the focus was on sealed, drainage-constrained or runoff-prone areas where adaptation solutions could improve infiltration, retention, slowing or redirection of water. For river flooding, the approach remained targeted and linked to local exposure, building vulnerability, safe access and existing flood-risk and civil-protection frameworks.

Based on this logic, a preliminary selection of nature-based adaptation solutions was prepared as a working tool for the workshop and co-design activities. The full preliminary catalogue is provided in “**Att.3_Preliminary selection of adaptation solutions”**. At this stage, the adaptation strategy focuses primarily on nature-based solutions and should be considered a strategic input for discussion and prioritisation, not a final list of measures to be implemented.

Complementary solutions, including grey/technical measures, digital tools, governance actions and communication measures, will be further explored in Phase 3, together with the spatial translation of selected measures into solution bundles.

2.5.2 Relation with morphological grouping areas

The morphological grouping areas map was used as an interpretative layer between the risk maps and the future definition of adaptation solutions. It helped relate climate risks to recurring urban conditions, such as compact residential fabrics, industrial and productive areas, public spaces, mobility corridors, green interfaces and flood-exposed zones. This made it possible to recognise where similar adaptation logics may apply and where adaptation solutions will need to be differentiated according to morphology, exposure, land use and feasibility.

The clusters are particularly useful for identifying **suitable nature-based solutions** typologies, such as tree planting, de-sealing, rain gardens or green roofs, but they can also support the later selection of complementary **technical, planning or maintenance measures** where nature-based solutions alone may not be sufficient.

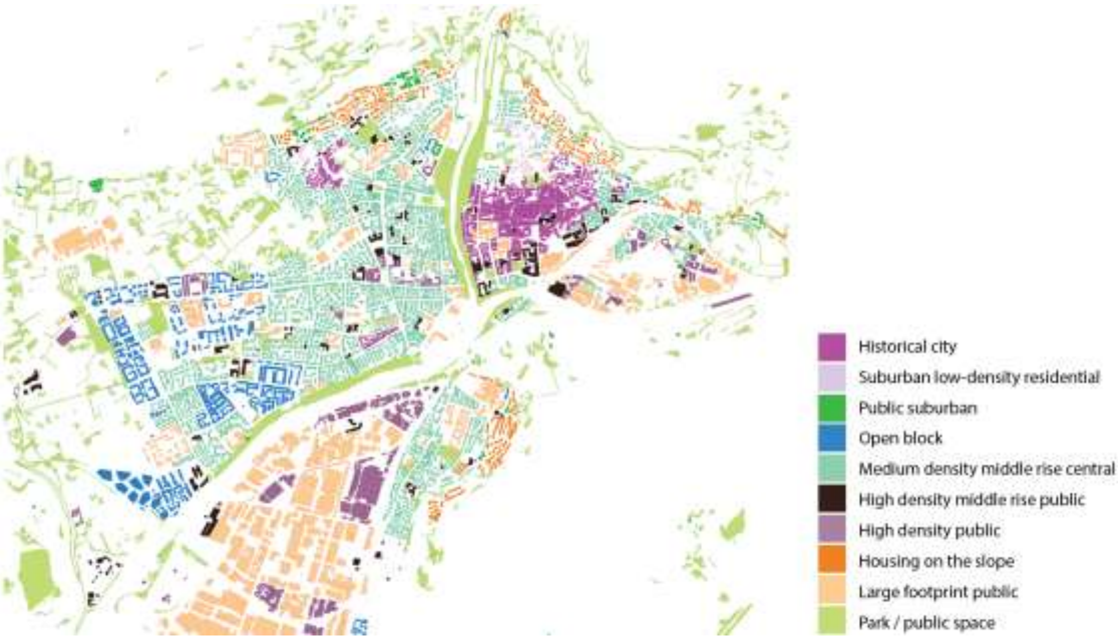

Figure 2-18 morphological grouping of urban areas as a base for nature-based solutions adaptation strategy.

The map does not define final project areas by itself. Rather, it supports a planning-oriented and strategic reading of the city, helping to understand how different spatial conditions may influence the type, scale and priority of future adaptation actions. These interpretations remain preliminary and will be developed more specifically in Phase 3.

2.5.3 Use in the participatory process and next steps

The preliminary nature-based adaptation solutions were used in the participatory process as a practical support for discussion with stakeholders. Their role was to help connect the mapped risks with possible response options and to collect feedback on relevance, perceived feasibility, local needs and implementation barriers. Nature-based solutions were prioritised at this stage because they are **spatially visible, easy to discuss with non-technical participants, and directly connected to everyday public-space experience**, while more technical or governance measures require further specialist assessment.

The outcomes of this process will inform Phase 3, where the preliminary adaptation directions will be refined and translated into spatially explicit adaptation-solution bundles for the selected blueprint areas. This next step will include a more detailed evaluation of technical feasibility, spatial constraints, expected benefits, planning coherence, maintenance implications and possible integration with municipal investment and implementation priorities.

2.6 Monitoring and Evaluation

Phase 2 showed that local datasets are essential to make the CLIMAAX Climate Risk Assessment useful for municipal decision-making. Standard workflows provided a solid methodological basis, but their relevance increased when combined with local observations, municipal data and knowledge of the urban system. The main difficulties concerned data availability, scale, completeness and original purpose, especially for ambulance and fire-brigade records, which required cleaning, harmonisation and cautious interpretation. Further limits concerned drainage information, temporary exposure in public spaces and workplaces, vulnerable groups beyond age categories, and future river-discharge scenarios. Stakeholders helped validate and refine the technical outputs by confirming perceived local problems and highlighting aspects not fully captured by spatial data, such as comfort, accessibility, maintenance, safety, daily use and feasibility of intervention. Their feedback strengthens the link between the CRA and future policy outcomes, supporting the translation of risk evidence into adaptation priorities understandable for municipal departments and local actors.

Learning is ensured through documented methods, assumptions, data sources, limitations and workflow adaptations, and through the possibility to update the assessment when new data become available. Technical annexes and non-dataset supporting materials can be shared through Zenodo, while datasets and spatial layers should be uploaded and managed through GeoNode. Final outcomes should be communicated through technical maps, workflow documentation, spatial layers, blueprint-area sheets, solution bundles, city-wide adaptation guidelines, visual summaries, workshops and dashboards. Bolzano does not yet have a fully integrated monitoring system for the three analysed risks, but existing data streams can support its development, including meteorological data, satellite-derived temperature layers, emergency and intervention records, municipal flood maps, building data and population data. Phase 3 should define a simple monitoring framework with indicators, responsible actors, update frequency and data-management procedures. Possible indicators include heatwave days, hot days, tropical nights, heat-related emergency interventions, rainfall-related fire-brigade interventions, recurrent surface-water accumulation points, exposed population and buildings in flood-prone areas, and implementation status of adaptation measures.

Overall, the process worked well when CLIMAAX workflows were combined with local datasets and stakeholder input, making the CRA more spatially explicit, realistic and decision-oriented. What worked less well was the integration of heterogeneous datasets with incomplete metadata, uneven resolution or limited compatibility with climate-risk indicators. Resources were used efficiently by adapting existing workflows and available data, although additional effort was needed for cleaning and interpretation. The main value of the CRA lies in improving risk understanding, institutional capacity, stakeholder awareness and the evidence base for future investment, funding and municipal climate-resilience planning.

2.7 Work plan Phase 3

The final phase of the BOMAAX project will translate the Phase 2 Key Risk Assessment into concrete adaptation measures for selected blueprint areas in Bolzano. The work will focus on heat stress in dense and highly used urban areas, extreme rainfall and urban flash flooding in sealed or drainage-constrained areas, and targeted river-flood exposure in specific vulnerable locations. The final blueprint areas will be confirmed by combining mapped risk levels, intervention potential, urban morphology and stakeholder feedback. Phase 3 will move from risk identification to implementable adaptation strategies. For each blueprint area, spatially explicit solution bundles will be developed, combining Nature-based Solutions with complementary technical or planning measures where needed. The approach will build on Section 2.4.7 and consider risk evidence, spatial conditions, feasibility, planning constraints and stakeholder input.

For heat-stress areas, measures may include tree planting, shaded pedestrian routes, soil de-sealing, permeable and light-coloured surfaces, green roofs or façades, cooling pockets, shaded waiting areas and better access to existing green areas. For extreme rainfall and urban flash flooding, measures may include permeable paving, rain gardens, bioswales, tree trenches, detention and retention areas, runoff redirection, local drainage improvements and protection of recurrently affected ground floors or basements. In highly sealed areas, NbS will be assessed together with technical stormwater measures where infiltration alone is not sufficient. For river-flood risk, Phase 3 will not develop a broad city-wide flood strategy, as Phase 2 identified a more localised exposure. The work will focus on targeted measures for exposed buildings, streets, vulnerable groups and infrastructure, including building-level protection, safe access, evacuation considerations and coordination with existing flood zoning and civil-protection procedures.

The final outputs will include the confirmed blueprint areas, risk-specific solution bundles, implementation-oriented maps and city-wide adaptation guidelines. In Phase 2, the preliminary solution bundle was developed primarily around Nature-based Solutions, while complementary measures for a broader adaptation strategy will be explored and integrated in Phase 3 including grey / technical / engineering measures, digital and data-driven tools, governance and planning measures, communication, awareness and stakeholder-engagement actions.

The project will not produce detailed engineering designs, hydraulic dimensioning, construction-level cost estimates or permitting documentation, as these require additional surveys and design mandates beyond the scope of the CLIMAAX assessment.

3 Conclusions Phase 2- Climate risk assessment

Phase 2 of the BOMAAX Climate Risk Assessment refined the findings of Phase 1 and translated the initial screening of climate risks into a more detailed, locally grounded and planning-oriented assessment for the Municipality of Bolzano. The analysis confirmed heatwaves, extreme rainfall/urban flash flooding and river flooding as the main climate-related risks for the city. The main added value of this phase is that these risks were no longer assessed only through broad regional datasets, but were refined through local data, local impact evidence and spatially explicit analysis at the urban scale.

The assessment showed that local data substantially improves the relevance of the CRA for municipal decision-making. The integration of municipal population data, local meteorological records, updated flood maps, ambulance intervention data and fire brigade intervention data made it possible to identify not only where hazards occur, but also where they create practical problems for residents, workers, public-space users, buildings, streets and infrastructure. This represents an important step from risk identification toward adaptation planning and the selection of blueprint areas for Phase 3.

The clearest conclusion of Phase 2 is that heat risk is the most urgent priority for Bolzano. Heat risk is already visible across much of the built-up area and is expected to increase in the future due to more frequent heatwaves, hot days and tropical nights. The most relevant areas are dense residential districts with vulnerable residents, the historic centre, highly used public spaces and the industrial area, where high temperatures overlap with daytime worker exposure.

Extreme rainfall and urban flash flooding also remain a significant concern. Phase 2 showed that rainfall-related impacts are linked to two different situations: short-duration, high-intensity events that can trigger sudden runoff and local flash flooding, and longer rainfall events lasting more than 48 hours that can affect streets, buildings and drainage systems.

The interpretation of river flood risk changed compared with Phase 1. The use of updated municipal flood maps, 50 m population data and building-level exposure information reduced the apparent extent of river-flood exposure, and the estimated damages compared with the earlier, broader assessment. However, this does not mean that river flooding is irrelevant. Instead, the risk should be understood as more localised and targeted, affecting specific exposed buildings, vulnerable population groups, infrastructure and emergency-planning needs.

The Key Risk Assessment step provided the bridge between technical analysis and adaptation planning. It helped distinguish between risks that require immediate intervention, risks that require targeted local measures and risks that require further monitoring or additional data before final prioritisation. The participatory process refined the interpretation of heatwave and extreme-rainfall risks by adding local knowledge on how exposed public spaces are used in everyday life and which adaptation measures are considered relevant by local actors. Three workshop tables were organised: two focused on heatwave risk and one on extreme rainfall. For heatwaves, participants confirmed that the most problematic areas are those with extensive paved and sealed surfaces, limited vegetation, lack of shade, insufficient water points and few places to rest. This was particularly evident in the industrial/work area, public streets and squares, Piazza Domenicani, Piazza Maria Montessori/Via Resia and Nikolaus Firmian, and other exposed urban spaces. Participants highlighted vulnerable users such as older people, children, outdoor workers, people with health conditions, people who walk slowly or need frequent breaks, and users of schools, playgrounds, bus stops and public squares. The feedback therefore confirmed that heat risk cannot be interpreted only through residential population data: temporary exposure, daytime use and public-space comfort are essential for selecting intervention areas.

For extreme rainfall, participants confirmed that the main concerns are drainage capacity, maintenance, road safety, slippery surfaces, narrow pedestrian spaces and the management of rainwater in paved urban areas. Piazza Gries and Piazza Fiera–Via Marco Polo were discussed as areas where rainfall adaptation should be integrated with public-space redesign. Proposed measures included permeable paving, rain gardens, bioswales, vegetated drainage channels, green parking areas, retention systems and better maintenance of drains, gutters and catch basins. Across all tables, participants preferred multifunctional solutions: trees and pergolas should provide shade and improve public-space quality; water systems should manage rainfall and support cooling; and temporary interventions should be used where useful to test measures before permanent implementation. The workshop therefore helped refine the selection and design direction of blueprint areas by linking technical risk maps with perceived exposure, accessibility, feasibility, maintenance needs and the social use of public space.

Several challenges were addressed during Phase 2. The project improved the spatial relevance of the CRA, integrated multiple local datasets, introduced impact-based evidence for heat and rainfall, and produced outputs that can support the next phase of adaptation planning. The assessment also clarified where the standard CLIMAAX workflows need to be adjusted to local conditions, especially in a compact Alpine city where urban morphology, slope conditions, sealed surfaces and valley-basin effects strongly influence risk patterns.

Some challenges remain only partly addressed. Climate projection datasets are still too coarse to fully capture urban-scale temperature and rainfall processes. Short-duration rainfall is particularly difficult to assess because standard climate data do not adequately represent sub-hourly events, even though these events are relevant for urban flash flooding. Ambulance and fire brigade records proved useful, but they were not originally designed for climate risk assessment and require careful interpretation. Further information is also needed on drainage-network capacity, public-space use, vulnerable groups beyond age categories, future river-discharge scenarios, existing adaptation measures, maintenance responsibilities and monitoring indicators.

Overall, Phase 2 provides a stronger evidence base for practical climate adaptation in Bolzano. The main takeaway from Phase 2 is that effective adaptation in Bolzano requires moving from hazard maps to intervention-oriented risk interpretation. The value of the CRA lies in showing where climate risks intersect with people, buildings, public spaces and infrastructure, and in identifying where adaptation measures can have the greatest practical benefit. Phase 3 should therefore focus on converting these findings into feasible, site-specific and implementable measures that strengthen the city’s resilience over the short and medium term.

4 Progress evaluation

The project is structured in progressive phases, each building on the previous one. Phase 1 provided the initial screening of climate-related risks for Bolzano, identifying heatwaves, extreme rainfall/urban flash flooding and river flooding as the main hazards, while also highlighting relevant data gaps and methodological limitations.

Phase 2 has now refined this assessment through local data and spatially explicit outputs. The three workflows identified in Phase 1 — heatwave, heavy rainfall and river floods — were tested with local data and adapted to the Bolzano context. Climate risk maps have been developed, improving the understanding of where risks occur, who or what is exposed, and which areas require targeted attention. The results strengthen the usefulness of the Climate Risk Assessment for local decision-making. Heat risk emerges as the most urgent priority, while extreme rainfall requires integrated stormwater-management responses and river flooding calls for targeted interventions in exposed areas, in coordination with existing flood-risk and civil-protection procedures. Some challenges remain, particularly regarding data scale, completeness and suitability for future monitoring and planning.

The stakeholder meeting held on 22nd May 2026 connected the technical outputs with local knowledge and practical adaptation needs. The discussion supported the identification of priority areas and intervention contexts, including vulnerable residential areas, public spaces, work areas, walking routes, schools, bus stops and other places where exposure may be high. For rainfall risk, participants highlighted drainage capacity, maintenance, road safety and rainwater management in public-space design.

Phase 3 will build on these outputs and translate them into city-wide climate adaptation guidelines, Nature-based Solution bundles and spatially explicit pilot-area proposals. In line with the project framework and the Grant Agreement, it will also include cost analysis, multi-scenario maps and a risk management plan. While Nature-based Solutions will remain central, Phase 3 should also consider a broader range of adaptation measures at different scales, supporting the Municipality of Bolzano in moving from climate risk assessment toward actionable and locally relevant adaptation measures.

Table 4-1 Overview key performance indicators

Key performance indicators	***Progress***
M3: stakeholders meeting realised	The stakeholder meeting was held on 22 May 2026
M5: Risk-assessment completed phase	The risk assessment has been completed

Table 4-2 Overview milestones

Milestones	***Progress***
1 CLIMAAX workflow adopted and tested with local data sets	Three workflows — heatwave, heavy rainfall and river floods — as identified in Phase 1, were tested with local data
Climate Risk maps for urban heat waves and flash floods (heavy rainfalls) developed	Climate risk maps have been developed

5 Supporting documentation

Upon completion of the current deliverable, further documentation produced during Phase 2 of the project has been made available on Zenodo. Since Zenodo does not support the creation of folders, the materials are provided as a sequence of files reproducing a logical folder–subfolder structure.

The supplementary documentation is organized as follows:

1. **Technical clarifications**
- Att.1_Data overview regionalised risk analysis
- Att.2_Heavy rainfall technical document

2. **Workshop 2 and Preliminary adaptation solutions**
- Att.3_Preliminary selection of adaptation solutions
- Att.4_Report of second workshop with stakeholders

3. **Workflow datasets**
   This third section mirrors three logical sub-folders, one for each selected CLIMAAX workflow (HEATWAVES, HEAVY RAINFALL and RIVER FLOODS):

- Att.5_bolzano_heatwaves_workflow.zip
- Att.6_bolzano_heavy_rains_workflow.zip
- Att.7_bolzano_river_flood_workflow.zip
- README_Attachments.txt (containing further info to explore the three folders).

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