CLIMAAX
climate ready regions

Deliverable Phase 1 – Climate risk assessment

BOMAAX – CLIMAAX for Bolzano

Italy, Trentino-Alto Adige/Bolzano

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

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Document Information

Deliverable Title	Phase 1 – Climate risk assessment
Brief Description	This deliverable, the first of three within BOOMAX, applies the CLIMAAX Climate Risk Assessment framework to Bolzano/Bozen. It establishes a baseline risk profile, identifying heatwaves and floods as the most urgent climate risks. The results provide insights into vulnerabilities and methodological gaps, laying the groundwork for refined assessments, downscaled hazard data, and city-wide adaptation guidelines in the next project phases.
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Region/Municipality	Bolzano Municipality
Leading Institution	Bolzano Municipality
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Abbreviations and acronyms

Insert here all acronyms appearing along the deliverable in alphabetical order. This text marked in green should be deleted before submitting the deliverable.

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
FSTP	Financial Support to Third Parties
GIS	Geographic Information System
IDF	Intensity-Duration-Frequency
JRC	European Commission’s Joint Research Centre
LAND	Landscape Architecture Nature Development
LST	Land Surface Temperature
NBS	Nature Based Solutions
NDVI	Normalized Difference Vegetation Index
PAESC	Piano di Azione per l’Energia Sostenibile e il Clima
PZP	Hazard Zoning Plan
RCP	Representative Concentration Pathway
SECAP	Sustainable Energy and Climate Action Plan
UHI	Urban Heat Island

Executive summary

This deliverable is the first of three produced within **BOOMAX**, a subproject of the **CLIMAAX project** applied to the city of Bolzano/Bozen in Northern Italy. It documents the initial application of the **CLIMAAX Climate Risk Assessment (CRA) framework** and provides an overview of climate hazards, vulnerabilities, and risks relevant to Bolzano. The results form the analytical basis for refining risk assessments and preparing city-wide adaptation guidelines in the next project phases. This deliverable was developed to equip Bolzano with a systematic and downscaled climate risk assessment, overcoming gaps in hazard mapping and preparedness. It responds to the urgency of addressing heatwaves and heavy rainfall and related hazards increasingly affecting the city. Readers gain insights into the most critical risks, the testing of **CLIMAAX workflows**, and methodological gaps to be addressed in subsequent phases.

The following activities and outputs summarize the progress and insights gained in **Phase 1**:

• **Scoping and stakeholder engagement:** a participatory workshop involving municipal offices, civil protection, utilities, research institutes, and citizen representatives helped identify priority hazards and critical hotspots.

• **Risk exploration:** based on regional data, European datasets, and local knowledge, the assessment prioritized three hazards: heatwaves, heavy rainfall/flash floods, and river floods.

• **Application of CLIMAAX workflows:**

– **Heatwaves:** satellite-based land surface temperature analysis and EuroHEAT methodology identified urban heat island hotspots and vulnerable groups (elderly, children).

– **Heavy rainfall:** workflow applied to assess extreme precipitation trends, with fire brigade data and vulnerability information highlighting flood-prone districts.

– **River flooding:** Copernicus and JRC datasets were tested, providing insights but limited by coarse resolution and lack of local protection data.

• **Key findings:**

– **Heatwaves and flash floods are the most urgent risks for Bolzano**, due to topographic setting, urbanization patterns, and demographic trends (aging population).

– Resolution of hazard projections is a major limitation; **downscaling is essential** for both heatwaves and floods.

– Current municipal measures (**Hazard Zoning Plan, Sustainable Energy and Climate Action Plan (SECAP), civil protection protocols, "Estate da brivido" awareness campaign**) provide a foundation but require integration with refined risk mapping and planning tools.

– Stakeholders emphasized the need for **nature-based solutions** (green infrastructure, permeable surfaces, shading, rain gardens) that can simultaneously mitigate heat and flood risks.

In conclusion, this deliverable established a baseline risk profile for Bolzano, highlighting vulnerabilities to **heatwaves** and **floods** and the need for urgent adaptation measures. It also demonstrated the usefulness of **CLIMAAX workflows** while pointing to limitations in spatial resolution and data assumptions. The **key takeaway** is that **Phase 2 must focus on downscaling hazard data, improving exposure and vulnerability mapping with local datasets, and enabling what-if scenarios to test adaptation options**. These steps will provide the foundation for robust, locally grounded adaptation guidelines to be delivered during the third and final phase of the project.

1 Introduction

1.1 Background

Bolzano/Bozen is the capital of the Autonomous Province of Bolzano – South Tyrol. The city itself has a population of ~100k. It lies on the bottom of a wide basin (4 km wide) at the junction of three, **deep Alpine valleys, namely:** the Isarco/Eisack Valley (E), the Adige/Etsch Valley and the Sarentino/Sarntal Valley. The basin and its tributary valleys are characterised by steep slopes with crests line exceeding 1200 m Above Sea Level (ASL). From the hydrographical point of view, Bolzano is placed at the confluence of the **Talvera (Talfer)** stream **with Isarco (Eisack) river** that, after 6 km southward, join into the **Adige (Etsch)** river. It has a **strong economy with sectors including tourism, services, high-tech research, and agriculture—especially apple orchards and vineyards**. The city has a temperate continental climate, with **harsh winters** (climate zone E) **and hot summers**[1], with mild and pleasant spring and autumn in between.

The city today faces increasing challenges related to climate change. In recent years, Bolzano has experienced an increase in the frequency and intensity of extreme weather events, including **urban heat waves, intense precipitation, and localized flooding phenomena**. Landform morphology, compact urbanization, and increasing pressure on green spaces make the urban context particularly vulnerable to climate impacts. In particular, **Urban Heat Islands (UHIs)** represent an increasing criticality in the summer months, with significant implications for public health, quality of life and energy consumption. At the same time, the **increase of intense and sudden rainfall** exposes portions of the city to risk of **sudden urban flash flooding** with implications for infrastructure, mobility and essential services.

1.2 Main objectives of the project

BOMAAX project, funded by the European CLIMAAX[2] initiative, serves as a strategic initiative to support the city of Bolzano in enhancing its climate resilience, overcoming the current limits and barriers of Bolzano's climate-adaptation planning, activating and engaging regional and local stakeholders, strengthen municipal capacities, building consensus on existing risks and derive concrete actions to increase the city's climate resilience. In particular:

- **Enhance Climate Risk Assessment**: Improve knowledge of urban heat islands and flash floods through CLIMAAX workflows, refining risk maps and data-driven adaptation.
- **Strengthen Engagement and Awareness**: Involve stakeholders and citizens to raise awareness and build consensus on adaptation actions.
- **Build Municipal Capacities**: Equip local authorities with tools and skills for climate forecasting and long-term resilience.
- **Develop Adaptation Guidelines**: Create city-wide guidelines with Nature based solutions (NBS) and best practices, tested in a pilot area.

1.3 Project team

The BOMAAX project is being carried out by a group of companies with complementary expertise in the areas of climate change adaptation, urban resilience, and open-source data-driven risk assessment, engaged under subcontracting arrangements. The group support the City of Bolzano — beneficiary of the CLIMAAX Financial Support to Third Parties (FSTP) program — in the implementation of BOMAAX project through the development of detailed climate risk assessments, the elaboration of city-wide adaptation guidelines, the preparation of a pilot blueprint integrated into planning, and the strengthening of municipal capacities and stakeholder awareness.

Municipality of Bolzano

The Municipality, already described in Section 1.1, contributes through its Office for Geology, Civil Protection and Energy (Ufficio Geologia, Protezione civile ed Energia) which previously developed and implemented the Sustainable Energy and Climate Action Plan (SECAP). Within BOMAAX it oversees the project's progress, engages with the subcontracted team, participates in selected activities, facilitates stakeholder interactions, and ensures that the methodologies tested are consistent with the city's strategic objectives and policy framework.

LAND Italia Srl

LAND, an acronym for Landscape, Architecture, Nature and Development - is an international landscape consultancy company with offices in Saudi Arabia, Austria, Canada, Germany, Italy and Switzerland. Andreas Kipar and a team of 200 landscape architects, architects, urban planners, agronomists, engineers and researchers have been concretely committed, since 1990, to the regeneration of territories, cities and places.In this project, LAND's role is to coordinate the activities of the team and guide the analyses in order to achieve results that are truly useful for the municipality from a strategic perspective. In addition, LAND will define the project actions and integrate them into the strategic guidelines document for climate resilience.

Studio Calas GbR

Studio Calas is a multidisciplinary studio that operates on different design scales, integrating eco-social practices at every stage of the work. The projects move between sustainable architecture, research, urban planning, development strategies, interventions in rural contexts, participatory processes, digitalization, design and exhibition curation. The approach combines praxis and research, allowing for cross-sectional exploration across disciplines.

AIT Austrian Institute of Technology GmbH

The Austrian Institute of Technology (AIT), Austria's leading applied research organization, focuses on developing innovative solutions to address key societal challenges such as climate change, digital transformation, and sustainable development. Cooperative Digital Technologies department focuses on climate-resilient societies, offering expertise in system development, data analysis, and the integration of satellite and environmental data for adaptive urban solutions and scalable, interoperable system designs. AIT will primarily contribute with know-how on climate change challenges and adaptation for urban, development and implementation of workflows and scientific analysis.

CISMA

CISMA Ltd. is a technology company of NOI Techpark in Bolzano, Italy. Since 2005, CISMA has been providing services and consulting in the field of environmental engineering and applied meteorology. The team consists of environmental engineers with expertise in hydrology, hydraulics, hydrogeological risk mapping, meteorology, air quality, acoustics, and mobility. To address various environmental problems, the company develops operative tools and offers solutions based on data analysis, physically based numerical modelling, or integrated approaches (models and observations). CISMA will mainly contribute to the BOMAAX project for the downscaling of climate projections and the evaluation of local effects at Bolzano.

1.4 Outline of the document's structure

The document follows the template guidelines provided by the CLIMAAX Project team. It starts with an Executive Summary and is structured into three main parts: Introduction, Climate Risk Assessment – Phase 1, and Conclusions – Phase 1. The Introduction provides an overview of the project and its objectives. The Climate Risk Assessment – Phase 1 section is subdivided into scoping, risk exploration, risk analysis, preliminary key risk assessment findings, and preliminary monitoring and evaluation. The Conclusions – Phase 1 summarizes the main outcomes of this first phase.

These core sections are complemented by Progress Evaluation and Contribution to Future Phases, Supporting Documentation, and the References section. The section "Supporting documentation" lists and briefly describes the material available on Zenodo (see Chapter 5), which includes media outputs, the results of the stakeholder workshop, and the Jupyter notebooks of the selected workflows with related data and results.

2 Climate risk assessment – Phase 1

2.1 Scoping

2.1.1 Objectives

The Climate Risk Assessment (CRA) for the City of Bolzano aims to deliver a robust, locally relevant understanding of the main climate-related hazards affecting the municipality, with a primary focus on urban heatwaves and urban (flash) floods due to intense rainfall. The purpose is to produce urban-scale risk maps and hotspot identification, strengthen the integration of local data through downscaling, and align stakeholder risk perception with evidence-based analysis. Expected outcomes include actionable recommendations for risk reduction and adaptation, a city-level Climate Adaptation Guideline outlining measures including Nature-Based Solutions alongside other adaptation options, and a pilot blueprint in a strategic urban area to test and validate selected interventions. A further objective is to assess the usability of CLIMAAX workflows in the Bolzano context and to provide feedback to improve methods for prevention and response. **To ensure the project's long-term relevance**, its findings will be systematically integrated into Bolzano's climate resilience strategies, including the **SECAP**, the Municipal Civil Protection Plan, and relevant urban development and planning instruments. The adaptation measures and climate risk assessment data developed through BOMAAX will provide spatially detailed evidence to prioritise interventions where vulnerabilities are highest, support integrated urban planning through green infrastructure, water management, and sustainable urban design, and serve as a transparent basis for funding applications and policy alignment across sectors such as health, infrastructure, water management, and biodiversity. Continuous public updates through the Municipality's digital platforms will keep the community informed about the project's progress, fostering transparency and civic engagement in climate resilience efforts. Main limitations concern the availability and systematic collection of local impact, exposure, and vulnerability data, the need for broader engagement of vulnerable groups in the assessment process and the requirement for higher-resolution hazard data to ensure spatial accuracy and usability for urban-scale planning and decision making.

2.1.2 Context

Primarily due to its specific geographical configuration, located in a basin at the confluence of three alpine valley that hinders air exchange, and induces typical valley phenomena such as thermal stratification, the city of Bolzano experiences **very high temperature in summer**, a hazard for the city that is exacerbated by climate change. In addition, climate change is increasing Bolzano's exposure to **urban flash floods caused by intense rainfall**, creating further hazards for its infrastructure and residents.

Until now, climate hazards, impacts and risks in the City of Bolzano have been assessed through a combination of strategic planning, technical studies, and operational preparedness. The **SECAP**[1] provides the main framework, analysing past climate records and future projections to identify key risks such as heatwaves, floods, landslides, and droughts. Complementary measures include the **Municipal Civil Protection Plan**, which establishes protocols for natural and socio-health hazards, and the **Hazard Zoning Plan (PZP)**, which classifies flood and landslide risks and prioritizes areas for intervention. Specific attention has been given to heat-related risks through the **Summer Heat Emergency Plan for the Elderly**, providing air-conditioned spaces, social activities, and transport services during the hottest periods. Beyond technical and emergency planning, Bolzano has invested in awareness campaigns to promote renewable energy, energy-efficient building retrofits, sustainable mobility, and resource conservation. Despite this robust structure, the current SECAP **reveals some limitations in terms of spatial detail.** In particular, the plan does not provide specific urban-scale mapping of climate hazards within the municipal territory. The BOMAAX project aims precisely to **address this gap by applying a downscaling approach to climate risk analysis at the local level.** Moreover, although the existing planning tools provide a comprehensive assessment of potential climate hazards and associated risks, Bolzano still lacks a territorially grounded strategy that translates this knowledge into concrete, site-specific actions. The absence of such a locally tailored approach limits the city's capacity to effectively address climate risks and to prioritise interventions where vulnerabilities are highest within the urban fabric. In addition, the systematic use of local impact, exposure, and vulnerability data remains challenging, as information is often incomplete, unavailable, or collected for other purposes. Stakeholder involvement has so far been effective with institutional and emergency actors, but participation of civil society and vulnerable groups remains limited and should be strengthened in the next steps.

Climate change adaptation in Bolzano is part of broader provincial efforts, including the Adaptation ST project[3] and the Provincial Environmental Protection and Prevention System (SPPS). These initiatives link scientific assessments with coordinated actions across sectors — such as health, environment, and land use — following the One Health approach, which recognises that human, animal, and environmental health are closely connected. Recent assessments point to a high level of urgency in addressing climate risks, underscoring the need for targeted adaptation measures. **BOMAAX builds on these themes by verifying which risks should be further analysed through the CLIMAAX workflows, with the aim of developing a climate adaptation guideline for the city.** The suggested actions for adaptation interventions will address the main climate risks identified. These actions **will be tested and validated through a selected blueprint in the city**, chosen from possible strategic areas in the planning context.

2.1.3 Participation and risk ownership

The BOMAAX project brings together a wide range of stakeholders whose expertise directly contributes to climate risk management in Bolzano. These include municipal offices (green areas, infrastructure, mobility, geology, civil protection, energy), utilities (ECO-CENTER, Edyna, SEAB), social and economic actors (IPES, Bolzano Fair, South Tyrolean Farmers' Union), emergency services (permanent and volunteer fire brigades), EURAC Research, and interested citizens. The participatory process was initiated with the **BOMAAX Kickoff Workshop on 18 July 2025**, structured around collaborative mapping exercises (Figure 2-1). Participants identified climate hazard hotspots, associated risks, and proposed site-specific adaptation measures. Using color-coded maps and post-its, they highlighted both critical areas and existing good practices. Several risk hotspots in residential and industrial zones were identified; these will be cross-checked against scientific risk maps from Phase 1 and refined in Phase 2 to align risk perception with data-driven analysis. Representatives of **priority groups** were actively involved, including IPES (social housing residents), the Farmers' Union (representing agricultural areas exposed to flooding, drought and hailstorms) and citizens from high-risk districts. These stakeholders reflect populations that are particularly vulnerable to climate risks. Participants also included those directly involved in **risk management responsibilities**, namely the Municipality of Bolzano - Civil Protection and Energy Office, in coordination with the Provincial Functional Centre and the permanent and volunteer fire brigades. Public service and infrastructure operators also fall into this category of stakeholders, with specific responsibilities for their own sector, such as flood protection and energy and water supply management[i]. The **outcome of the workshop discussion** was that the community does not tolerate risks that pose a direct threat to life and health, while a limited level of residual risk is considered acceptable for economic or infrastructural damage, provided that preventive and adaptation measures are implemented to mitigate the impacts. The **results** will be communicated to stakeholders and the community at large through technical reports, open-access publications (e.g. Zenodo, see Chapter 5), public workshops and municipal channels. This approach ensures transparency, facilitates policy integration and strengthens community resilience through knowledge sharing.

Figure 2-1 Selected photos from the BOMAAX Kick-off Workshop

2.2 Risk Exploration

2.2.1 Screen risks (selection of main hazards)

The *Risk Exploration* phase represents a key step in identifying the most relevant climate-related risks for the city of Bolzano. Starting from the full range of risks outlined by the European CLIMAAX framework, we carried out an initial analysis to narrow down the focus in a targeted and context-specific way. Several of the available workflows (in form of notebooks) were briefly reviewed to understand how they work and presented to stakeholders. A detailed testing was conducted for the risks of heat and flood, each of which is represented by several notebooks. This preliminary exploration was based on two main sources: on the one hand, a historical analysis of past extreme

[i] The stakeholder diagram is available among the project's supporting outputs (see Chapter 5).

events, reconstructed through official data and available documentation such as the SECAP[II] and the Copernicus Climate Atlas[4]; on the other hand, the collection of experiential knowledge and direct input from local stakeholders who actively participated in the project's first workshop. Findings from the Copernicus Climate Atlas confirm that the Alpine region, including South Tyrol, will face an increasing frequency and intensity of heatwaves and heavy precipitation events under future climate scenarios, in line with the local trends already observed in Bolzano and confirmed by local insights gathered during the workshop. As a result, **heatwaves, and urban (flash) floods due to heavy rainfall** were selected as priorities for this assessment because of their high frequency and direct impacts on urban health, infrastructure, and liveability. In addition to these two CLIMAAX workflows the River Flood workflow was also chosen as it could provide further insight into flooding dynamics and impacts. Specific information related to the screened risks for the chosen workflows is reported below. To refine the analysis further, higher-resolution climate projections and more systematic local vulnerability and exposure data will be needed in future phases.

HEATWAVES

Average annual temperatures In South Tyrol have already risen by about +2 °C since 1980 and are projected to increase by another 1 °C by 2040 and 1.5–2 °C by 2060[5]. In Bolzano, rising mean temperatures and prolonged heatwaves intensify the Urban Heat Island effect. While the number of heatwaves is slowly increasing, their duration has grown significantly—from 4 days in 2017 to 11 in 2022 and 15 in 2023. This trend is also visible in the sharp rise of tropical nights (minimum temperature >20 °C) since 2000 (Figure 2-2).

Stakeholder mapping in July 2025 highlighted several public areas highly exposed to extreme heat. Key factors include extensive sealed surfaces (e.g. unshaded parking lots), lack of vegetation and permeable ground for natural cooling, and additional heat from cooling systems, all of which amplify the UHI effect and energy demand.

Particularly vulnerable groups include elderly people, children, and residents in social housing who are more exposed to prolonged heat stress.

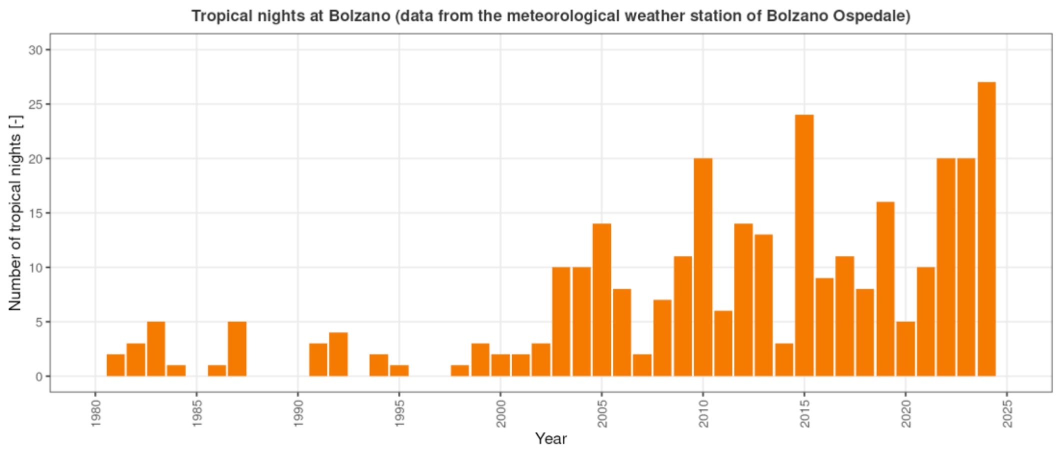

Figure 2-2 Number of tropical nights occurred at Bolzano since 1981, obtained from the temperature data measured by the reference meteorological station of Bolzano

HEAVY RAINFALL

[II] As outlined in the SECAP, Bolzano has already carried out a climate risk assessment: the main hazards considered as high risk are rising temperatures and more intense precipitation.

In South Tyrol other extreme weather phenomena are increasing in intensity and frequency due to climate change, in particular intense rainfall. Heavy precipitation could become much more intense, as warmer air can absorb and release more moisture. Furthermore, a greater quantity of humidity and energy for intense rainfall will arrive in Alto Adige from the Mediterranean Sea, whose temperature has significantly increased (for example in the typical situation "Genoa low", i.e., a low-pressure system forming over the Ligurian Sea). Regarding extreme events such as storms (such as Storm Vaia in October 2018), hailstorms and thunderstorms, there are strong indications of an increase in the Alpine region. The short- or long-term succession of various extreme events poses major challenges for risk management (e.g., forest damage following Storm Vaia in 2018, snowfall in 2019 and 2020, heat and drought in 2022, forest in the period 2022-2024). Local precipitation data (Figure 2-3) suggests **an increase in frequency of short-time events characterized by heavy precipitation rates**, that is compatible with the effects of the climate change.

Mapping activities that were carried out during the workshop in July 2025 highlighted locations prone to surface floods, groundwater flooding, flash floods, and debris flow. Vulnerabilities were most pronounced where impermeable infrastructure intersects with natural drainage patterns. Key causes included: sealed ground surfaces that increase runoff and prevent natural infiltration; paved parking areas and dense urban development, which limit water absorption; low-lying topography and structural bottlenecks (e.g., underpasses) that exacerbate flooding risks. The most exposed groups are residents living in low-lying districts or in areas with insufficient drainage infrastructure, as well as people working in industrial areas prone to flooding.

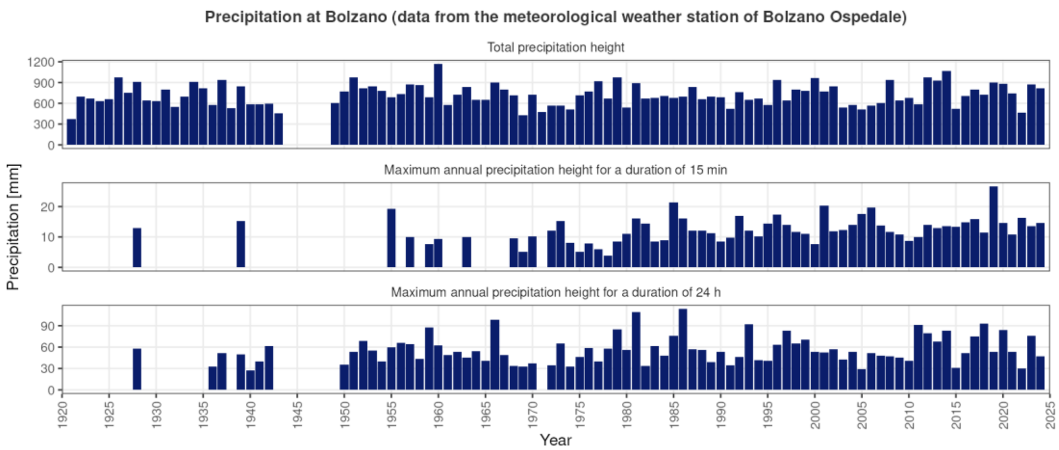

Figure 2-3 Time series of precipitation at Bolzano since 1921.

RIVER FLOODS

Local flood events triggered by heavy rain, landslides, and mudslides are becoming more intense, especially in autumn. However, large-scale flood events along the Isarco and Adige rivers remain relatively rare, making long-term trend analysis difficult. However, the risk of potentially more intense events is increasing due to the growing intensity of extreme rainfall, especially in already known danger areas (for example in the municipality of Chiusa). The increasing waterproofing of the valleys and the limited availability of natural retention areas in South Tyrol increase the risk of flooding. In addition to the increased intensity of rainfall, the current poor conditions of protective forests damaged by storms, snowfall, drought and bark beetle epidemics increase the risk of mass movements. Furthermore, the retreat of glaciers and the thawing of permafrost at high altitudes (above 2500 m) cause intense rainfall to displace a greater quantity of material, which can lead to mass movements and flood events with a particularly high damage potential. Communities established near natural waterways and residents in neighbourhoods historically affected by debris flows are particularly vulnerable to river flood events due to their direct exposure.

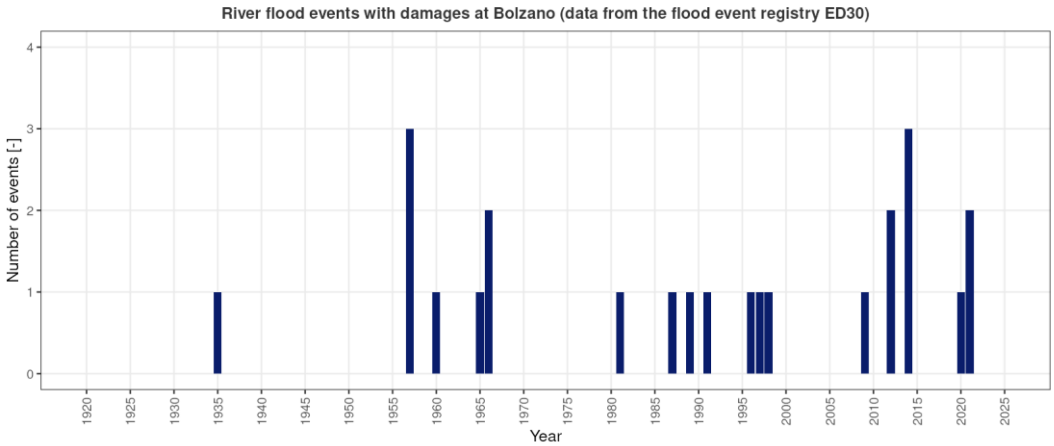

Figure 2-4 Trend of flood events in the ED30 registry that generated damage in the area of the city of Bolzano since 1920.

The ED30 flood event registry has been managed by the Civil Protection Agency since 1998 and contains records of floods and debris flow events along with related metadata, such as localization of the event, meteorological conditions, damages and photographic documentation. Figure 2-4 shows the flood events from the ED30 registry at Bolzano since 1921.

2.2.2 Workflow selection

As explained in previous sections, the priority concerns of the city of Bolzano are **urban heat islands and floods, both urban flash floods (after heavy, short-duration precipitation events) and river floods.** Accordingly, the "HEATWAVE", the "HEAVY RAINFALL – Extreme Precipitation" and the "RIVER & COSTAL FLOODS - River flood" workflows of the CLIMAAX toolbox have been selected and run in this phase 1. The hope is that the output of these workflows could provide in the second project phase a more comprehensive picture of Bolzano's exposure and vulnerability to climate-related hazards, as well as to assess response strategies. The workflows were applied largely in their basic form, using the available pan-European data, during this first phase. Following the guidelines of the CLIMAAX Handbook, a working environment was established, workflows adapted to the regional context and visualization needs and subsequently executed. Analysis relied primarily on pan-European datasets of hazard, exposure, and vulnerability to implement the different risk assessment methods.

2.2.2.1 Workflow #1: Heatwaves

The "HEATWAVES" workflow allows to investigate the spatial distribution of the Urban Heat Island (UHI)of the city in the current and in future climate scenario, to identify the most critical areas and the exposed population. The increasing temperature in highly urbanized areas tends to affect more young and elderly citizens. Bolzano ("Bolzano 2025 – La città in cifre"[6] statistical office of the Municipality of Bolzano) is experiencing a progressive ageing of the population: young (< 18 years old) and elderly (> 65-year-old) people represent the 16.3% and the 24.3% of the resident population, while the greatest part of citizens are 45-64 years old. The intercomparison of these trends with those related to tropical nights and heat-wave events suggests a future scenario in which more of the population might be exposed and made vulnerable to the heat-wave risk and suffer its effects.

The areas of Bolzano that are potentially more exposed to the effects of heatwaves are the city center, the industrial area and those remaining spaces with a poor coverage of urban green.

2.2.2.2 Workflow #2: Heavy rainfall

The "HEAVY RAINFALL – Extreme Precipitation" workflow appears promising for investigating the effects of the climate change on heavy storms that, especially during the summer period, that develop causing urban floods. The areas of the city most prone to flooding are the lowest-lying areas (basements and underpasses) and those located near slopes. In fact, during intense rainfall, surface runoff generated along slopes reaches built-up areas, overloading the urban drainage system. Parks and tree-lined avenues are other areas of the city exposed to damage from heavy rainfall, not so much due to flooding, but rather due to falling branches, twigs, or entire trees. In fact, storms are often accompanied by violent gusts of wind, which can damage trees and sometimes the roofs of buildings. Flooding and obstacles on the road also cause traffic problems.

2.2.2.3 Workflow #3: River flood

The "RIVER & COSTAL FLOODS - River flood" workflow evaluate the effects of prolonged rainfall and river floods on Bolzano's hydraulic risk, integrating structural (e.g., hydraulic defence structures) and not structural (e.g., PZP) measures. Considering that the catchment area above Bolzano is small, one could expect that rainfall reaches the city very quickly, and with saturated ground, clouding could occur within hours (REF). However, the workflow still provides useful information about floods in Bolzano that, once integrated with the output coming from the "HEAVY RANFALL – Extreme Precipitation" workflow, will depict a more complete picture about the exposure and vulnerability of Bolzano to flood events and how they can be managed. The most exposed groups include residents and businesses located in historically flood-affected neighbourhoods, and areas situated close to riverbeds and debris flow channels.

2.2.3 Choose Scenario

The most relevant assumptions for Bolzano concern climate change (increasing extreme events such as heatwaves, heavy precipitation, floods, droughts), socio-economic developments (stable population in the short term, moderate growth and urban densification in the medium term), and energy dynamics (rising importance of efficiency, renewable integration, and exposure to fluctuating energy prices). Given these drivers, the most appropriate time horizon for local planning is the **short (5 years) to medium term (20–30 years)**. This aligns with the SECAP framework and with the implementation times of adaptation and mitigation measures (e.g. soil de-sealing, green roofs, district heating/cooling). Long-term scenarios (50–100 years) are mainly relevant at regional, national, and EU levels and provide boundary conditions rather than actionable local guidance. Among the workflows, **short- and medium-term scenarios** are the most useful for Bolzano, as they support integration of climate adaptation, energy transition, and risk management into municipal planning. **Long-term scenarios** are considered relevant only as a strategic reference at higher governance levels.

2.3 Risk Analysis

2.3.1 Workflow #1: Heatwave

Table 2-1 Overview of data collected for the CRA related to heatwave events (Workflow #1)

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Meteorological data measured at the reference station of Bolzano: (i) Raw data at 10 min resolution since 2014; (ii) Time series of minimum and maximum daily temperature since 1981.	Population data - see the *Exposure data* column which contains the data on the vulnerable groups (i.e., children, elderly).	Population data[III]: Italy Age and Gender Structures[7]: Constrained estimates of total number of people per grid square broken down by gender and age groupings (including 0-1 and by 5-year up to 90+) for Italy, version v1. The dataset is available to download in GeoTIFF format at a resolution of 3 arc (approximately 100m at the equator). The projection is Geographic Coordinate System, WGS84. The units are estimated number of males, female or both in each age group per grid square. Year available: 2015-2030; resolutions: 100m and 1km.	Preliminary risk maps for vulnerable population (<5 and >65 years old) affected by heat in the city of Bolzano, under actual climate conditions, and at the Province scale under the RCP 4.5 and RCP 8.5 climate scenarios.
EURO-CORDEX[8] temperature projections, 12 km resolution, Europe, 21st century, dynamical downscaling from CMIP5 GCMs, providing high-resolution climate hazard scenarios for extreme heat and temperature-related impact studies.			Projected changes of heatwave events (frequency, duration) under the RCP4. And 8.5 scenario.
Landsat 8 satellite observations using thermal infrared radiometers, producing land surface temperature. Temporal resolution (revisit time) of 16 days. Spatial resolution of 100m and resampled resolution of 30m per pixel.			

2.3.1.1 Hazard assessment: EuroHEAT and Xclim methodology

Aiming at identifying the most suited approach for the heatwave risk assessment at Bolzano, both the EuroHEAT and the Xclim methodologies were examined in Phase 1. These methodologies make use of the EURO-CORDEX data that is available on the Climate Data Store (CDS) of Copernicus at the resolution of 12 x 12 km. The **EuroHEAT methodology** makes use of pre-computed indicators, and it allows to define heatwave events based on the "Health-related EU-wide definition" or the "National heat-wave definition". Italy applies one single definition of heatwave at the city-scale, with different thresholds for each city per month. A heatwave day for the current climate corresponds to a heat warning and is triggered from day 1 when daily maximum apparent temperature exceeds threshold of the daily maximum apparent temperature between 15th of May and 15th of September. In the case of Bolzano, the EU-wide and the Italian definition of heatwave coincide, and threshold values of maximum apparent temperature are: 31.5°C for May and 32.5°C from June to September.

[III] When appropriately filtered (e.g., <5, >80 years), these data can serve as a proxy for vulnerability.

The EuroHEAT approach, at first, appears to be a straightforward method to assess heatwave occurrences. Figure 2-5 presents preliminary results for Bolzano.

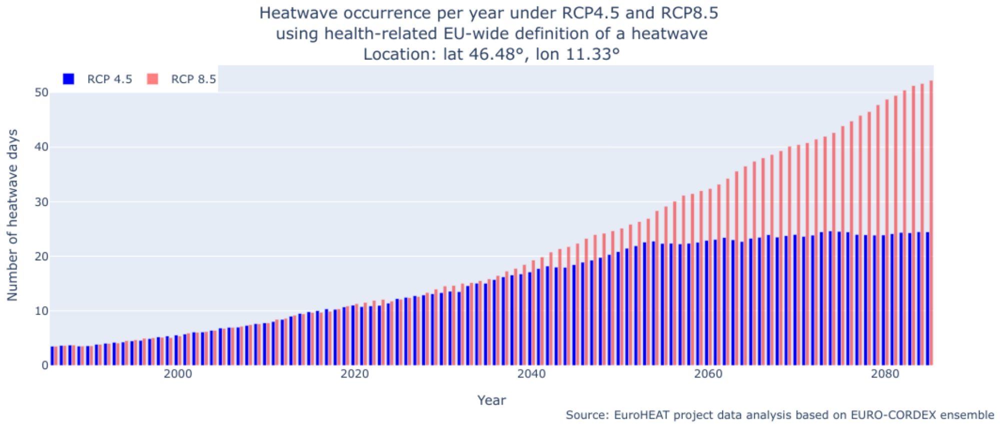

Figure 2-5 Estimated number of heatwave days at Bolzano under two different RCP scenarios, from the EuroHeat methodology. In the case of Bolzano, the Italian definition of heatwave coincides with the EU-wide one.

The timescale of the available data, however, prevents considerations about changes in frequency, duration and intensity of heatwave events.

The **Xclim methodology** takes into account the annual frequency and length of heatwave events, from user-defined thresholds that define the heatwave event and its duration. The workflow uses EURO-CORDEX temperature projections of from the RCP4.5 and RCP8.5 (Representative Concentration Pathway) scenarios. The city of Bolzano falls within a single cell this dataset (horizontal resolution of 12 km) at the elevation of 897 m ASL, which is very different from the actual elevation of Bolzano (~258 m ASL). This leads to (potentially dramatic) underestimation of heatwave frequency and intensity within the urban area. Accounting for deficiency of available hazard data, a decision was made to at least apply a correction for the height difference, under assumption of the mean adiabatic lapse-rate for moist atmosphere[IV] of −6.5 km/K. The total number of days with heatwave per year and the heat-wave frequency were obtained using the following threshold temperatures: **27°C for daytime** (24°C at 897 m ASL); **22°C for nighttime** (18°C at 897 m ASL) and a **minimal heatwave duration of 3 consecutive days**. In Phase 2 of the project, **it will be necessary to implement downscaling techniques to locally increase the spatial resolution of climate projections**, leveraging proxy parameters (e.g., ground meteorological observations and European satellite data) as a paradigm for the system calibration.

2.3.1.2 Risk assessment: leveraging satellite data and population distribution

This workflow helps crisis managers, planners, and policymakers to identify heat-prone areas and assess who or what is at risk. The workflow includes preparing the environment, analysing hot day trends under climate change scenarios, and detecting heat islands from Landsat 8 data at 30 m resolution. It then maps vulnerable populations and combines exposure with vulnerability in a risk matrix. The result is a heatwave risk map that highlights areas most at risk during extreme heat events, supporting decision-making and targeted adaptation measures.

Land Surface Temperature (LST) Analysis

[IV] Assumed moist adiabatic lapse rate; alternative dry lapse will be evaluated in Phase 2

The analysis was carried out using the RSLab[9] portal. The study area has been identified with the built-up area of the municipality, excluding other natural surroundings areas (e.g., woods and forests), while only hot summer days (June to August) occurred in the years 2013–2024 were selected. This period is indeed consistent with the availability of satellite data, such as the Landsat 8 for the land surface temperature (LST, resolution: 30x30 m), and the MODIS for the surface emissivity (NDVI-based emissivity method)[10]. Where applicable, local meteorological data were consulted to verify the presence of notable heatwave events. The temperatures extracted from the LST data were then classified into 10 classes that improve the sensitivity of the results. The thresholds for each class can be adjusted depending on the analytical focus, allowing finer distinction between thermal conditions within the city (see Figure 2-6). This flexibility is particularly useful for highlighting micro-variations between different urban districts or land cover types. **It is important to note that the results reflect surface temperature rather than air temperature**. Land surface temperatures typically exceed air temperatures by more than 10°C during daytime under clear and sunny conditions, while at night, surface temperatures may fall below air temperature due to radiative heat loss[11]. This distinction is essential, as surface temperatures directly influence the microclimate of urban environments and strongly affect how heat is perceived by residents. As such, LST analysis offers a valuable lens for understanding the UHI and assessing thermal stress experienced in built-up areas.

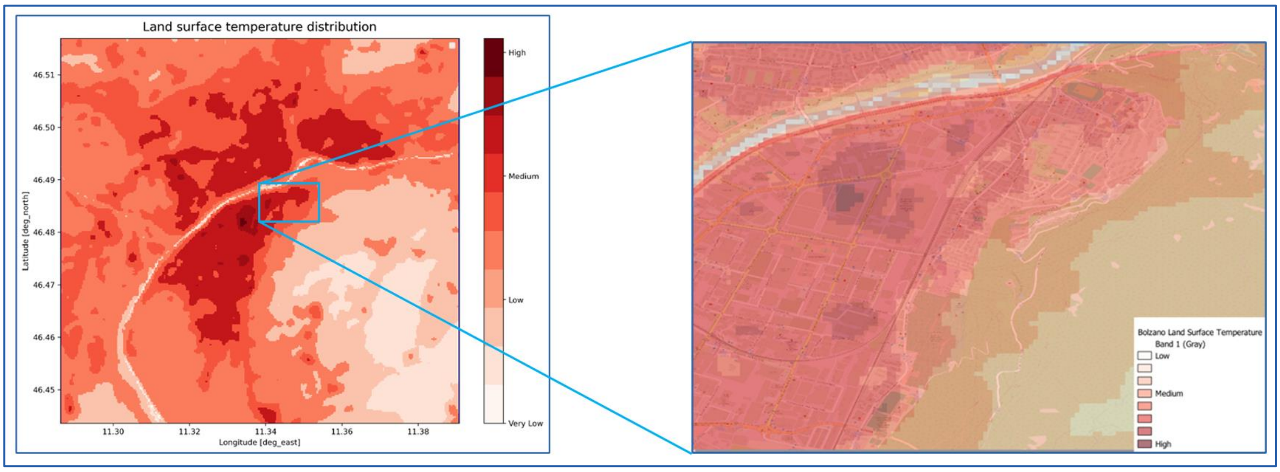

Figure 2-6 Left: Landsat satellite 30-meter resolution data showing land surface temperature for the city of Bolzano and surrounding areas. Right: Zoomed-in view of the selected area, highlighting risk areas.

Risk assessment with population data (vulnerable groups)

Exposure of the population to overheated areas was then performed by combining the output of the LST analysis with the distribution of population in Bolzano. In this phase of the project, the "standard" WorldPop dataset (default option of the workflow) was used as a source of data. This data is derived from census and land cover information and mainly reflects the "residential" population distribution. The distributions of children aged between 1 and 5 and elderly people over the age of 65 in the Bolzano area were extracted from the WorldPop database, as these are the groups most vulnerable to the risk of heat waves. Data were then clustered into five groups of vulnerability, based on their density and using equal intervals. Each cluster was further refined into two categories, from very low to very high, thus improving the sensitivity in urban areas, where variations in population density are more pronounced. Maps in Figure 2-7 show the most overheated areas of Bolzano in combination with the population density of the vulnerable groups.

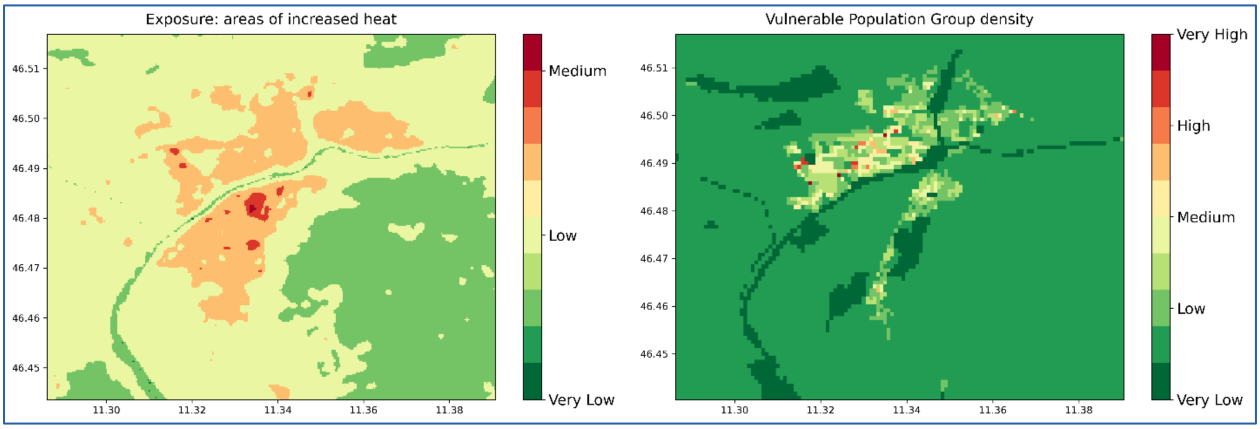

Figure 2-7 Exposure to heat comparison to distribution of vulnerable population.

The ten categories used to map the distribution of heat exposure and those used to map the distribution of vulnerable population within the city of Bolzano represent the entries of the risk matrix. The resulting risk map (Figure 2-8) finally allows to visualize the spatial distribution of the risk for heatwave events and their related level of risk. **The risk workflow therefore helps to pinpoint places most exposed to the combined effects of extreme heat and vulnerable populations (based on age classification). These results, once integrated with those produced by the hazard assessment workflow for future heatwave occurrences, will allow to obtain a comprehensive picture of heatwave-related risks in Bolzano.** As an example at the regional scale, the workflow was run under the RCP4.5 and RCP8.5 climate scenarios to assess the areas of the Province of Bolzano that could be mostly affected by changes in heatwave occurrences and that contain the highest concentrations of vulnerable populations (Figure 2-9).

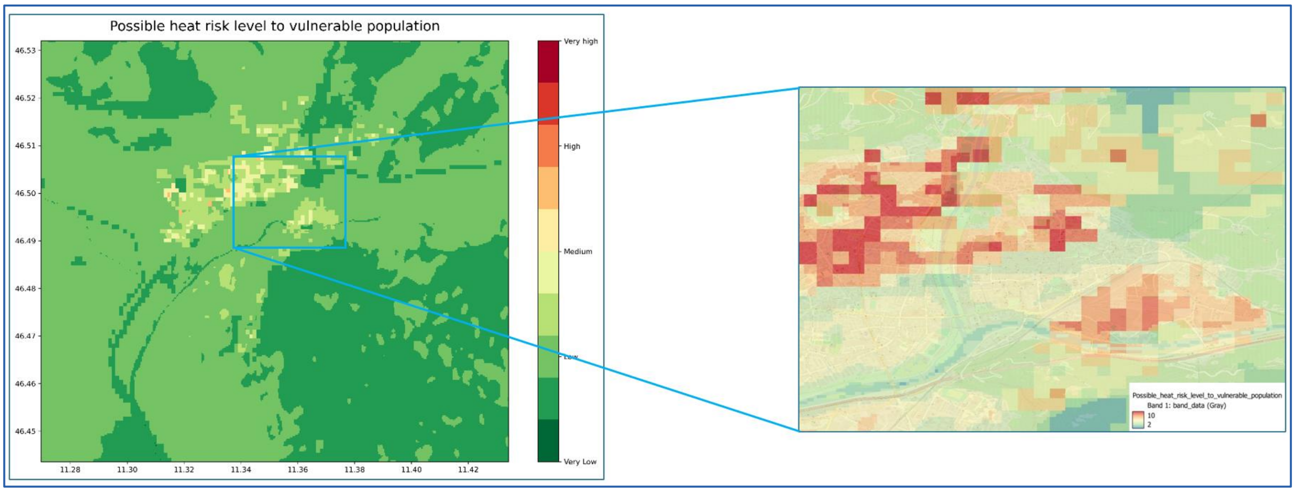

Figure 2-8 Left: Risk levels for the area of Bolzano. Right: Zoomed-in view of the selected area, highlighting possible heat risk level to vulnerable population. Somewhat different color levels are used to highlight the identification of high-risk areas.

The reliability of the risk maps (in the current and future climate scenarios), however, depends on some crucial key-points. One is the availability and quality of the data used to address the UHI. For instance, the LST from Landsat 8 are available for a limited number of days and their quality is cloud-cover dependent. Moreover, their resolution (30x30 m) can be still too coarse in densely built-up areas. Second important factor is representativeness of the data (or proxies) that are used to assess the exposure and vulnerability of the population. Default WorldPop dataset, used in this preliminary CRA, only considers the resident population (information on where the population lives and not where it works), and only very young and elderly people. While these groups are indeed more vulnerable to heat waves, part of the working-age population that works in particularly exposed areas (e.g., construction sites) may be at equal or even higher risk. *For example, the industrial area of Bolzano has a very low resident population but high density of the workers during working hours. Also, in the case of Bolzano, the significant flow of commuters, approximately 50% of residents (estimate based on traffic volumes) should be considered. These people tend to populate the craft, industrial, and public office areas.*

These considerations are in line with the results of the workshop, which identified areas where the UHI is felt (e.g., industrial areas) but which appear to have a medium risk on the map in Figure 2-10. Finally, the use of population density as a proxy for vulnerability is reasonable, but far from perfect.

To reduce this uncertainty and improve the robustness of the results, the availability of **local data useful for evaluating exposure and vulnerability of the population to heatwaves** can play a key role. Accordingly, the emergency department at the Bolzano hospital and the Provincial Emergency Coordination Center were contacted. As first feedback, a connection between interventions and hot week has been confirmed. However, **these data are not explicitly reported as being related to heatwaves, a cross-check with meteorological data could identify potential correlations and assess any increase in frequency**.

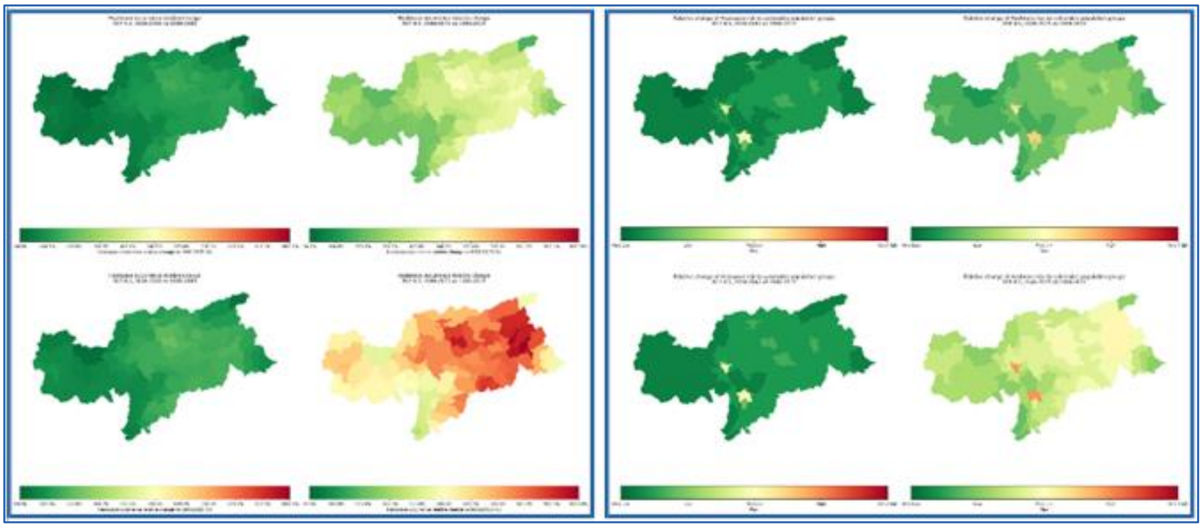

Figure 2-9 Left: Heatwave occurrence relative change considering two different RCPs and time periods. Right: Relative change of heatwave risk to vulnerable population groups.

2.3.2 Workflow #2: Heavy Rainfall

Table 2-2 Overview of data collected for the CRA related to heavy rainfall events (Workflow #2), and the CRA related to flood events (Workflow #3, Section 2.2.2.3).

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Meteorological data measured at the reference station of Bolzano: (i) Raw precipitation at 5 min resolution since 2014; (ii) Daily precipitation since 1981; (iii) Maximum precipitation height for a given duration. For durations from 1 to 5 days, data are available since 1921. For hourly durations, data are available since 1935. For sub-hourly durations, data are available since 1971.	Vulnerability map from the hazard zone plans at the block scale.	List of interventions by the permanent and volunteer fire brigade in Bolzano since 2018.	Projected change of extreme precipitation event frequency under the RCP4.5 and 8.5 climate scenarios
		List of trees felled due to wind damage, provided by the Parks Department of the Municipality of Bolzano.	Maps of water depth within the flooded urban area and related damages to buildings and selected critical infrastructures.
Rainfall intensity-duration-frequency (IDF) curves at basin scale provided by the Province of Bolzano (https://webbasin.afbs.it/webbasin/login#)			
ED30 (river) flood event register of the Province of Bolzano			
Data of groundwater levels in 20 sites in the city of Bolzano.			
Hydrometric data (level and discharge) for the Talvera stream, the Isarco and the Adige rivers.			
EURO-CORDEX[8] datasets - precipitation projections, 12 km resolution, Europe, 21st century, dynamical downscaling from CMIP5 GCMs, providing high-resolution climate hazard scenarios for extreme rainfall analysis and impact studies.			
JRC Flood maps[12], Gridded flood hazard maps for Europe–Mediterranean river basins >150 km², 100 m resolution. Inundation depths (m) simulated with LISFLOOD/LISFLOOD-FP for nine flood return periods (10–500 years), supporting population and asset exposure assessments within Copernicus Emergency Management Service.	Population data - see the Exposure data column which contains the data on the vulnerable groups (i.e., children, elderly).	Gridded residential population dataset[13] (100 m), 1975–2020 in 5-year steps with projections to 2030. Derived from GPWv4.11 and GHSL built-up data, providing exposure estimates for risk and vulnerability assessments.	
	Critical infrastructure buildings as categorized and provided in the OSM buildings data (see the Exposure column).	OpenStreetMap buildings data: Global building footprint dataset derived from OpenStreetMap, representing	

Hazard data	***Vulnerability data***	***Exposure data***	***Risk output***
		individual structures with attributes (e.g., type, height, use).	

2.3.2.1 Hazard assessment

Preliminary hazard assessment for the “extreme precipitation workflow” has been conducted by assuming **threshold[V] precipitations from the rainfall intensity-duration-frequency (IDF) curves, which are published by the Province of Bolzano** through a web-Geographic Information System (GIS) application[14]. The reference weather station for the city of Bolzano has a sufficiently extensive series of precipitation data over time and at different temporal resolutions. All these data are available in open format[15]. For example, since 2013, raw data measured by the rain gauge with a temporal resolution of 5 minutes have been available. Every year, the Provincial Meteorological Office updates precipitation statistics in terms of daily precipitation (since 1981) and intense precipitation of a given duration (since 1921**).** As a preliminary investigation, EURO-CORDEX climate projections (RCP8.5) for precipitation flux at a 12 km spatial resolution have been used for assessing future climate hazards for precipitation events with actual return period of 10 years and duration of 3 h and 24 h, respectively. The workflow returns precipitation magnitude changes in the future scenario (Figure 2-10). **According to the obtained preliminary result an intensification of short duration precipitations is anticipated.** Similarly, to heat waves prediction, the intensity of the change is probably underestimated since small-scale phenomena aren’t adequately accounted for due to low hazard prediction resolution.

[V] Thresholds are based on the 10-year return period, consistent with the design criteria of the urban drainage system.

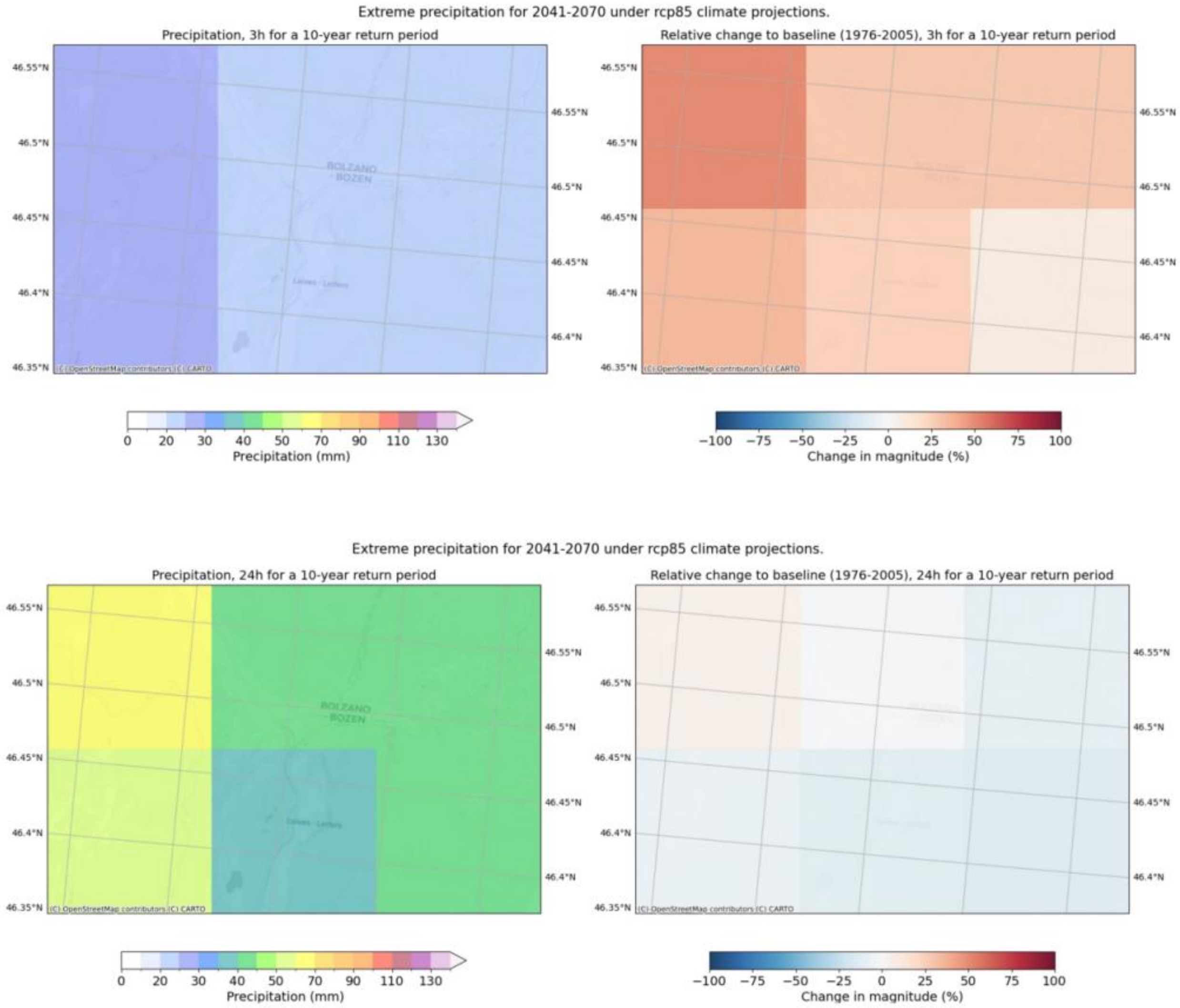

Figure 2-10 Percentage change of precipitation in the future scenario for actual 10 year-return-period precipitations of 3 h and 24 h duration at Bolzano.

2.3.2.2 Risk assessment

To carry out an accurate risk assessment, data were collected from fireman interventions for flooding and for damages caused by weather events on urban trees. These datasets were not designed for use in the manner envisaged in the project. Therefore, pre-processing and correlation with meteorological data are necessary to extract information relevant for the project. For example, data on flood response operations provided by permanent and volunteer fire departments cover the period 2018-2025. A preliminary analysis shows that the districts of Bolzano where the most interventions have been carried out over the years are: “Centro-Piani-Rencio” (27.7%) and “Gries-S. Quirino” (27.3%), followed by “Don Bosco” (20.9%), “Oltrisarco-Aslago” (12.4%) and “Europa-Novacella” (11.7%). Moreover, it appears feasible to relate the damages (dependent on exposure and vulnerability) reported in the datasets with the return period of the precipitation event that caused them (hazard). Such an approach should allow to identify the threshold values required in the workflow. In Phase 2 of the project these analyses will be performed and, if possible, extended to other datasets. The Jupiter notebooks and further outputs from the hazard and risk assessment are published on Zenodo (see Chapter 5).

2.3.3 Workflow #3: River flood

2.3.3.1 Hazard assessment

This workflow was applied to retrieve European river flood maps for different return periods and to prepare them for hazard assessment in the selected area of interest. The procedure defined the main input parameters, including geographical bounds, return periods, directory locations, and map visualisation settings. Flood depth raster data from the Copernicus Land Monitoring Service at 3 arc-seconds resolution (approximately 30–75 m depending on latitude) were downloaded and the bounding box of the area of interest was then used to crop the datasets, and the geographic coordinates were re-projected into the coordinate system of the raster files. Shapefiles were generated to document the spatial extent, and the cropped datasets were prepared for plotting. The outputs included overview graphics of all available return periods, as well as comparative plots between two selected return periods, illustrating differences in expected flood depths as the probability of occurrence decreased (Figure 2-11). The workflow produced tailored maps that supported the identification of flood hazard patterns in the study area. Already at this stage, one could draw conclusions that support future decision making.

However, relatively coarse resolution of JRC flood maps severely limits their applicability in highly complex terrain or smaller catchments, such as the one encountered in Bolzano. Moreover, these maps do not account for local flood protection structures. Moreover, the spatial resolution of future flood maps from Aqueduct Floods data portal (second pan-European data source recommended by CLIMAAX) is too low to be of any use in the context of this project. These shortcomings can be addressed in the second project phase, as the code was structured in a modular way, which allows for substitution of default maps with higher-resolution or locally produced datasets (when available).

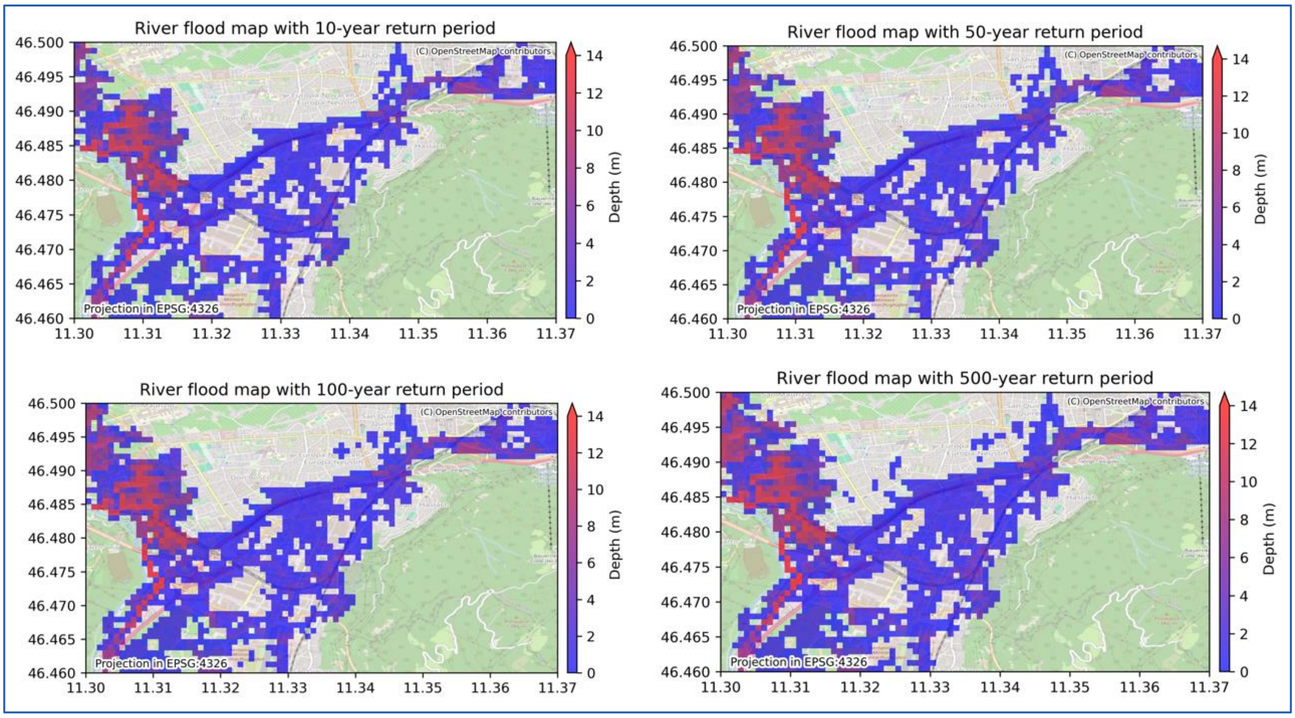

Figure 2-11 Water depth due to river floods considering different return periods. Note the limitations related to spatial resolution.

2.3.3.2 Risk assessment for buildings and population

This workflow assesses the economic damage to buildings, the exposure of critical infrastructure, and population exposure and displacement by combining flood hazard maps with building and population data. For each flood event, the building-level flood damage was evaluated using flood depths, building footprints, reconstruction costs, and contents values. The results were then integrated over all return periods to determine expected annual damage (Figure 2-12). Finally, to visually assess exposure and apply customizable depth-damage relationships, critical infrastructure was mapped in Figure 2-13.

Exposure and displacement of population, based on a flood depth threshold, were estimated using JRC flood maps and default population datasets (see Table 2-2). Results were aggregated over all return periods to calculate expected annual population exposed and displaced. The results are available in a separate data set as noted in Chapter 5.

Overall, this workflow allows for the use of alternative flood maps, building data, population datasets, and exposure thresholds to adapt to different contexts, and clearly features a potential for active decision support. **Main limitations that could be addressed in the second project phase include the absence of flood protection infrastructure in default flood maps, resolution constraints, vulnerability assumptions and potential overlaps of buildings or populations with water bodies that may overestimate damages or displacement**. Using higher-resolution local data can improve accuracy and provide a better representation of actual risks.

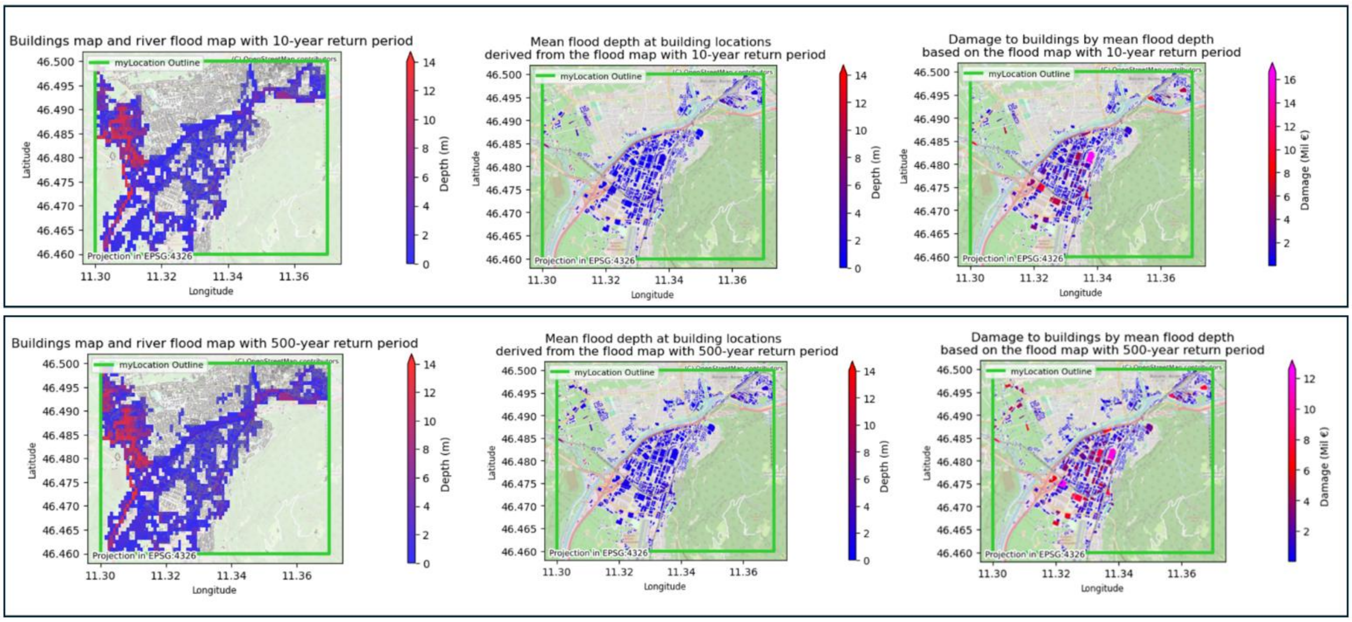

Figure 2-12 Mapping buildings, flood depth and estimated costs.

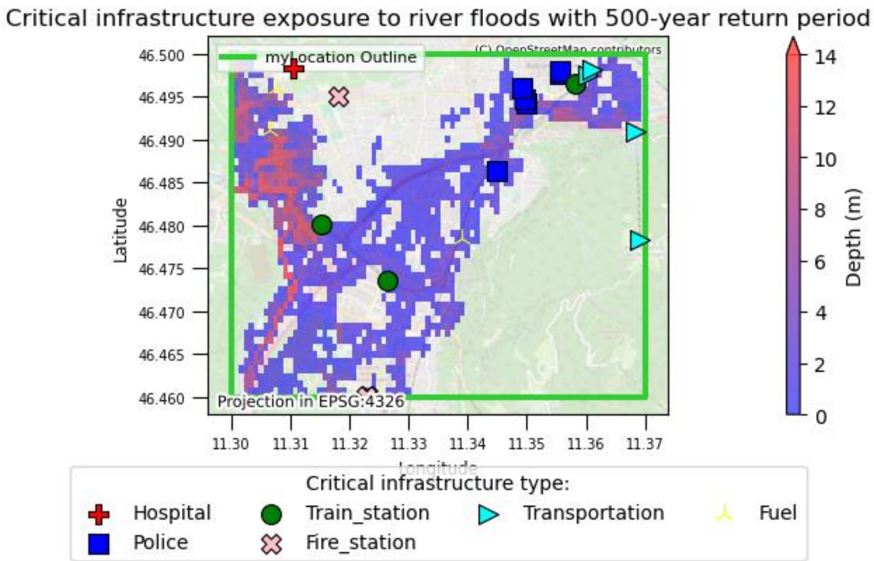

Figure 2-13 Workflow allows for mapping exposure of (selected) critical infrastructure.

Bolzano PZP (Hazard Zoning Plan[16]) includes the output of hydrological and hydraulic modelling at a very high level of detail (scale 1:5000), which should be used in phase 2. The hazard maps available for the municipality of Bolzano for flood events contain water levels, maximum water flow velocities, and the corresponding hazard classification according to the Buwal scale. These quantities are obtained for return periods of 30, 100, and 200 years. On the other hand, the vulnerability map is estimated for zones or macro-areas, thus preventing a proper evaluation of the risk at the very local scale. During phase 2, the possibility to improve the spatial detail of the vulnerability maps could be addressed by using available data on infrastructure and urban buildings. In this way, it would be possible to move on to a risk map using the existing official and detailed hazard maps, cross-referencing them with those of urban vulnerability.

2.4 Preliminary Key Risk Assessment Findings

2.4.1 Severity

The most relevant climate risks for the city of Bolzano are those related to **heatwaves and sudden urban (flash) floods caused by heavy precipitation**[17]. The exposure of the population to the effects of these risks can be reconducted to two main contributions: an environmental or exogenous contribution and a city-dependent contribution.

The peculiar configuration of the topography and of the landforms surrounding the city and the presence of highly urbanized and impermeable areas with poor urban greenery tend to enhance the effects of both phenomena. In recent years, the population has begun to become aware of the effects of climate change and the associated risks to everyday quality of life. Currently, the damage caused by heatwaves and heavy precipitation is still limited, with (relatively rare) river floods causing far more damage than (relatively frequent) flash floods. However, their severity is rising, with heat related risks already being 40% higher than in 1980es for the whole region[18] and the entire alpine region experiencing an increase in intense precipitation over short periods. High temperatures, especially in an urban context like Bolzano pose a major health hazard, as they can cause fatigue (which can lead to higher rate of accidents), heat strokes, dehydration, and worsen pre-existing conditions, especially among the most vulnerable parts of the population, such as the elderly and children. In extreme cases, heatwaves can also cause loss of life and ecosystem degradation. On the other hand, intense rainfall can cause minor (direct) damage to buildings, whereas infrastructure, such as drainage networks, which is often not designed to handle high volumes of water, can collapse - causing urban flooding and disrupting traffic. Such flash floods may also damage critical infrastructure, leading to water contamination, power outages, transportation blockages, and disrupted emergency and health services. These cascading effects can amplify the vulnerability of the community and generate long-term social and economic consequences.

2.4.2 Urgency

The urgency of intervention is linked to both the impact and the recurrence time of natural events. As mentioned before, heatwaves and intense rainfall / urban floods were considered for the municipality of Bolzano. Both phenomena are increasing in frequency and intensity (there were already three heatwaves recorded in June and July in the current year, 2025).

The first aspect (heatwaves) is considered more urgent, as it has a direct impact on public health and urban liveability, with a return period of a single year. An alarming fact for Bolzano is the increase in "tropical nights," with temperatures not dropping below 20°C. The problem is related to the morphology of the Bolzano basin and urban structure, which results in poor ventilation in the summer, aggravated by an uneven distribution of urban greenery and heat island effect. The issue is deeply felt by the population as it has become a recurring problem. Adaptation must aim to mitigate these effects through solutions such as creating more green spaces and parks, for example implementing green roofs, or isolating buildings to improve thermal insulation. The urgency for intense rainfall is linked to hydrogeological risks that mainly threaten the infrastructure. Flooding of the Isarco and Adige rivers has a high return period (tens/hundreds of years) and poses a threat to a limited area of the municipality. Consequently, the perceived urgency of addressing this risk is relatively low. In comparison, local flooding caused by heavy rainfall occurs more frequently, resulting in higher perceived urgency for this risk. Both heatwaves, as a recurring slow-onset process, and extreme rainfall, as a sudden-onset hazard, are expected to persist and intensify under future climate scenarios, reinforcing the urgency of adaptation.

2.4.3 Capacity

The capacity of the municipality of Bolzano to manage climate risks can be considered solid, though with room for improvement. Since the early 1980s, measures have been in place to manage rockslides and mudflows, with dedicated financial and human resources and the Piano Zone di Pericolo (PZP) providing hazard mapping and planning instruments. The PZP also covers flooding, though not specifically pluvial floods. For heatwaves, no structured measures exist, though the Municipal Civil Protection Operational Center (COC) could be mobilized in case of emergency, and the capacity to issue alerts is adequate. Awareness initiatives such as “Estate da brivido” (Summer Heat Awareness Campaign) and the “Piano del Verde” (Urban Greening Plan), which integrates greening as a climate adaptation tool, contribute to preparedness. The European *JustNature* project[19] further supports this approach, with pilot interventions in the industrial zone combining green infrastructure and citizen involvement to mitigate urban heat.

Overall, capacity is good, especially regarding financial and human resources for landslides and river flooding. However, more detailed hazard, exposure and vulnerability mapping is needed, together with stronger citizen involvement, to ensure a more inclusive equitable and effective approach to climate risk management.

2.5 Preliminary Monitoring and Evaluation

From the first phase of the Climate Risk Assessment it emerged that Bolzano is mainly exposed to **heatwaves, urban flash floods induced by heavy rainfall, and to a lesser extent also to river floods**. The CLIMAAX workflows proved effective in outlining these risks, but significant difficulties were encountered due to the coarse resolution of regional and European datasets and the fragmentation of local data, which often require extensive pre-processing and downscaling to be useful at the urban scale.

The stakeholder workshop held in July 2025 confirmed that heatwaves and urban flash floods represent the most relevant hazards for the city. Stakeholders also stressed the importance of considering specific local features, such as sealed surfaces, large unshaded areas, low-lying infrastructures and daytime exposure of working age population. For future iterations, the involvement of additional actors responsible for **critical infrastructure and social services** would be beneficial to refine the analysis and adaptation strategies.

Some local datasets, such as precipitation records, fire brigade interventions, and demographic data, are already available but are not systematically collected for CRA purposes. Overall, the first phase highlighted clear risk priorities and stakeholder consensus but also revealed significant data and capacity gaps that must be addressed in Phase 2. To strengthen the assessment in the next phases, there is a need for higher-resolution hazard data, localized exposure and vulnerability datasets, stronger stakeholder involvement, and interdisciplinary expertise combining climate science, urban planning, and social dimensions of risk.

2.6 Work plan

Building on the foundations laid in Phase 1, the next phases will not only refine the risk assessments but also translate them into targeted, locally relevant actions. The activities are designed to bridge the gap between data-driven analyses and practical adaptation strategies for Bolzano. The main activities include:

- **Critical site focus**: attention will be concentrated on **urban hotspots** identified jointly by stakeholders and preliminary models, **such as *public squares, transport underpasses, hospital facilities, and large sealed surfaces***. These will serve as testbeds for assessing both hazards and adaptation measures.
- **Integration of multifunctional solutions**: the work will explore **nature-based solutions** capable of addressing heat and flood risks simultaneously, technical measures, and governance actions, systematically evaluating their feasibility and co-benefits for urban resilience.
- **Stakeholder co-design**: engagement will move beyond risk identification to **co-creation of adaptation pathways**, involving municipal offices, civil protection, utilities, and—where relevant—representatives of health, education, and transport services.

Some elements fall outside the project's scope and will not be addressed:

- **Long-term supra-regional dynamics** (e.g., full Adige/Isarco basin flooding or national-level policy frameworks), as the focus remains on actionable strategies at the city scale.
- **Creation of entirely new primary datasets** (e.g., new climate monitoring stations or large-scale socio-economic surveys), since the project will build on and refine existing data sources.
- **Broader socio-economic transitions** not directly linked to climate hazards (e.g., structural changes in industry or demography unrelated to vulnerability), which are beyond the project's mandate.

3 Conclusions Phase 1- Climate risk assessment

In recent years, the vulnerability of Bolzano and of its citizens to climate-related events, such as heatwaves and heavy rainfall is progressively increasing.

In BOMAAX, during this first phase, the standardized CLIMAAX approach has been applied to gain preliminary insights on the city's climate hazards, the severity of related risks, the potential impacts, and the identification of adaptation measures, to be refined in the next phases.

This deliverable presents the results of the preliminary CRA (Section 2): an initial scooping (Section 2.1) of the CLIMAAX workflows was carried out to identify the main hazards relevant for the city of Bolzano. This step also included a workshop, held in July 2025, at which a broad audience of stakeholders participated (Section 2.1.3). The outcomes of the workshop strengthen the relevance of heatwaves and floods induced by heavy rainfall as the most significant hazards for Bolzano. The CLIMAAX workflows devoted to HEATWAVES, HEAVY RAINFALL and RIVER FLOODS were then investigated in more detail and run to assess their effective applicability for the case of Bolzano. The preliminary CRA (Section 2) was conducted by inputting the workflows with two main sources of data coming from regional and European data sets (e.g. the EURO-CORDEX climate scenario) and published studies.

The analysis allowed to:

1. assess the applicability of the identified workflows;

2. identify limits and constraints for an application at the very local scale.

The analyses carried out produced several **key findings**:

- **Heatwaves** – Rising mean annual temperatures, longer and more frequent heatwaves, and the intensification of the Urban Heat Island effect are exposing Bolzano's population—especially elderly and young residents—to growing risks. The workflow application demonstrated the potential of combining hazard projections with vulnerability data, providing first risk maps that identified the city center, the industrial area, and zones with low vegetation cover as the most exposed areas.
- **Heavy rainfall** – Short-duration but high-intensity precipitation events are increasingly affecting the city, overwhelming drainage infrastructure and causing local flooding. The districts of "Centro-Piani-Rencio" and "Gries-S. Quirino" emerged as particularly exposed, with fire brigade interventions providing valuable, albeit indirect, data for correlating meteorological extremes with impacts.
- **River floods** – Although large-scale river floods remain rare, future climate scenarios indicate an increased probability of extreme events due to more intense precipitation, weakened protective forests, and glacier retreat. The preliminary use of European-scale datasets allowed to produce indicative flood hazard maps, though these remain too coarse to fully capture Bolzano's complex topography and hydraulic structures.

The HEATWAVES workflow allows to evaluate both the spatial structure of the Urban Heat Island of Bolzano and the risk related to heatwave events. Similarly, the integration of the outputs coming from the HEAVY RAINFALL and RIVER FLOODS workflows contribute in **depicting a more complete picture of the risk** of flood events in the city due to heavy rainfall. On the other hand, the complex topography surrounding Bolzano prevents a direct use of regional and European data sets, resolutions of which appear to be too coarse for the objects of the project. Therefore, downscaling approaches in the next phase will be mandatory to properly evaluate the selected hazards at a very local scale. In parallel with the use of workflows, **datasets at the local scale are necessary to estimate the exposure and the vulnerability** of the city and of its citizens, and therefore to obtain reliable maps of the risks. These data, often, are not collected and catalogued for the purposes of the project, so they must be pre-processed and interpreted to extract the information of interest.

In conclusion, Phase 1 established a solid baseline for understanding Bolzano's climate risks. The results highlight different constraints and limits that can be solved through downscaling approaches, improved integration of local datasets, and refined vulnerability assessment. Addressing these challenges will be the central task of Phase 2, ensuring the transition from preliminary assessment to reliable, high-resolution risk maps and evidence-based adaptation strategies for the city of Bolzano.

4 Progress evaluation and contribution to future phases

The project is structured in distinct phases, with the present deliverable serving as a critical foundation. The outputs and conclusions from this initial phase directly inform and guide the planned activities for the subsequent, more detailed stages of the project. **Phase 1** outputs represent the groundwork for the entire project by identifying the most critical risks but also the specific data gaps that must be addressed for the project to succeed.

Future **Phase 2** is designed to directly address the limitations identified in the initial assessment. The core activities of this phase will be hazard downscaling and improving of exposure maps. The primary goal is to overcome the issue of low-resolution data. The project will undertake a downscaling of the heatwave and river flood hazard projections to create more accurate, city-specific maps. This will transform the coarse-grained projections into high-resolution data that can be used for detailed analysis and planning at the neighbourhood or even street level. The project will then move beyond the generic assumptions of the CLIMAAX workflows. Phase 2 will involve the integration of regionally available data to critically examine and refine the exposure and vulnerability models. This includes possibly incorporating local data on building types and demographic information to create a more realistic and tailored picture of who and what is at risk. Also, an activity in Phase 2 is the exploration of extending the improved workflows to allow "what-if" assessments, shifting the project from a purely diagnostic tool to a strategic planning instrument.

Finally, in **Phase 3**, thanks to the refined data and sophisticated analytical tools from Phase 2, these refined data and tools will be used to produce practical guidelines, including nature-based solutions. These will be tested by applying them to a pilot area in Bolzano, evaluating the feasibility and effectiveness of the proposed strategies.

Table 4-1 Overview key performance indicators

Key performance indicators	***Progress***
2 workflows successfully applied (D1)	Heatwave, heavy rainfall and river floods workflows for Bolzano Municipality were applied during this phase.
35 stakeholders involved in the activities of the project (D1)	One workshop with stakeholders was organized on the 18th of July 2025, to inform the scoping phase of CRA.

Key performance indicators	***Progress***
1 article in regional media mentioning the project (D1)	A few articles were published in regional media mentioning the project.

Table 4-2 Overview milestones

Milestones	***Progress***
M4: Attend the CLIMAAX workshop in Barcelona (D1)	LAND and Bolzano Municipality attended the CLIMAAX workshop in Barcelona.
M1: Test of the workflows made (D1)	Three workflows were tested during this phase: "HEATWAVES", “HEAVY RAINFALL – Extreme Precipitation" and “RIVER & COSTAL FLOODS - River flood”.
M2: One workflow successfully applied (D1)	The three selected workflows were successfully applied to Bolzano case study.

This progress confirms that the project is on track: Phase 1 delivered the expected outputs, established stakeholder engagement, and highlighted data gaps. These achievements create the foundation for Phase 2, where downscaling and refined models will directly support actionable adaptation strategies.

5 Supporting documentation

Upon completion of the current deliverable, further documentation produced during Phase One of the project has been made available on Zenodo (https://doi.org/10.5281/zenodo.17055591). Since Zenodo does not support the creation of folders, the materials are provided as a sequence of files reproducing a logical folder–subfolder structure:

This documentation includes:

- The sum up of the workshop held on 18th July 2025 with the stakeholders.
- The Jupiter notebooks of the selected workflows and run for Bolzano, including data or information on how to access them through open data portals.
- The outputs of the notebooks as GeoTIFF and png images, including supporting material in form of, e.g., power point slides containing images, and a QGIS project.

The supplementary documentation is organized as follows:

- **Communication outputs**
  This set of files includes a press review of local newspapers and a file with links to press releases published on the Municipality of Bolzano website.
  - Pressreview_Bomaax.pdf
  - Links to press releases on the Municipality of Bolzano website.docx

- **Workflow datasets**
  This section mirrors three logical sub-folders, one for each selected CLIMAAX workflow (HEATWAVES, HEAVY RAINFALL and RIVER FLOODS), which include Jupyter notebooks, local input data from Phase 1, and the obtained results.
  - Datasets_README.txt
  - heatwaves.zip
  - heavy_rains.zip
  - river_flood.zip

- **Outputs of stakeholder workshop**
  This section contains a document reporting the sum up of the workshop held on 18th July 2025 with the and the stakeholder's map.
  - Sum up Mapping interaction at stakeholders workshop.docx
  - Stakeholder Map.pdf

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