Climate RESiliEnt COastal planning in Adriatic

Programme: (Interreg VI-A) Italy- Croatia

A 1.4 Pilot area climate change sensitivity survey

D 1.4.3 Vulnerability assessment of the coastal area

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1. Introduction

This document presents Deliverable **D.1.4.3**, the **Coastal Vulnerability Assessment Map**, prepared within the CRESCO Adria project. The assessment addresses pilot areas on both sides of the Adriatic — the City of Crikvenica and Selce in the Primorje-Gorski Kotar County (Croatia), and the coastal zone of "Nuova Pescara" in Abruzzo (Italy). These areas have been selected as representative sites to explore common challenges and vulnerabilities along the northern and central Adriatic coast.

Climate change is a key driver of pressures affecting coastal regions, intensifying phenomena such as shoreline erosion, sea-level rise, and extreme hydrometeorological events that trigger floods, landslides, drainage problems, and inundations of low-lying areas. Both Croatian and Italian pilot sites are characterized by high exposure to these hazards due to dense urbanization, tourism concentration, critical infrastructure, and fragile ecosystems. In Crikvenica and Selce, the focus is on shoreline evolution, erosion processes, and the influence of urban planning solutions on coastal resilience. In Nuova Pescara, vulnerability is assessed through the interaction of hazard levels with the exposure of people, infrastructure, ecosystems, and economic activities such as tourism, agriculture, fishing, and aquaculture.

The methodology combines hazard and exposure to produce vulnerability maps and identify vulnerability levels, following guidelines established by international bodies such as the Intergovernmental Panel on Climate Change (IPCC) and drawing inspiration from the Interreg Italy–Croatia Adriadapt project. In both pilot areas, the overarching aim is to provide a clearer understanding of current and future risks, thereby supporting municipalities and regional authorities in strengthening resilience and adaptive capacity in the face of climate change.

2. Report: Croatian Pilot Areas

Background

Sea-Level Rise

Observed trends show mean sea-level rise in the Adriatic of 1.5–2.5 mm/year during the 20th century, with acceleration in recent decades confirmed by satellite altimetry. Future projections, based on IPCC scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5), suggest a rise of ~0.4 m to >1.0 m by 2100. For Croatia, national strategies estimate a rise of 60 ± 14 cm by the end of the century.

Sea-Level Rise Scenario for the Adriatic

For the purposes of this report, a **realistic mid-range scenario** of mean sea-level rise in the Adriatic by **2100** is adopted:

- **Central estimate: +0.6 m** relative to present mean sea level
- **Likely range: +0.4 to +0.8 m**
- **Source:** IPCC AR6 (2021) global projections combined with Mediterranean/Adriatic regional studies (e.g., Antonioli et al., Anzidei et al.)

This scenario is consistent with the **SSP2-4.5 pathway** (intermediate emissions), which is recommended for planning in Croatia. For robust design, sensitivity checks should also be carried out at lower (+0.4 m) and higher (+1.0–1.5 m) sea-level rise values, reflecting uncertainty and potential high-end ice-sheet contributions.

Extreme Sea Level Baseline (Bakar tide gauge)

Recent analyses of the long-term Bakar tide-gauge record (Vilibić, Pasarić, Međugorac, Šepić and co-authors) indicate that the **highest sea level ever measured** at Bakar occurred on **1 November 2012**, reaching **+113 cm above mean sea level** (Međugorac et al., 2022; 2025; Šepić et al., 2022). This value is taken here as the **baseline present-day extreme event** for inundation modelling.

Scenarios applied in this study:

- **Present extreme (baseline): +1.20 m** above MSL (observed maximum at Bakar +1,13 m).
- **Optimistic 2100 scenario: +1.560 m** (baseline +0.40 m SLR).
- **Pessimistic 2100 scenario: +2.00 m** (baseline +0.80 m SLR).

These scenarios are consistent with the **IPCC AR6 likely range (0.4–0.8 m by 2100)** for the Adriatic under intermediate emissions (SSP2-4.5). They provide a robust framework for LiDAR-based inundation mapping and subsequent SWAN wave simulations.

Coastal Vulnerability and Erosion

Coastal vulnerability results from both natural and human-induced drivers. Natural drivers include lithology, geomorphology, slope, exposure to wave climate and storm surges, and sediment budget. Human-induced drivers include coastal urbanisation, rigid coastal defences, beach narrowing due to interrupted sediment supply, and unsustainable land use. In PGŽ, rapid urban development and tourism have strongly affected coastal dynamics, often increasing exposure to erosion and flooding.

The coastal vulnerability map was prepared using the methodology developed in the study by Ružić et al. (2022), *Analysis of the coastal vulnerability of Primorje-Gorski Kotar County due to sea-level rise* (PGŽ Spatial Planning Institute). The approach combines:

- **Physical indicators** (coastal slope, lithology, geomorphology),
- **Hydrodynamic exposure** (wave climate, extreme water levels), and
- **Anthropogenic factors** (land use, coastal defences).

Each indicator was normalised, weighted, and integrated into a composite Coastal Vulnerability Index (CVI). The GIS-based index was then applied to the Crikvenica shoreline, focusing on the section between **Crni mol** and **Podvorska**, to identify areas most sensitive to sea-level rise and flooding (Figure 1).

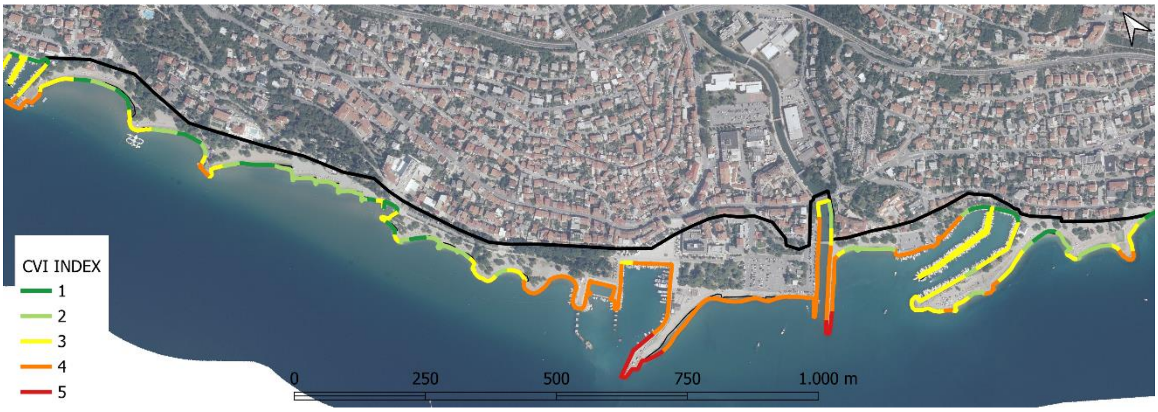

Figure 1. Coastal vulnerability of the Crikvenica shoreline (section between Crni mol and Podvorska), based on the Coastal Vulnerability Index methodology of Ružić et al. (2022).

The analysed coastline of the City of Crikvenica proved to be **highly vulnerable according to the Coastal Vulnerability Index (CVI)**. Previous assessments at a scale of 1:25,000 indicated that the **central part of the city** is the most exposed to sea-level rise and flooding. In this project, a more detailed scale will be applied to refine the vulnerability assessment. Figure 1 clearly illustrates the concentration of high CVI values in the city centre.

Geographical and Geological Characteristics

The Crikvenica-Selce coastal area extends along the Vinodol Channel, with a shoreline length of nearly 26 km. The hinterland is marked by carbonate ridges and flysch slopes, prone to erosion and landslides. Natural beaches make up ~16% of the Crikvenica shoreline. Historical maps and field evidence show extensive shoreline modification since the 18th century.

Case Study: Crikvenica

The City of Crikvenica is today not exposed to marine flooding thanks to planned coastal setback, carried out systematically since the mid-18th century. Reclaimed land created large open public spaces, which remain mostly undeveloped and function as natural buffers against extreme sea levels.

Shoreline changes are traceable in old maps, which document seaward movement of the coastline from the 18th century onwards (figure 2). Buildings that once bordered the sea became distanced from it and thus protected from flooding.

Figure 2. Shoreline changes in Crikvenica (source: Arcanum Maps).

Figures 3–6 present detailed **shoreline changes** for four selected areas of the City of Crikvenica, illustrating the extent of land reclamation and coastal transformation over time.

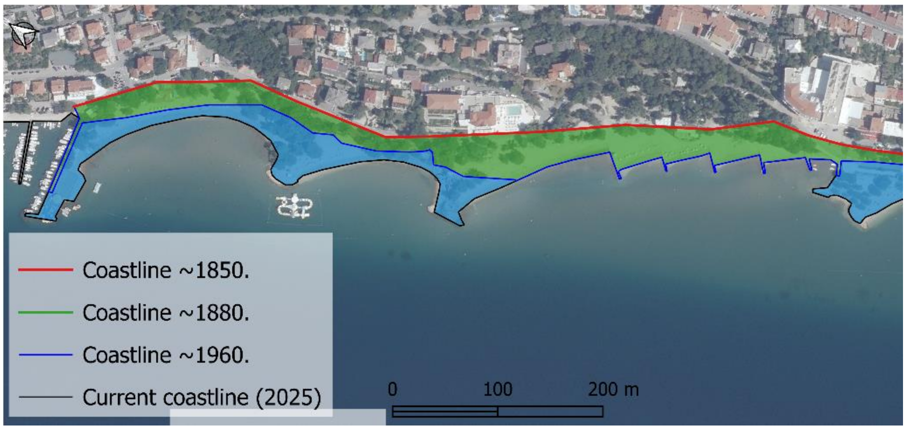

Figure 3. Crikvenica bathing area – reclaimed surfaces

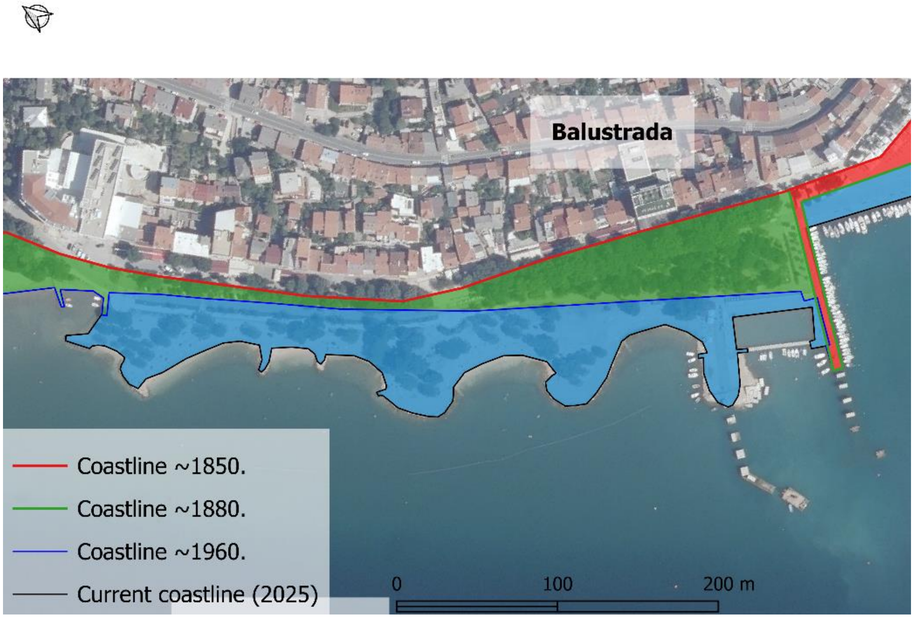

Figure 4. Balustrada – reclaimed surfaces

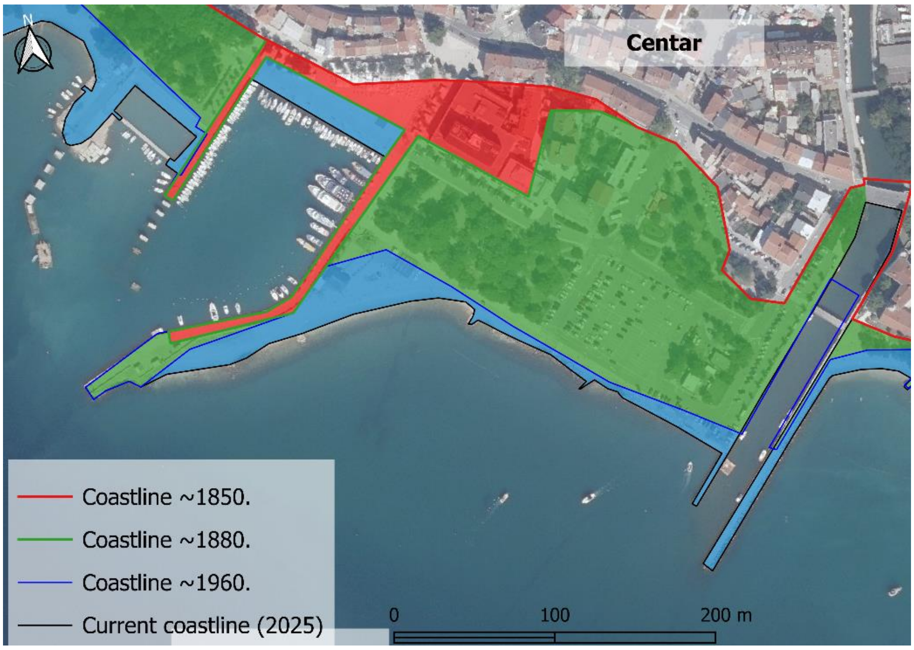

Figure 5. City centre – reclaimed surfaces

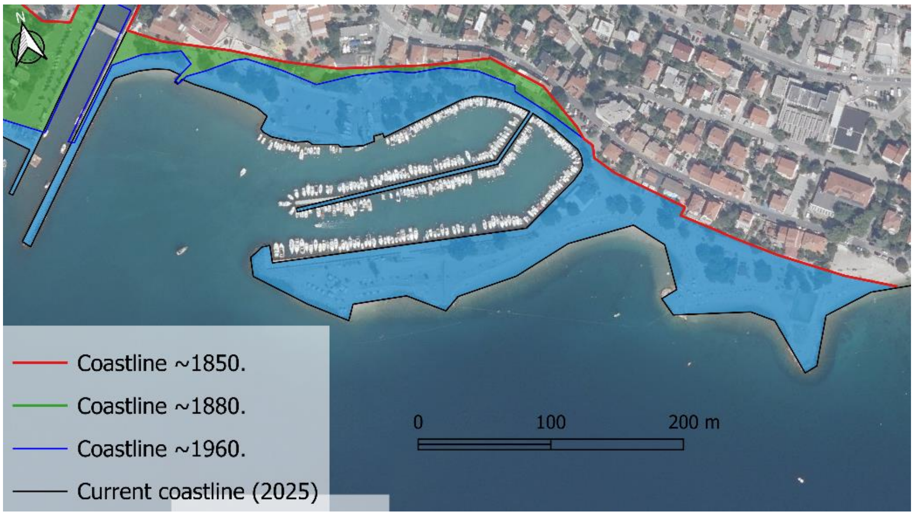

Figure 6. Podvorska – reclaimed surfaces (Arcanum Maps).

Between **1850 and the present**, approximately **140,000 m² of new land** has been reclaimed along the Crikvenica waterfront. With the exception of the bus terminal and a few surrounding buildings, the reclaimed areas were **not developed with any construction**. Instead, they were largely transformed into **public spaces** such as promenades, parks, beaches, and squares, which today represent some of the most intensively used urban amenities.

A significant portion of these areas was planted with vegetation, resulting in the creation of an **artificially induced urban microclimate** that is considerably more favourable than in the historical densely built-up zone. The presence of green infrastructure reduces heat stress, improves air circulation, and enhances the quality of life for residents and visitors.

From the perspective of **climate change adaptation**, these reclaimed and vegetated open spaces can be considered a highly beneficial urban intervention. They provide multiple co-benefits: mitigating the urban heat island effect, acting as buffer zones against extreme sea levels, and delivering recreational and ecological services. In the future, the importance of these areas will only increase, as green coastal buffers become a cornerstone of sustainable and resilient coastal cities.

Numerical Simulations of Waves (SWAN)

Numerical simulations of significant wave heights (Hs) were carried out using the SWAN model. The calculations considered extreme conditions corresponding to a 50-year return period for SW sector waves, with elevated mean sea level of +0.60 m. Two variants were analysed: before and after the construction of the new western breakwater in 2021 (figures 7 and 8). Results show that the breakwater significantly reduced wave heights inside the harbour, thus reducing overtopping and flooding risks.

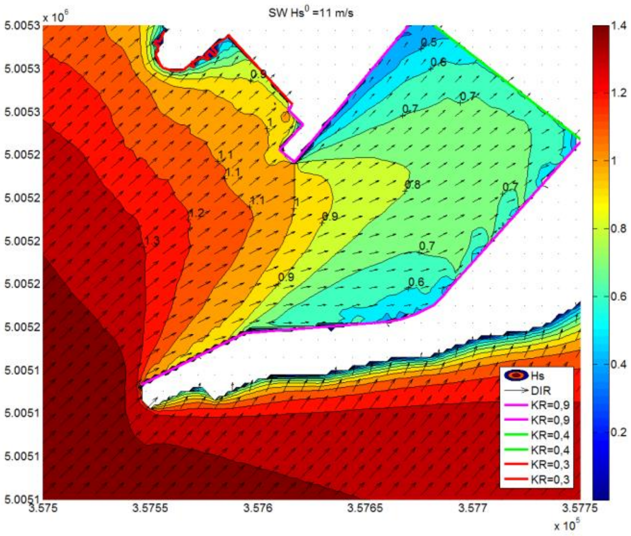

Figure 7. Significant wave height Hs (m), SW direction, T50, MR = +0.60 m — before breakwater

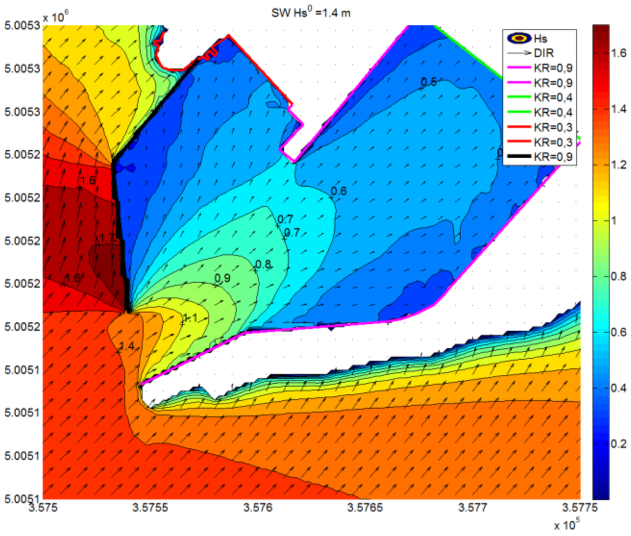

Figure 8. Significant wave height Hs (m), SW direction, T50, MR = +0.60 m — after breakwater

In Crikvenica, the construction of a secondary breakwater has significantly reduced wave energy and agitation in the very centre of the harbour. In addition, the new quay structure, built during the harbour extension, was designed with reduced wave reflection compared to the former solid vertical quay, which had reflected incoming waves and caused severe agitation inside the basin.

Together, these two interventions have already substantially improved harbour conditions, ensuring calm water and protecting the waterfront even during major storm events. As a result, wave overtopping and coastal flooding in the central harbour area are no longer reported as critical issues.

From a climate change perspective, these measures also provide a robust level of protection for the future. The combination of a secondary breakwater and an anti-reflective quay design can be considered a sustainable adaptation strategy, increasing the resilience of the harbour to projected sea-level rise and intensification of extreme storm events.

Case Study: Selce

In Selce, a new waterfront and square were constructed in the town centre as part of an urban design project. The intervention shifted the coastline seaward, but had unintended hydrodynamic impacts. Reflection of waves on the vertical quay increased, amplifying standing waves (seiche) and oscillations inside the harbour. This led to overtopping, flooding and discomfort for moored vessels.

To mitigate the problem, an anti-reflective quay structure was implemented. This represents a concept of how to tackle wave agitation, overtopping and climate-change-induced sea-level rise in small harbours.

Figures 9 and 10 show the results of numerical wave simulations, comparing the effects of a solid vertical quay wall with those of a quay wall designed with reduced wave reflection.

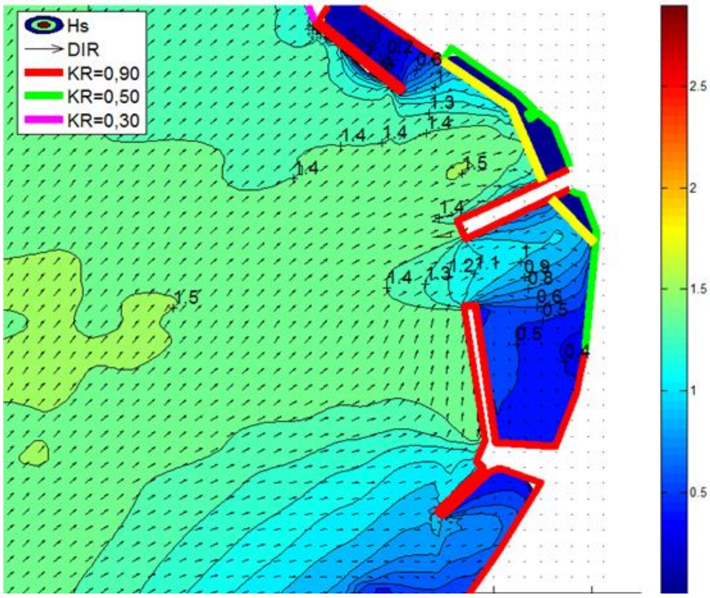

Figure 9. Selce harbour SWAN simulation results for the Crikvenica harbour with a solid vertical quay wall, showing strong wave reflection and increased agitation

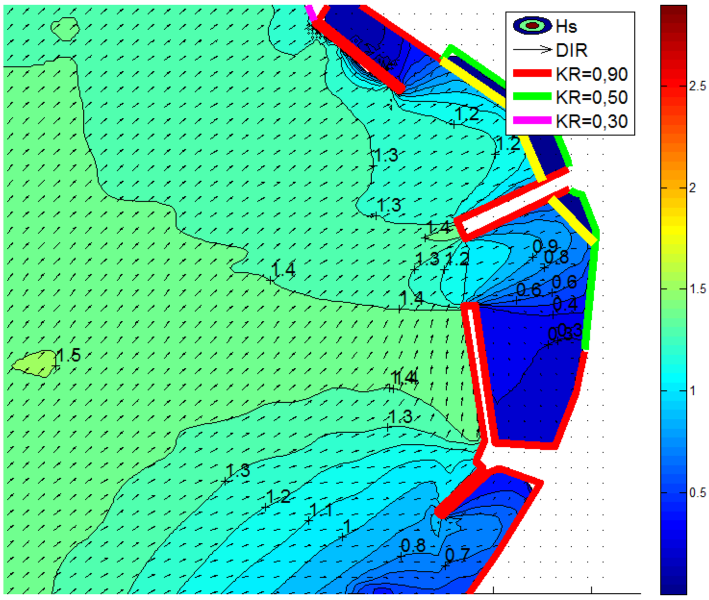

Figure 10. Selce harbour SWAN simulation results for the Crikvenica harbour with a quay wall designed for reduced wave reflection, resulting in calmer harbour conditions

The results of the wave simulations clearly demonstrate the importance of carefully considering maritime hydraulic parameters when designing coastal interventions that involve a shift of the shoreline. An inappropriate choice of coastal structure can significantly deteriorate harbour conditions. Instead of reducing risks, such designs may even increase wave agitation and coastal flooding due to excessive wave reflection. Conversely, properly designed low-reflection structures can enhance harbour safety and resilience to extreme events.

Methodology

The assessment combined historical cartographic sources (Austro-Hungarian surveys, Arcanum Maps), orthophotos (1968–2019), numerical models (SWAN), and GIS analyses. Indicators included shoreline retreat/advance, lithology, slope, land use, and exposure to extreme events. Comparative case studies (Crikvenica vs Selce) allowed identification of successful and unsuccessful planning practices.The vulnerability assessment applied a combination of geospatial analyses, historical shoreline reconstructions, and numerical modelling. The workflow is structured in three stages:

(i) LiDAR-based inundation mapping

- The official Croatian national LiDAR DTM (1 m resolution) was used to delineate coastal flood lines and inundation areas.
- Three water-level scenarios were applied:
  - **Present-day extreme:** +1.13 m above mean sea level (observed maximum at Bakar tide gauge, 1 Nov 2012).
  - **Optimistic 2100 scenario:** +1.53 m (baseline +0.40 m sea-level rise).
  - **Pessimistic 2100 scenario:** +1.93 m (baseline +0.80 m sea-level rise).
- Inundation polygons and flooded areas were mapped for each scenario to estimate potential exposure of land and assets.

(ii) SWAN numerical simulations

- For each scenario, SWAN was run to simulate significant wave heights (Hs) in the coastal zone and harbours.
- Boundary conditions were derived from extreme wave statistics (50-year return period) for four directional sectors (SE, SW, W, NW).

- Existing coastal layouts were modelled first, followed by sensitivity simulations with alternative boundary reflection coefficients.

(iii) Counterfactual shoreline configuration

- A “no reclamation” scenario was prepared for Crikvenica, simulating the coastline as if no land reclamation had been carried out between Podvorska and Crni mol.
- The modified DTM was used to re-run inundation mapping and SWAN simulations, enabling comparison with the actual present-day shoreline.

Deliverables

- Flooding maps and exposure areas for all scenarios.
- SWAN wave height maps and harbour agitation indicators (Hs at control points).
- Comparative assessment of Crikvenica and Selce as case studies of planned vs. unplanned coastal interventions.

Coastal Vulnerability Assessment Map

The Coastal Vulnerability Assessment Map provides an integrated overview of shoreline evolution, urbanisation impacts and exposure to extreme sea levels. Crikvenica illustrates how planned setback and reclamation can reduce vulnerability, while Selce illustrates how inadequate planning may aggravate hazards.

Figures 11–13 present the **combined coastal hazard maps of Crikvenica**, showing flooded areas (inundation extents) and significant wave heights (Hs) from SWAN simulations for sea-level scenarios of **1.20 m, 1.60 m, and 1.80 m**. For reference, both the **present-day shoreline** and the **historical shoreline from 1850** are shown.

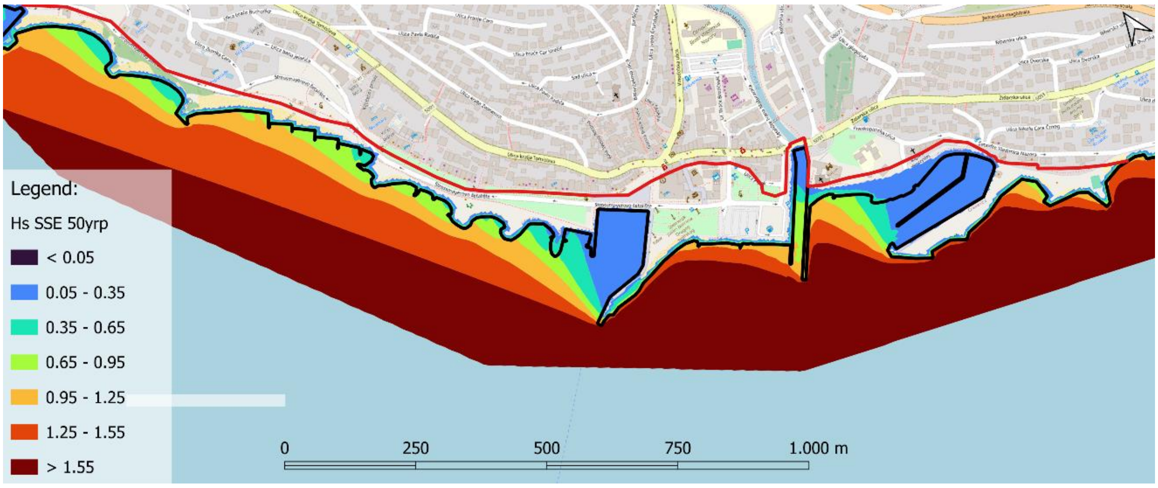

Figure 11. Combined coastal hazard map of Crikvenica for sea level 1.20 m (inundation + SWAN Hs), including present and 1850 shorelines.

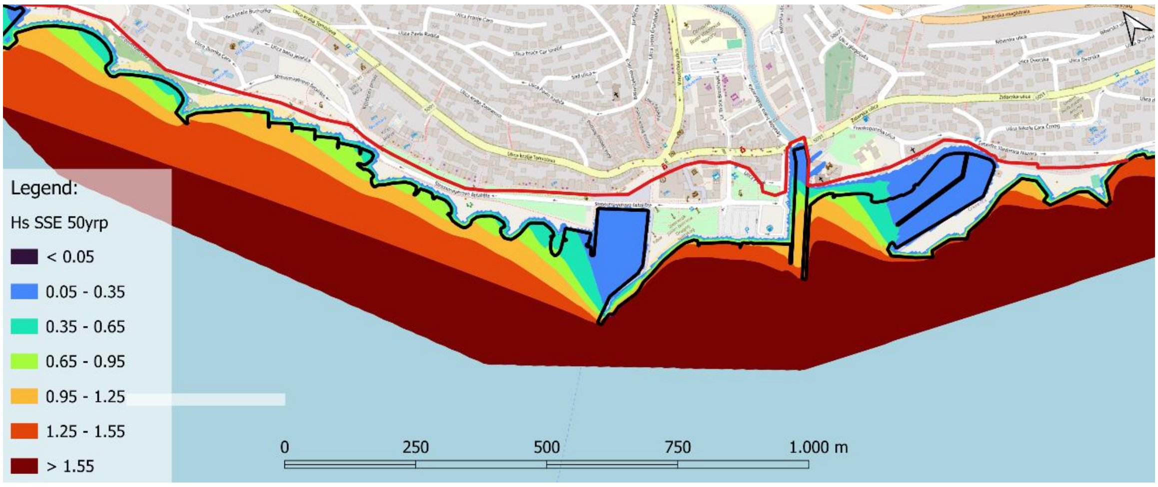

Figure 12. Combined coastal hazard map of Crikvenica for sea level 1.60 m (inundation + SWAN Hs), including present and 1850 shorelines

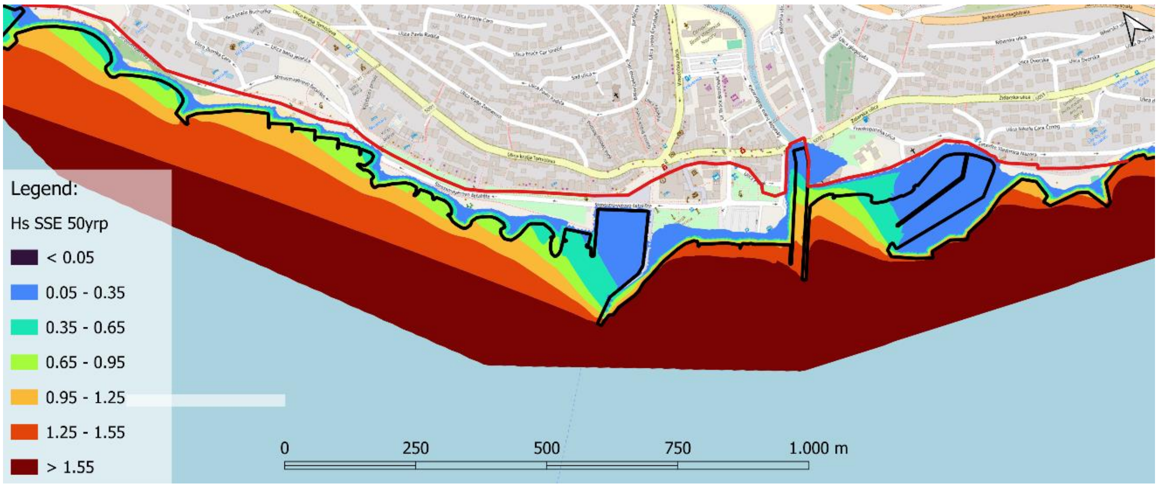

Figure 13. Combined coastal hazard map of Crikvenica for sea level 1.80 m (inundation + SWAN Hs), including present and 1850 shorelines

The conducted simulations demonstrated that **Crikvenica will not face significant problems with coastal flooding**, even under an increase of extreme sea levels by up to **+0.80 m relative to present values**. Flooded areas expand only locally on beaches, which could lead to **increased erosion**; however, such impacts can be effectively mitigated through technical measures (e.g., nourishment, structural protection).

Apparent flooding at the **Dubračina river mouth** is not realistic, as the DEM used for modelling does not account for existing structures that now protect this area. A minor issue may occur in **Podvorska**, the most recently reclaimed zone. Since this area is largely free of buildings, the **coastal elevation can be easily adapted** to new sea levels, reducing potential risks.

Wave simulations further confirmed that **wave agitation does not extend beyond historical shorelines**, illustrating the protective effect of reclamation and setback. Without reclamation and coastal setback, Crikvenica would today face severe problems with flooding and wave action; under projected sea-level rise scenarios, these problems would be considerably greater.

Conclusions

The comparison of **Crikvenica and Selce** demonstrates how similar types of coastal engineering interventions — such as **quays, breakwaters, and land reclamation** — can produce very different outcomes depending on the planning process and design approach.

In **Crikvenica**, systematic coastal setback and phased reclamation since the 19th century created wide open public spaces that function as protective buffers. Together with more recent measures — the construction of a secondary breakwater and low-reflection quay structures — these interventions have significantly reduced vulnerability to flooding and wave agitation. Simulations indicate that the city is well protected even under scenarios of sea-level rise linked to climate change.

In **Selce**, the design of a new quay and waterfront raised concerns that wave reflection and harbour agitation might increase if a solid vertical wall were built. However, the project was immediately implemented with a **low-reflection quay structure**, thereby avoiding the negative impacts and ensuring stable harbour conditions. In this way, Selce avoided a potentially serious problem by integrating hydrodynamic considerations into the design from the outset.

These experiences confirm the importance of **integrating urban design with hydraulic modelling and climate adaptation principles** at the earliest stage of planning. Interventions that neglect hydrodynamic assessments risk amplifying hazards instead of reducing them. Conversely, combining **setback policies, nature-based solutions, and appropriately designed technical structures** can provide multiple benefits:

- reducing flood and erosion risks,
- enhancing resilience to sea-level rise and extreme storms,
- improving the urban microclimate through green infrastructure, and
- ensuring safer, more sustainable, and climate-resilient coastal communities.

3. Report: Italian Pilot Areas

Background

Hazards

A hazard refers to a physical event, a trend, or its potential occurrence that can cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental degradation.

In the case of the coastal area of New Pescara, the main hazards highlighted by literature reviews, documents from various territorial bodies (as evidenced in Del. D.3.1.1), and field experience concern:

a. Landslides and floods

b. Coastal erosion

c. Rising temperatures and urban heat island formation

d. Areas prone to fires

Exposure

Exposure refers to the presence of people, livelihoods, species or ecosystems, services, infrastructure, or economic, social, and cultural assets in places and contexts that could be negatively affected by hazards. More precisely:

a. The resident population. The Adriatic coast is densely populated. Many of these communities live in low-lying and dense areas, directly exposed to floods, storm surges, and rising temperatures.

b. Critical infrastructure, such as:

Port and maritime infrastructure, essential for the fishing economy and tourism, are directly exposed to floods, storm surge damage, and coastal erosion.

Transport networks: roads and railways and other communication routes running parallel to the coast and crossing vulnerable areas.

Industrial and energy plants: some coastal areas host industrial or energy generation plants that could be damaged by extreme events.

Wastewater treatment and sewage systems: often located near the sea, they are vulnerable to floods and saline intrusion.

Public and private buildings and equipment that can be directly affected by storm surges, floods, and rising temperatures.

c. Economic activities, such as:

Beach tourism: a pillar of the coastal economy, with establishments, hotels, and services highly exposed to coastal erosion and extreme weather events.

Fishing and aquaculture: vital sectors for coastal communities, dependent on the health of marine ecosystems and vulnerable to changes in water temperature, acidification, and extreme events.

Agriculture: in coastal plains, agriculture is exposed to saline intrusion into aquifers due to sea-level rise and storm surges, as well as to droughts, rising temperatures, intense rainfall, hailstorms, and floods.

Commercial activities exposed to extreme atmospheric events

d. Natural ecosystems, protected areas, and urban greenery: coastal pine forests and other natural areas, as well as urban greenery, are exposed to erosion, sea-level rise, salinity changes, and rising temperatures which can affect their health and quality.

Vulnerability

Vulnerability is the propensity or predisposition of a system to be negatively affected by climatic hazards. It is not the event itself, nor the mere presence in a risk area, but the intrinsic characteristics of the system (people, places, sectors) that increase its susceptibility to damage and/or reduce its capacity to cope or adapt.

Case Study: New Pescara

For the construction of the vulnerability map, knowledge of the hazards was first deepened, based on official documents from the PSDA and PAI, and other sources, such as the AnCoRa project and the Coastal Defense Plan, scientific literature, local knowledge, and historical context.

Hazards

Coastal erosion, average sea-level rise, and extreme hydrometeorological events, such as intense rainfall, floods, and landslides (Ud'A-TEMA University "G. d'Annunzio" Chieti – Pescara. Prof. E. Miccadei, Dr. B. Milojkovic, Dr. S. Sticca)

This section aims to analyze the vulnerability of the Abruzzo coastal territory with respect to three main themes: coastal erosion, average sea-level rise, and extreme hydrometeorological events, such as intense rainfall, floods, and landslides. D1.4.3 proposes a critical and integrated reading of official data and available bibliography, enriched by technical considerations gained in previous projects. The document intends to provide technical-scientific guidelines and indications of critical areas, useful for guiding urban planning policies and strategies for mitigation and adaptation to climate change and anthropogenic pressures.

The analysis is based on a set of institutional, regulatory, and scientific sources. The Hydrogeological Asset Plan (PAI) and the Flood Defense Sectional Plan (PSDA) were considered for defining hydraulic and geomorphological hazards; the Abruzzo Region Coastal Plan and the results of the AnCoRa project for coastal dynamics; as well as scientific publications related to coastal and fluvial geomorphology, subsidence phenomena, and the response of territories to extreme events. To these sources are added the Civil Protection archives, press reviews on recent events, and the expert knowledge of the working group, which allowed for data integration. The adopted methodology involves cross-referencing these sources with multi-temporal cartographic analyses and the use of interpretive symbols for representing the most problematic areas, to be subjected to subsequent detailed studies.

The Abruzzo coastline shows high geomorphological variability, with alternating sandy beaches, active cliffs, and rocky beaches. Numerous sandy stretches, such as in the coastal areas of Montesilvano and Pescara, show significant coastline retreat, with high erosion rates. The main causes are attributed to the reduction of solid fluvial inputs, the alteration of littoral transport induced by anthropogenic defense works, inert material extraction carried out in the last century, and anthropogenic modifications of river channels. IPCC projections for average sea-level rise indicate values between 0.44 and 0.77 meters by 2100 in the high-emission scenario (RCP8.5), with significant consequences for coastal plains and urban areas in river valleys. An increased frequency of marine intrusions, loss of usable beach area, worsening problems of stormwater drainage in urban areas near sea level and increasing pressure on residual dune ecosystems are expected.

Intense meteorological events constitute one of the main causes of hydrogeological instability in Abruzzo. In hilly areas, they can trigger superficial landslides, debris flows, and slope instability; in river basins, they cause sudden floods with a risk of overflowing; in coastal urban areas, they generate recurrent flooding.

A significant contribution in this area emerges from several recent studies that have analyzed the effects of intense meteorological events on the Abruzzo territory. Particularly relevant are the researche documenting geomorphological instability induced by critical rainfall in recent decades and the response of coastal and dune systems (Miccadei et alii, 2011). More recently, the article by Paglia et alii (2024) deepened the role of extreme weather conditions and local geomorphological dynamics in determining superficial landslides and floods, offering an updated framework useful for integration with risk planning and management tools in the Abruzzo territory.

The urban territory of Pescara represents an emblematic case of complex vulnerability to extreme events. Frequent floods do not exclusively result from river overflows but from a combination of anthropogenic and geological co-causes. Strong urbanization, accompanied by soil impermeabilization, has increased surface runoff; the closure and culverting of secondary river channels have reduced natural drainage capacity; hydraulic mitigation works are characterized by a punctual and fragmentary approach, lacking a systemic vision. The lamination basins built upstream are in the testing phase, and updated data on the design flood wave and real geomorphological effectiveness are lacking. Further complicating the picture is the widespread subsidence in the southern part of Pescara, documented by ISPRA (https://indicatoriambientali.isprambiente.it/it/pericolosita-da-subsidenza-e-sinkholes/comuni-interessati-da-subsidenza). Montesilvano and Spoltore are also included among the municipalities affected by subsidence. In these areas, building expansion and poor integrated management of the hydrographic network accentuate hydraulic and geomorphological vulnerability, leading to critical situations not only in the central areas of Pescara (Porta Nuova, Pineta d'Annunzio, Via Gran Sasso, tourist port) but also in the peri-urban sectors of neighboring municipalities.

Existing urban planning formally signals the main criticalities, but in a fragmentary manner and with uneven levels of detail among the various municipalities. In Pescara, the General Regulatory Plan (PRG) includes specific elaborations such as the geological study and the Geological Hazard Map, which report areas subject to hydraulic and geomorphological hazard. In these areas, constraints on new constructions, limitations on basements, and geological compatibility requirements are foreseen.

The geological report attached to the PRG underlines the city's location in the Pliocene foredeep and the presence of both Pliocene and current subsidence phenomena. The Flood Defense Sectional Plan (PSDA) identifies areas with hydraulic hazard from P1 to P4 along the terminal stretch of the Pescara River, with flood return periods ranging from 50 to 200 years, confirming a medium-high risk condition. The Geological Map of Italy (Sheet 351 – Pescara) highlights the widespread presence of sandy, gravelly, and silty-clayey alluvial deposits, which justify the reduced drainage capacity and consequent vulnerability to urban flooding.

In Spoltore, the General Variant to the PRG reports, in addition to the division into urban zones, graphic elaborations and prescriptions that include land use limitations deriving from the Regional Landscape Plan and the discipline of geological constraints. Urbanistic variants and attached studies indicate the presence of terraced alluvial deposits with alternating sands, gravels, silty-clayey, and peaty layers, which determine susceptibility to flooding. The PSDA also includes parts of the territory in areas of significant hydraulic hazard, particularly along the valley sectors.

In Montesilvano, the PRG includes, among the annexed elaborations, the Geological Report, the Geological-Geomorphological Map, the Hydrological Map, and especially the Map of Hazard and Geological Limitations to Land Use. These tables report criticalities related to both fluvial dynamics and coastal areas. The PSDA classifies large portions of the lower course of the Saline River and surrounding areas with hydraulic hazard P2 and P3. However, there is a noted absence of systematic reports on subsidence phenomena and ongoing landslide processes, despite general constraints and prescriptions being reported.

Therefore, the three urban planning instruments incorporate and represent the main factors of hydraulic and geomorphological hazard, but with differences in detail levels and in the capacity for integration with basin planning. The absence of a truly integrated approach persists, one that collectively considers anthropogenic factors (intense urbanization, soil impermeabilization, culverting of minor watercourses) and geological factors (subsidence, lithology, fluvial dynamics), and that supports coordinated inter-municipal planning.

All the evidence gathered highlights how the vulnerability of the Abruzzo coastal and peri-urban territory derives from the interaction between natural and anthropogenic factors. Subsidence progressively lowers elevations and compromises hydraulic works; culverting reduces outflow capacity; impermeabilization increases surface runoff volumes. It is, therefore, necessary to promote detailed studies and planning solutions oriented towards a systemic vision, capable of addressing the deep causes of vulnerability and strengthening territorial resilience.

The suggested directives include reducing soil impermeabilization, adopting sustainable urban drainage systems, continuous monitoring of subsidence, adapting design elevations in new urban developments, and integrated management of coastal dynamics based on "soft" interventions and nature-based solutions. These indications, while lacking regulatory value, aim to stimulate local administrations to promote adaptation actions and mitigation strategies consistent with the European framework for combating climate change.

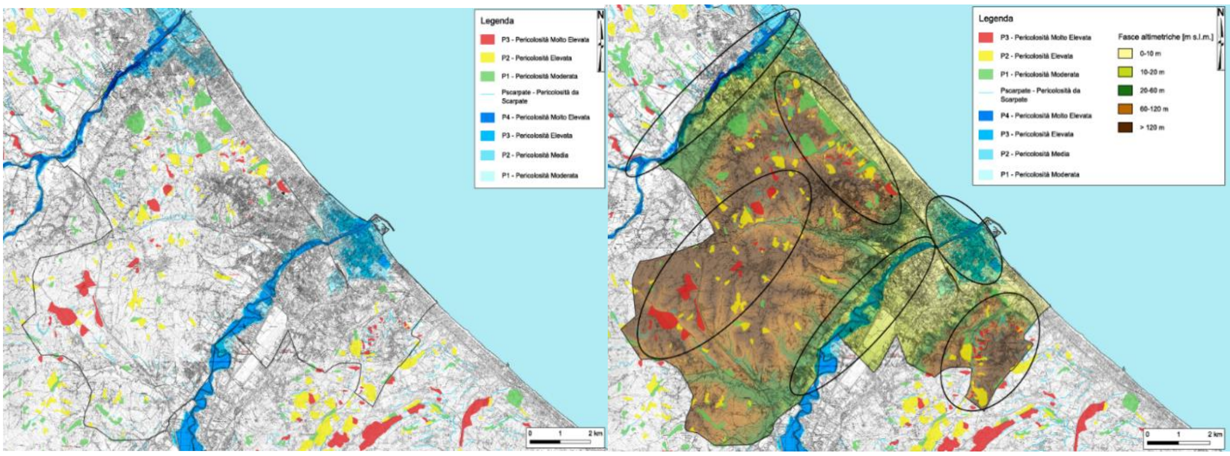

Figure 14. Hazard from PAI to PSDA. Hazard levels range from P1 to P3 for PAI (P3 red; P2 Yellow, P1 green) and from P1 to P4 for PSDA.

Regarding the multi-temporal analysis of coastlines from 1955 to 2020 (Fig. 15), integrated with orthophotos and the distribution of coastal defense structures, it highlights how the stretches of coastline between Pescara and Montesilvano exhibit complex dynamics, characterized by strong spatial and temporal heterogeneity.

In the period between 1955 and 1985, the coastline showed conditions of relative stability, with limited variations probably attributable to natural seasonal oscillation processes.

From the 1980s onwards, however, a widespread retreat of the coastline is observed, particularly evident in urban and densely anthropized areas. The reduction of solid fluvial input, a consequence of hydraulic regulation works and riverbed excavations, led to a deficit that amplified the erosive effects of the sea. Between 2007 and 2016, coastal evolution was influenced by the presence and strengthening of anthropogenic defense structures, such as groynes and parallel breakwaters. In correspondence with these structures, a tendency towards accumulation and beach stabilization is noted, with a partial advancement of the coastline. However, the effectiveness of these works proved to be limited to the protected sectors, while adjacent undefended areas underwent erosion processes, with retreats and an alteration of the longshore sedimentary balance. In more recent years, between 2016 and 2020, the coastline has shown significant oscillations, attributable both to the impact of extreme hydrometeorological events, such as the exceptional storms of 2019, and to the rise in mean sea level, which reduces the effectiveness of existing defenses and accelerates retreat phenomena. This results in a picture of strong instability, with sectors alternating local advancements with marked retreats in short time intervals.

Evolution of the coastline in Montesilvano from 1955 to 2020

Evolution of the coastline in Pescara from 1955 to 2020

Figure 15. The Evolution of the Coastline from 1995 to 2020

Overall, the analyzed coastal stretch can be considered to have high vulnerability.

The combination of erosive processes, rising sea levels, and extreme weather events determines an accentuated risk condition, especially in urbanized areas close to the coastline, where infrastructure, bathing establishments, and road networks are particularly exposed. In conclusion, Deliverable D1.4.3 provides an interpretation of the vulnerability of the Abruzzo coastal territory. The cross-referencing of data, bibliography, and knowledge has made it possible to identify the most problematic contexts, ascertain their causes, and outline intervention priorities. The adopted approach allows for moving beyond a simple survey of already mapped hazards, guiding urban planning towards greater adaptability and resilience within a framework of climate change and increasing anthropogenic pressures.

Temperature Rise

The temperature rise for the Spoltore-Montesilvano-Pescara area was analyzed in D.3.1.1, with the support of a time series of daily average temperatures showing a growth rate of 0.015 ± 0.010°C/year during the 1930-1979 period, a rate of 0.043 ± 0.006°C/year considering the 1950-2015 period, and a rate of 0.063 ± 0.013°C/year in the 1980-2015 period. Urban heat islands (UHIs) are linked to rising temperatures, a phenomenon where urban areas record significantly higher temperatures compared to surrounding rural areas. This is due to several factors:

- Building materials: Asphalt, concrete, and other building materials absorb and store solar heat more than natural surfaces like vegetation and soil.

- Lack of vegetation: The scarcity of trees and plants in cities reduces shading and cooling capacity through evapotranspiration.

- Urban geometry: Tall buildings and narrow streets trap heat and reduce ventilation.

- Anthropogenic activities: Energy released by vehicles, air conditioning systems, industries, and other energy consumption contributes to heating.

To study the hazard levels of rising temperatures and thus the formation of heat islands, WUDAPT (World Urban Database and Access Portal Tools) was used. This is an international initiative that aims to create a standardized classification of urban areas globally. The main objective is to provide data and tools to better understand how the physical characteristics of cities influence the local climate, particularly the urban heat island (UHI) phenomenon. WUDAPT provides a standardized classification of urban areas into Local Climate Zones (LCZ), each with specific physical characteristics (building density, building height, land cover, presence of vegetation, materials). These LCZs are the bridge between the city's physical characteristics and risk elements. Although classifying Local Climate Zones (LCZ) based on climatic hazard levels is a complex approach that depends on various factors, a general classification can be outlined based on the intrinsic characteristics of LCZs and their impact on the urban climate (Fig. 16):

- Very High Hazard Level:

o LCZ 1 (Compact High-Rise): Densely grouped tall buildings with impervious surfaces and a high street canyon aspect ratio. Traps heat, reduces ventilation, and creates very intense urban heat island effects.

o LCZ 2 (Compact Mid-Rise): Densely grouped medium-height buildings. Similar to LCZ 1 but with slightly less extreme effects due to lower building height.

o LCZ 3 (Compact Low-Rise): Densely grouped low-rise buildings. Again, high density and impervious surfaces contribute to significant heat islands.

o LCZ 8 (Large Low-Rise): Large low-rise buildings, often industrial or commercial, with extensive impervious surfaces (parking lots, roofs). These areas can be extremely hot due to large sun-exposed surfaces and lack of vegetation.

- High Hazard Level:

o LCZ 4 (Open High-Rise): Tall buildings with open spaces between them. Greater spacing can improve ventilation compared to compact LCZs, but the thermal mass of buildings and impervious surfaces maintain high heat hazard.

o LCZ 5 (Open Mid-Rise): Medium-height buildings with open spaces. Like LCZ 4, but with less pronounced effects.

o LCZ 6 (Open Low-Rise): Low-rise buildings with open spaces. The greater presence of open spaces can slightly mitigate the heat island, but artificial surfaces are still predominant.

o LCZ D (Heavy Industry): Heavy industrial areas with large buildings, chimneys, and processes that generate heat. In addition to the heat island, there can be risks related to air pollution and locally very hot microclimates.

- Moderate Hazard Level:

o LCZ 7 (Lightweight Low-Rise): Low-rise buildings with light materials, often prefabricated or metal sheet. They can heat up quickly but also cool down faster than buildings with greater thermal mass. Often associated with slums or less dense peripheral areas.

o LCZ C (Bush/Scrub): Areas with sparse vegetation and exposed ground. Can heat up significantly during the day but tend to cool down more at night compared to built-up areas. Higher wildfire risk in dry climates.

o LCZ E (Bare Rock/Paved): Areas of exposed rock or completely paved surfaces (e.g., large parking lots, highways). Absorb and radiate a lot of heat, creating intense surface heat islands.

- Low Hazard Level:

o LCZ A (Dense Trees): Dense forests and urban parks with high tree cover. Vegetation provides shade and cooling through evapotranspiration, significantly reducing air temperatures.

o LCZ B (Scattered Trees): Areas with scattered trees and vegetation. Less effective than LCZ A, but still offers cooling and shading benefits.

o LCZ G (Water): Water bodies (rivers, lakes, seas). Water has a large thermal capacity and a cooling effect on the surrounding environment, mitigating heatwaves.

o LCZ F (Bare Soil/Sand): Open agricultural land or sandy areas. Can heat up during the day but, unlike artificial surfaces, do not store heat with the same intensity and cool down more easily at night (unless they are dark, dry surfaces).

This classification primarily focuses on heatwaves. For other hazards such as floods, LCZs with high percentages of impervious surfaces (LCZ 1, 2, 3, 8) would be at very high risk due to surface runoff. Furthermore, it should be noted that even within the same LCZ, microclimatic conditions can vary significantly depending on street orientation, the presence of specific trees, or water bodies.

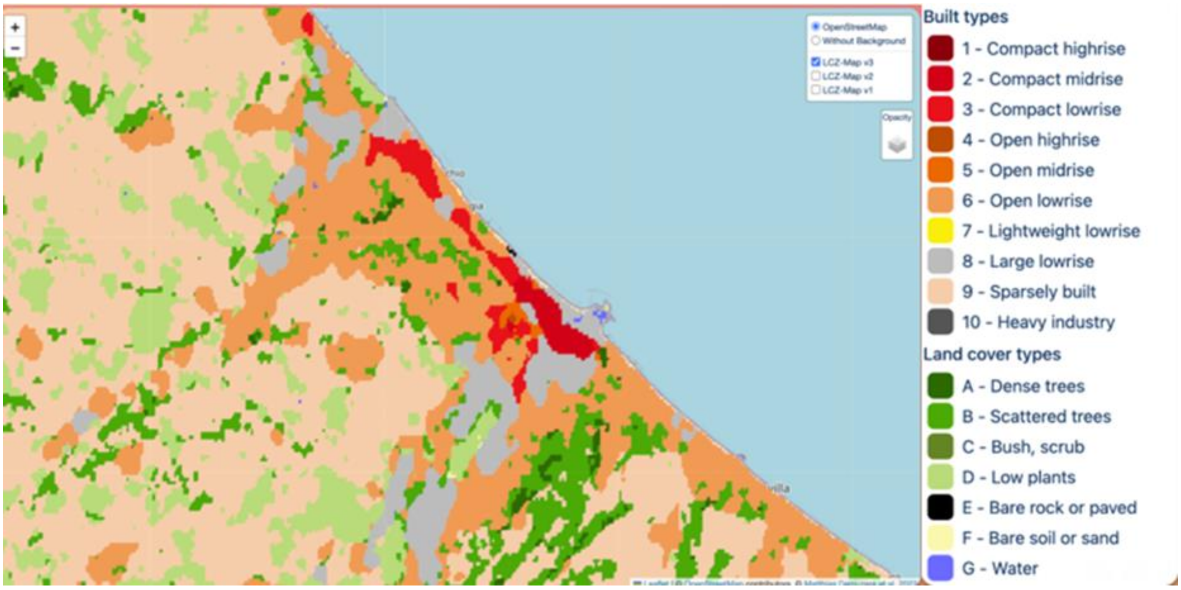

Figure 16. Wudapt Schematization for the NuovaPescara Pilot Area (to be checked)

Wildfires

The Regional Bulletin on Wildfire Ignition Susceptibility includes a textual part that collects meteo-climatic forecasts and a graphic part with the mapping of danger levels. Three levels of danger are defined for fire risk, corresponding to three different operational scenarios for potential containment:

Low hazard: Conditions are such that, once ignited, the event can be managed with ordinary means.

Medium hazard: Conditions are such that, once ignited, the event requires a rapid and effective response; without it, the intervention of aerial means might be necessary.

High hazard: Conditions are such that, once ignited, the event can only be countered by resorting to extraordinary means, such as the state and regional air fleet.

The danger levels are represented on the bulletin maps using three colors: * Green = Low Danger * Orange = Medium Danger * Red = High Danger (Fig. 17)

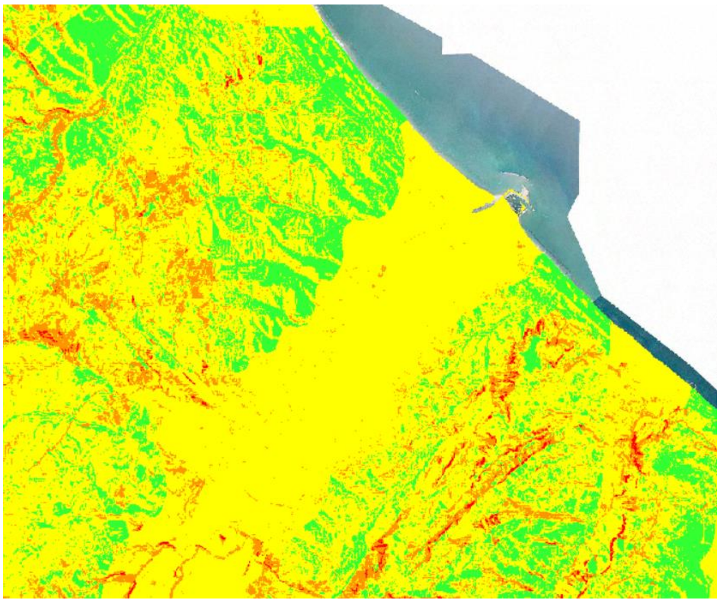

Figure 17. AIB Plan - Summer Fire Probability Map based on Predisposing Factors.

This document expresses the probability level of fire occurrence for both summer and winter situations. The predisposing factors considered and weighted according to an algorithm are Exposure, Slope, Phyto-climate, and Land Use, with in-depth analysis of silvo-pastoral vegetation. Source: Abruzzo Region Geoportal

Exposure

Exposure refers to the presence of people, livelihoods, species or ecosystems, infrastructure, or economic, social, and cultural assets in places and settings that could be affected by a hazard. It is not the damage itself, but the possibility of being affected, that is of interest. Although literature and common usage often erroneously conflate exposure and vulnerability, they are distinct. Exposure is a necessary, but not sufficient, determinant of risk. It is possible to be exposed but not vulnerable (for example, living in a floodplain but having sufficient means to modify building structure and behavior to mitigate potential losses). However, to be vulnerable to an extreme event, one must also be exposed. For measuring exposure, reference is made to the existence of anthropogenic elements within an area potentially affected by adverse events (Andreani and Azzari, 2008), and it is generally measured as the density of elements at risk (number/surface area).

In the case of the New Pescara pilot area, to map the various elements exposed to the identified hazards, it was decided to refer to the spatialization of census sections for which data on resident population could be obtained and spatialized (Fig. 18 and 19). The same spatial scope was used for:

Critical Infrastructures: the port and maritime infrastructures; transport networks: roads and railways and other communication routes running parallel to the coast and crossing the hazard areas; Industrial and energy plants; public and private buildings and facilities, that may be directly affected by storm surges, floods, and rising temperatures; buildings of historical and architectural interest (Fig. 20);

Economic Activities: Coastal Tourism: establishments, hotels, and services (Fig. 21) that are highly exposed to coastal erosion and extreme weather events;

Fishing and Aquaculture: Vital sectors for coastal communities, which depend on the health of marine ecosystems and are vulnerable to changes in water temperature, acidification, and extreme events; Agriculture: in coastal plains and hills, agriculture is exposed to drought, rising temperatures, intense rainfall, hailstorms, and floods, landslides; commercial activities exposed to extreme weather events (Fig. 22 and 23).

Natural Ecosystems: natural areas, as well as urban green spaces, are exposed to erosion, rising temperatures that can affect their health and quality, hailstorms, and extreme events in general.

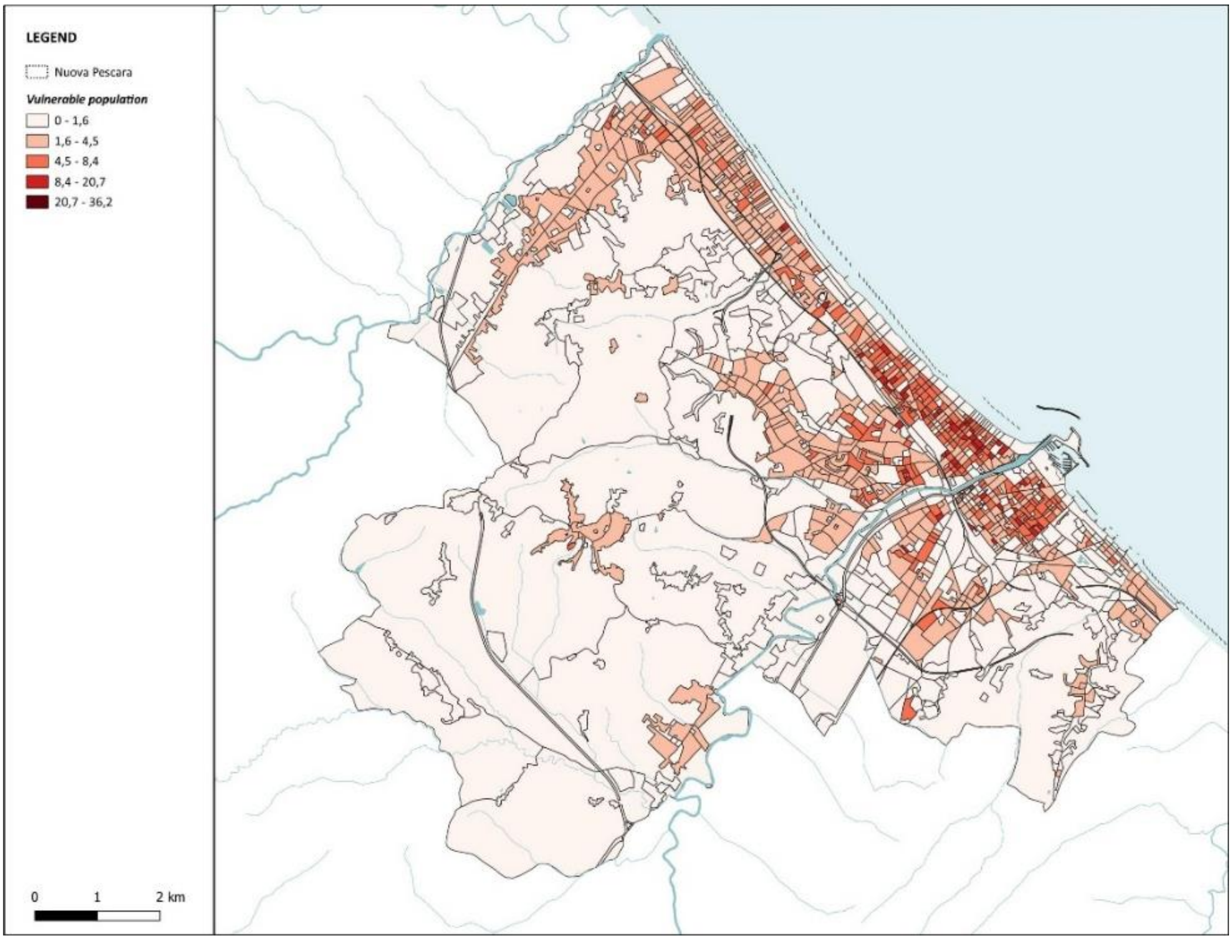

Figure 18. Identification of Vulnerable Population (0-15) and (Over 65) in Pilot Area

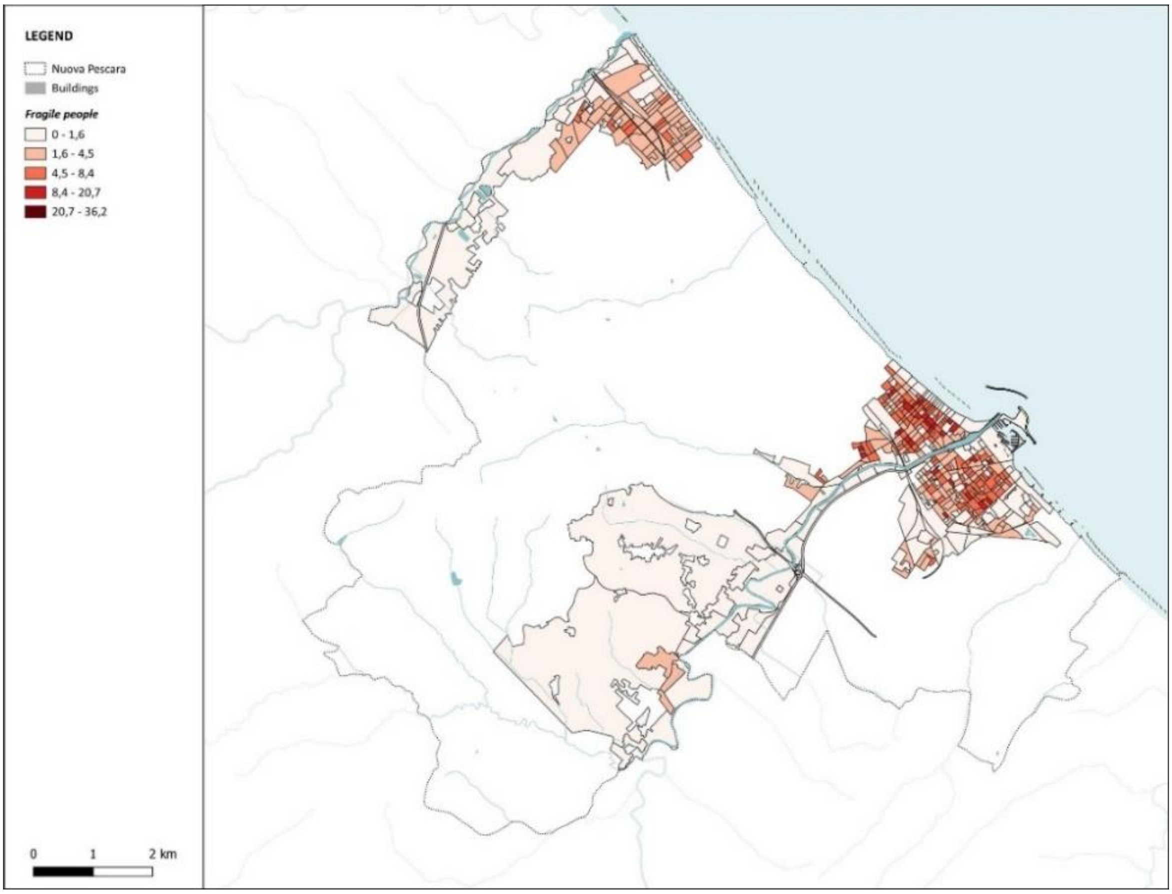

Figure 19. Density of the vulnerable population (0-15 and over 65) exposed to flood and landslide hazard by census in the pilot area

Figure 20. Identification of heritage Building and facilities in Pilot Area

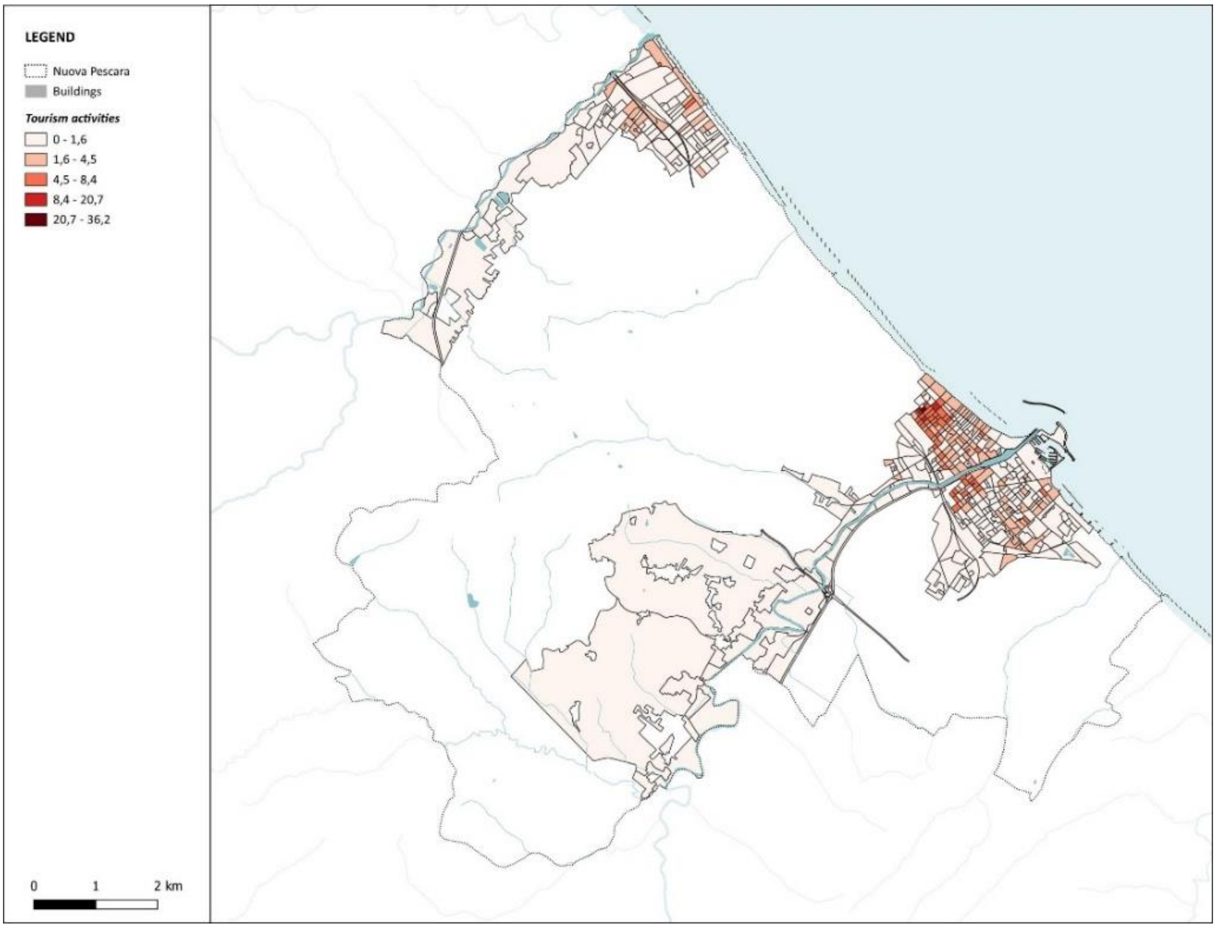

Figure 21. Density of tourist activities exposed to flood and landslide hazards by census in the pilot area

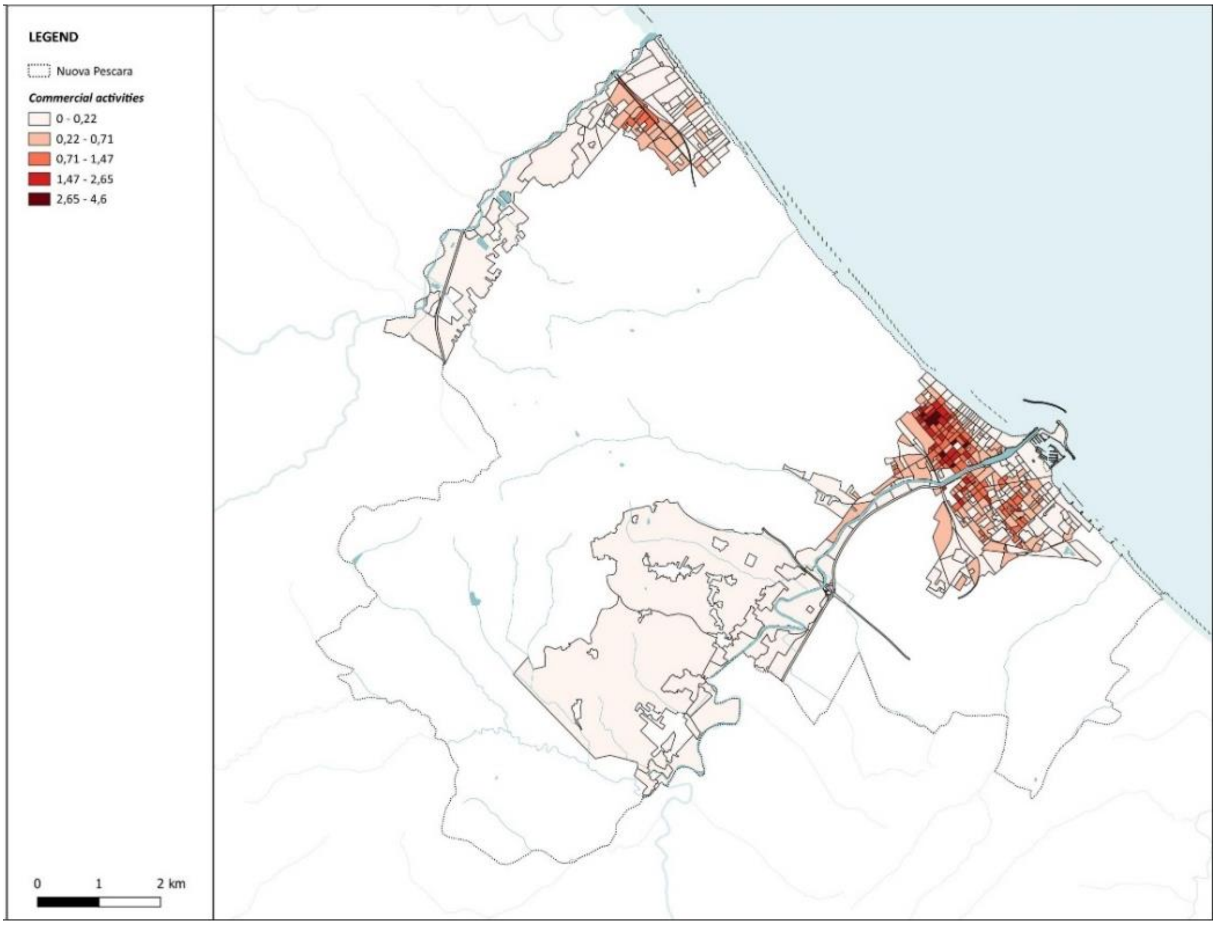

Figure 22. Density of commercial activities exposed to flood and landslide hazards by census in the pilot area

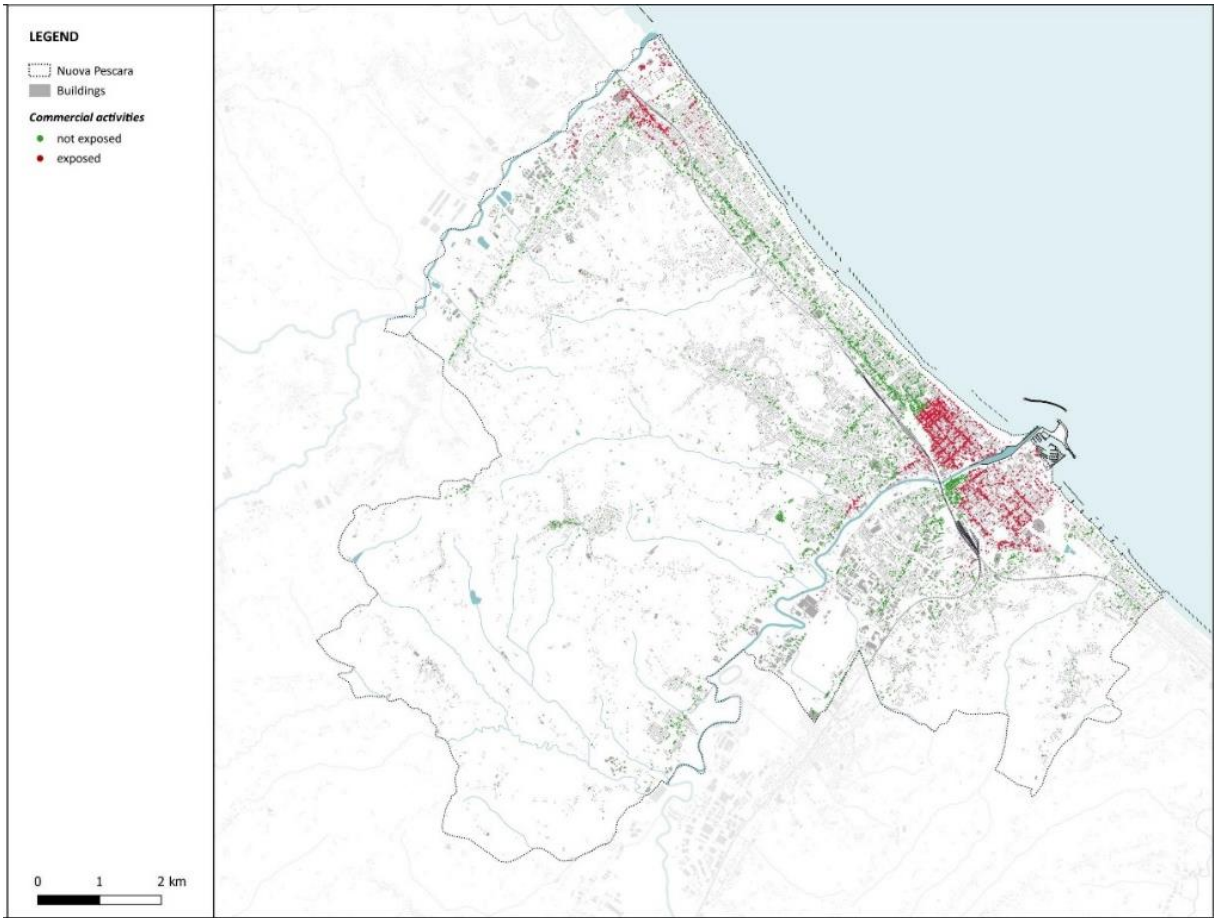

Figure 23. Density of commercial activities exposed and not exposed to flood and landslides hazards in Pilot Area

Vulnerability

Vulnerability describes the probable susceptibility to harm (Andreani and Azzari, 2008). There are many aspects of vulnerability, stemming from various physical, social, economic, and environmental factors. Examples can include poor building design and construction, inadequate protection of assets, lack of public information and awareness, limited recognition of risks and preparedness measures, and a lack of sound environmental management. Vulnerability varies significantly within a community and over time. Therefore, it was decided to consider certain categories of exposed anthropogenic components. Regarding the population, vulnerable individuals (the elderly and children) were included; among buildings, those deemed strategic in emergency plans and cultural heritage buildings were considered. Among economic activities, the most frequented commercial activities and tourist activities (hotels, restaurants, etc.) were included (Fig. 24). In a second step, agricultural production and the strategic transport network will be considered for the agricultural sector. Within natural ecosystems, protected areas and the most frequented urban parks will be taken as reference.

Vulnerability Calculation

To assess the vulnerability of a specific area, an analysis was conducted combining data related to vulnerable populations, anthropogenic components, the road network, and LCZ (Local Climate Zone) classification. The objective was to assign a vulnerability score to each census section and identify those most exposed.

The first step involved the quantification and identification of census sections affected by the presence of individuals considered fragile, i.e., the sum of people aged between 0 and 15 years and those over 65 years. These data were mapped for each census section and subsequently correlated with areas affected by flood and landslide hazards, as identified by the PAI (Hydrogeological Assessment Plans) and PSDA (Hydrogeological Structure Plans). Subsequently, the density of the fragile population was calculated, expressed as the number of people per 1000 square meters. This value provided a measure of the concentration of vulnerable individuals in each area exposed to PAI and PSDA hazards. In parallel, the anthropogenic components present, such as strategic buildings, tourist and commercial activities, and protected buildings, were mapped and assigned to each census section. In this case too, the density of these components was calculated in relation to the surface area of the census section, always considering the hazard-exposed areas indicated by PAI and PSDA. The results obtained, both for the fragile population and for the anthropogenic components, were categorized using a specific rule that allowed for the identification of a "weight" and the assignment of a score from 1 to 5. This score was then used to calculate the total vulnerability of the area. For the road network, vulnerability was calculated differently. Using vectorial data of the strategic road network, these were intersected with hazard-exposed areas. This allowed for the identification of road sections exposed to specific risk levels within each census section. This approach made it possible to evaluate the accessibility and functionality of communication routes in emergency situations. Finally, for risks related to rising temperatures and urban heat islands, the vulnerability value was identified based on the most represented Local Climate Zone (LCZ) in each area. This methodology takes into account the physical characteristics of the soil (such as the presence of concrete, vegetation, water) that influence an area's capacity to absorb and retain heat, providing an additional dimension to the overall risk assessment.

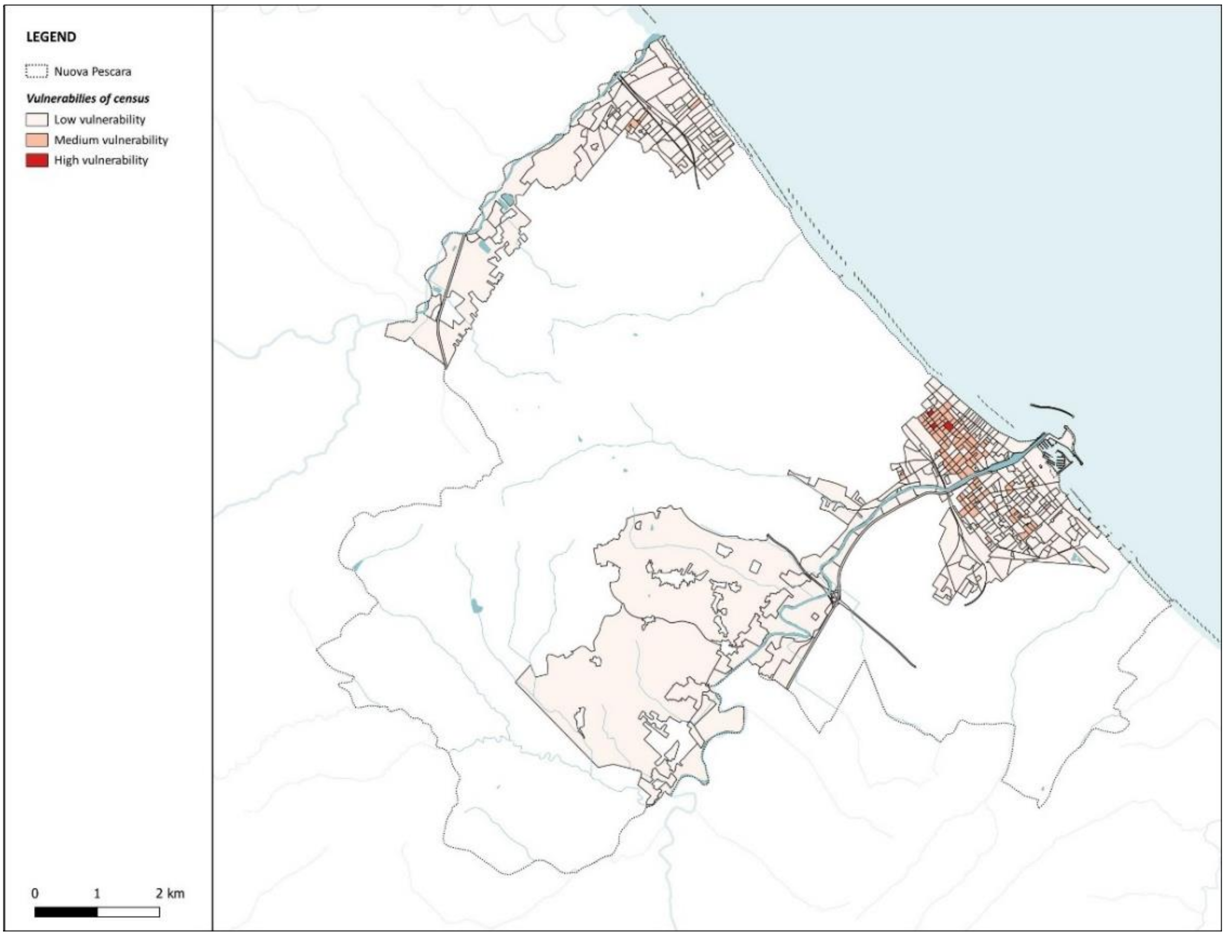

Figure 24. Levels of Climate Vulnerability in the Nuova Pescara pilot area

Conclusions

From this initial exploration of the climate vulnerabilities of the Nuova Pescara Pilot Area, the central city area north and south of the Pescara River emerges as an area of medium and high vulnerability. This summary map constitutes a first exploration of the vulnerability, to which other exposed components, such as high-value agricultural areas, the environmental system (parks and reserves), and strategic communication routes, will be superimposed as the project progresses. Furthermore, the hazard concerning rising temperatures will need to be investigated in more detail.

4. Sources

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5. List of Figures