European Investment Bank - EIB

CFT 1515 - Climate Resilience in Investment Projects - Component 2

Climate change adaptation investment options for the Island of Ischia – Recommendations for the post-disaster recovery and reconstruction

19.3.2024

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Version history:

Date	Editor	Changes / version
4.12.2023	All assignment team	First draft of Part 1
6.12.2023	Maribel Hernandez	Quality review
6.12.2023	All assignment team	Changes based on quality review
28.12.2023	All assignment team	First draft of full report
25.1.2024	Alastair Baglee	Quality review
29.1.2024	Anssi Karppinen, Philipp Stanzel	Full report for EIB review
20.2.2024	Elina Väänänen & EIB Team	Comments provided
8.3.2024	All assignment team	Comments addressed
14.3.2024	Anssi Karppinen	Final draft
19.3.2024	Elina Väänänen	Comments from EIB
19.3.2024	Anssi Karppinen	Final version

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Executive summary

In November 2022, extreme rainfall hit the Italian island of Ischia. Torrential rain caused landslides and flooding. The island suffered several casualties and damage to its infrastructure. The Italian government declared a state of emergency for the area and approved funds for recovery and rescue operations.

Previously, in 2017, an earthquake had already caused enormous destruction in the north of the island, and the government of Italy had assigned a Special Commission (Struttura Comissariale) for assistance to the population, reconstruction, and economic recovery. After the 2022 landslide, an additional Deputy Commissioner ("Commissario delegato") responsible for protection and reconstruction activities related to landslides was assigned.

This study aims to support the island of Ischia in planning for the post-disaster recovery and reconstruction and to provide the necessary information to "build back better", taking future climate change into account. The purpose of this study is to identify activities to adapt to climate change, investment options and requirements for the technical designs for the reconstruction of the island of Ischia. The results shall inform the Ischia reconstruction strategy aimed at rebuilding and enhancing climate resilience of the affected areas, and aim to strengthen preparedness of the relevant authorities.

This assignment is part of a collaboration between the Special Commissioner for civil protection in Ischia and the European Investment Bank (EIB).

To achieve these objectives, the assignment included the following main tasks:

- the development of an assessment of key physical climate risks resulting from climate hazards on the island of Ischia over the medium term (up to 2050), with a particular focus on changes in rainfall and the associated risk of flooding and landslides;
- the formulation of recommendations for public sector adaptation investments and actions, and of adaptation and design recommendations to be integrated in the technical design of infrastructure investments foreseen in the island's reconstruction plan;
- the elaboration of a Climate Change Adaptation Investment plan, including selected adaptation options and cost estimates;
- the compilation of recommendations to strengthen project management capabilities, project planning and execution monitoring, as well as risk management.

For the identification of key climate hazards and their impacts, and the development of recommendations for adaptation activities, the assignment made use of the following sources of information:

- data, information and analyses compiled by the Struttura Comissariale;
- information material on assessments carried out by other Italian entities;
- climate model data of the most recent high-resolution climate science results, in accordance with relevant national climate adaptation strategies;
- fact-finding missions to visit relevant areas of the island of Ischia and collect local information;
- stakeholder consultation events, with the Struttura Comissariale and other relevant entities;
- literature on climate change impacts and climate adaptation in similar contexts;
- calculations and numerical simulations to improve the knowledge on climate hazards and their impacts, and to formulate and prioritize recommendations for adaptation activities.

Missions to collect local information and data were planned together with the main local stakeholder, the Struttura Comissariale, and included contacts with other relevant groups. The inclusion of stakeholders throughout the project execution aimed not only to ensure successful collection of local information, but also to facilitate an active involvement and positive uptake of the results of the assignment.

The presented report provides a summary of the collected data, the conducted analyses and the main results as the main deliverable for the EIB and the Struttura Comissariale. Part 1 of this report (Chapters 1 to 3) provides an island-wide climate risk and vulnerability assessment (CRVA) for the most relevant infrastructure and economic sectors, including the assessment of key physical climate risks and recommendation of climate adaptation activities. Part 2 (Chapters 4 to 6) focuses on economic and financial assessments, with a cost-benefit analysis and subsequent prioritization of adaptation activities and recommendations on strengthening the project management in the island of Ischia.

Even though there are numerous adaptation recommendations provided as a result of this assignment, the list is not to be considered exhaustive. Further studies to identify appropriate adaptation options for several areas at risk are recommended as part of the results of this assignment. This assignment also focused on the vulnerabilities where the Struttura Comissariale had not already planned reconstruction or adaptation activities (Piano commissariale di interventi urgenti per la sicurezza e la ricostruzione" (2023)). However, this report provides recommendations and design criteria that should be followed in the planning and design of those activities.

Historical and current climate conditions and events

Chapter 1 of this report provides an overview of the historical and current climate conditions and observed weather events. The climatic analysis is based on ERA5@2km, also known as VHR-REA_IT, which stands for Very High-Resolution ReAnalysis for Italy, developed by the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC). ERA5@2km is a dataset for historical climate conditions over the entire Italian territory, obtained through the combination of observed data and weather model simulations, available at a resolution of approximately 2 km for the period 1981-2020 with hourly resolution. The use of this high-resolution dataset in this work is expected to enable the capture of more localized climate characteristics and allows analyses of longer periods than covered by local station observations.

For the analysis of hydro-geo hazards, information on historical landslides events and existing landslide and flood risk zonation was collected and analysed.

Climate change projections for the island of Ischia

Chapter 2 of the report describes climate change projections provided by Regional Climate Models of the EURO-CORDEX program, with a spatial resolution of approximately 12 km. The analyses of these model projections are in accordance with analyses carried out for the Italian national adaptation plan (Piano Nazionale di Adattamento ai Cambiamenti Climatici, PNACC). For each of the three greenhouse gas emission scenarios considered (RCP2.6, very low emissions; RCP4.5, medium emissions; RCP8.5, very high emissions), 14 EURO-CORDEX climate simulations provided by different combinations of Global Climate Models (GCMs) and Regional Climate Models (RCMs) were used. Sea Level Rise data was obtained from Global Climate Models and a regional ocean model of the Mediterranean Sea (NEMO). As the time horizon for the projections, a period around 2050 was considered, as decided between EIB, the Struttura Comissariale and the climate experts of the Consultant consortium.

Climate model projections are subject to uncertainties, due to different assumed concentration scenarios, imperfect simulation of the climate system by the models, and the inherent complexity and non-linearity of the system. For this reason, especially in decision support, a strategy that uses different scenarios and an ensemble of climate models is preferred. This strategy, as applied with the EURO-CORDEX models, allows for the quantification of some of the sources of uncertainty associated with the models.

The most relevant climate change projections for the island of Ischia for the period around 2050 are summarized as follows:

Temperature

- The average temperature is projected to increase between 1° C (RCP2.6) and 1.8°C (RCP8.5).
- The number of summer days (T > 29.2°C) is projected to increase across all emissions scenarios, between 7 days (RCP2.6) and 14 days (RCP8.5).
- The number of tropical nights (minimum temperature > 20°C) is projected to increase across all emissions scenarios, between 21 days (RCP2.6) and 36 days (RCP8.5).

Precipitation

- No relevant changes are projected for average daily precipitation during wet days.

- Extreme precipitation (annual maximum 1-day precipitation) is projected to increase across all emissions scenarios, between 4 mm (RCP2.6) and 8 mm (RCP8.5).
- Dry spell duration (number of consecutive dry days) is projected to increase under both RCP4.5 (+3 days) and RCP8.5 (+2 days), with no change projected under RCP2.6.

Wind

- No relevant changes in extreme wind speed are projected (with a small decrease indicated under RCP8.5).

Hydro-geo hazards

- *Landslides:* Based on climate change projections of precipitation, the occurrence probability of landslides is projected to change between -15 % and +20 % under a future climate for 2040-2060, depending on the applied climate scenario. A more pronounced increase might be expected for very extreme events with a disastrous potential like the event in 2022.
- *Floods:* Extreme precipitation with return periods between 5 and 100 years is projected to increase between 5% and 25%, depending on the return period and the emission scenario. The small scale, precipitation-driven floods on Ischia are expected to show a similar increase in flood discharge. Numerical simulations of flood discharge based on increased storm precipitation will be carried out in follow-up scientific studies for the Struttura Comissariale.

Wildfire

- With the Fire Weather Index clearly increasing (with higher increases in higher-emission scenarios) the danger of wildfire is projected to increase under a future climate.

Sea level rise

- Regional ocean models indicate an increase of 0.19m and under RCP8.5 by 2050. Global model projections under RCP8.5 range between 0.17 m and 0.34 m increase, with ensemble mean values around 0.25/0.26 m. These latter values were adopted for further impact modelling.
- A literature review does not show a clear trend for future changes in storm surges in the Mediterranean Sea. Therefore, no change was assumed in impact analyses.

Based on the expected changes in different climate variables and related climate hazards, the severity of the change of the main climate hazards was evaluated and classified on a scale from 1 (small change) to 3 (large change). This classification is based on expert judgement and considers the extent of the projected future change, the uncertainty related with the projections and the natural variability for each of the climate hazards. For heat and coastal flooding, the hazard change was classified as 3 (large). For drought, wildfire, storm precipitation, river flooding and landslides, the change was classified as 2 (medium). The exposure of infrastructure assets and economic activities to these changing hazards was assessed in the sectoral vulnerability assessment.

Vulnerability assessment, potential climate impacts and possible adaptation activities

Chapter 3 of the report provides an assessment of potential climate impacts on the main economic sectors and activities on the island of Ischia, based on the climate change projections for relevant climate hazards. In combination with the specific climate sensitivities of the assets and operations of each sector, the climate vulnerability of each sector is assessed. Considering the main climate vulnerabilities, possible adaptation activities are identified and, where possible, the cost of the recommended adaptation activities is estimated.

Chapter 3 provides sectoral assessments for the key sectors of roads, buildings including the island hospital, ports and coastal infrastructure, water supply and wastewater, energy supply, tourism, agriculture and forestry and nature-based solutions. Cross-sectoral recommendations for the most effective adaptation activities related to hydro-geo hazards (landslides and floods) are provided, given they are perceived as the most dangerous climate hazards on Ischia. A further cross-sectoral section provides general design recommendations for a climate-resilient reconstruction. The key findings can be summarized as follows:

Cross-sectoral adaptation to hydro-geo hazards

- Landslides and floods are considered as the main climate hazards. Due to their characteristics and widespread occurrence, they have the potential to impact several infrastructures and economic sectors simultaneously.
- Structural adaptation activities can selectively reduce the hydro-geological risk.
- Non-structural adaptation activities, such as updated landslide and flood hazard mapping for improved spatial and landscape planning and an island-wide natural hazard monitoring and warning system, will improve the preparedness of the Island's society to respond to hydro-geological hazards.

Roads

- In general, roads in Ischia are suffering from the lack of continuous condition monitoring and maintenance. It is recommended to prepare systematic maintenance plans annually, using modern Road Asset Management System (RAMS). Well maintained roads are generally more resistant to climate hazards than roads having structural weaknesses and pavement defects.
- For many locations, especially for higher category roads, specific adaptation activities are proposed, based on findings from a field mission and information provided by the Struttura Comissariale and local stakeholders. These include, for example, landslide protection measures and improved drainage.
- A more detailed climate risk assessment for roads is recommended, and a methodology for such an assessment is provided. More detailed risk assessment, including field inventories, can provide baseline information for further climate change adaptation activities.

Buildings

- The most significant risks to buildings are related to landslides. Precise risk assessments are recommended to the identified risk areas to determine the specific local activities and to prioritize the recommended projects. For flood risk areas, more granular flooding studies are needed to assess the risk in detail and develop precise adaptation activities.
- Drought will induce wildfires that threaten densely populated areas. Vegetation control and enhanced supervision are recommended to reduce the risks of fires spreading to urban areas.
- Increasing temperatures will affect buildings and occupants. Passive adaptation activities such as sunshades can be utilized to reduce indoor heating load, but very likely air conditioning will also be needed to provide immediate cooling in periods of extreme heat. The Ischia hospital as a critical infrastructure is brought up as a potential adaptation priority.

Ports and coastal infrastructure

- Coastal submersion is expected to reach 1.26 meters above sea level during a 100-year return period storm surge in Ischia by 2050 and + 2.26 m when wave run-up is also considered (relevant for areas without coastal protection structures). Especially the Ischia port is already threatened by current water levels, with higher risk expected in the future. Urgent measures are required in Ischia Porto to increase the height of the eastern side quays.
- Coastal erosion is affecting Ischia especially on the south-western, western and north-western coasts of the island. Some touristic sites, roads and even the island heliport are being threatened by coastal erosion and adaptation recommendations for protection measures for the most severe locations have been provided.
- It is likely that several other coastal structures also need to be redesigned and improved to take into account the increasing water level. However, the inaccuracy of the digital elevation model did not allow this mapping within this assignment, and further studies are required.

Water supply and wastewater

- Currently, the water supply system relies on mainland sources, and a diversification of water sources would be an important long-term adaptation activity.
- Large parts of the island's water supply and sewerage network infrastructure are at high risk to landslides.

- Recommended priority adaptation activities for the water supply system are the implementation of redundant systems in high-risk areas and the preparation of emergency treatment systems; the resilience of the sewage system should be improved by transforming the mixed sewer system.

Energy supply

- Despite missing detailed maps of the electricity distribution network, the main climate risks for the transmission and distribution network, including substations and overhead cables, were identified as landslides, flooding, wildfire and sea level rise. For two substations, more detailed flood risk studies are recommended.
- Most of these risks are shared with the overall built environment, and the energy infrastructure would in general benefit from adaptation activities at district level. However, energy-specific adaptation activities have been identified, like underground cabling for the distribution network.
- As for the underground gas network, where present, it may be affected by a minimum level of risk related to landslides, wildfire and flooding.

Tourism

- Several of the touristic sites and resorts of Ischia have been identified vulnerable to rock falls, landslides, and coastal erosion. Several adaptation activity recommendations have been provided for these touristic sites and resorts.
- Climate hazard-related damages to infrastructure in Ischia also cause challenges for tourism due to longer travel times, safety problems and water quality issues. The recommended adaptation activities for other sectors therefore also provide improvements from the point of view of tourism.

Agriculture

- Grape production and wine quality might be reduced due to temperature increase and reduced water availability. Agricultural practices that support climate change adaptation are the use of heat and drought tolerant grape varieties, the use of shade nets or sunscreen materials, designing vineyards in a way to reduce exposure to sun and extreme heat, and soil management techniques for higher yield and conserving moisture like mulching.
- Drastic grape production reductions could be caused by diseases, such as flavescence dorée, due to higher humidity levels in the atmosphere during dry and warm periods. A continuous monitoring is recommended, as well as early warning systems.
- Soil erosion and damage to vineyard agriculture buildings and assets as well as to connecting roads can result from extreme precipitation events and precipitation induced landslides. Continuing vine cultivation in terraces as is the case on the island already is a good adaptation activity, in addition to accessing early warning systems.

Forestry and nature-based solutions

- Managing Mediterranean forests according to a management plan helps to mitigate landslide risk in the andic soils of Ischia.
- Mountain cliff forest vegetation requires management to control landslide initiation.

Design recommendations for reconstruction

- For all future hydraulic design, an increase of 5-25% of design rainfall assumptions based on observed rainfall (IDF curves) is recommended to account for higher precipitation intensities under climate change.
- Coastal protection structures require more detailed design studies for an updated design (based on metoceanic studies to determine wave characteristics and consider future sea level rise).
- For buildings, passive cooling measures are recommended to adapt to increasing temperatures. Active cooling systems, at least in critical infrastructure like hospitals, should be designed with consideration of temperature projections.

Further studies required to confirm major possible physical climate vulnerabilities

Several possibly major climate vulnerabilities were detected during the study, but they could not be confirmed due to the base data unavailability and the uncertainties in the high-level approach taken for the CRVA of the island:

- The electricity substation next to Ischia Porto is located at a relatively low level, but with the current data available it cannot be confirmed if the site is at risk from sea level rise. The same applies also for the other buildings in the area south and southwest from the Ischia seaport.
- The electricity station (cable connection to mainland) near the Ischia hospital is located near a flood risk area but the current modelling results cannot confirm if the site is at risk.
- The eastern part of Ischia port area is vulnerable to submersion, but the current accuracy of the digital elevation model does not allow to assess if the urban area around the port (south, southwest, west) is also vulnerable. The area in question also includes a large electricity substation.
- Separate studies are required to determine the required landslide and flood related adaptation activities for several areas at risk in Ischia. These areas include mostly houses, hotels, roads and other infrastructure.

A large portion of the recommended adaptation activities are at the level of detail where their costs and some details and schemes are included in this report, but many sites still require further assessments to clarify the risks and to determine the exact adaptation activities required. The studies recommended for more precise, often local level risk assessments and adaptation activity planning and design, should be performed with the highest priority to allow further identification of possible climate vulnerabilities and the detailed planning of recommended adaptation activities or other activities conducted by the Struttura Comissariale. Table 0.1 presents the recommended studies, and the prerequisite studies for recommended adaptation activities are presented in Chapter 6.1.

Table 0-1. Recommended further studies to provide information for more precise risk assessment and adaptation activity planning and design.

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Cost estimate [M€]
39	All	**Study**	Common	Digital elevation model	0,05 M€
41	All	**Study**	Common	Natural Hazard Event Cadastre, Inventory and Documentation	0,3 M€
36	All	**Study**	Flood	Flood model	0,25 M€
37	All	**Study**	Landslide	Landslide assessment	0,25 M€
40	All	**Study**	Sea level rise	Coastal model	0,2 M€
42	All	**Study**	Landslide	Feasibility studies for investments 4,5,6 (high risk landslide prone areas)	0,3 M€
43	All	**Study**	Common	Road inventory for condition and granular risk mapping. Should include the dimensions and traffic amounts of roads.	0,1 M€

Cost Benefit Analysis

The multi-hazard challenges of Ischia call for an integrated multi-disciplinary analysis of risks, drivers, and opportunities. Chapter 4 of this report presents a cost-benefit analysis (CBA) of the adaptation activities identified in the sectoral assessments. It should be noted that given the remit of the project the CBA was conducted primarily at the level of the individual identified adaptation activities, rather than for alternative packages of activities in which interaction effects on remaining risk levels would be accounted for. Lack of data precludes the latter option.

A diverse investment portfolio to improve the resilience of infrastructure and sectors against natural hazards will eventually only structurally reduce risks if sustainable use of land and water resources is systematically pursued. This means that in addition to protective measures, maintenance, monitoring, and warning systems, which are mentioned in this report, an overarching plan and supporting policy is necessary to ensure sustainable use of land and water resources. This can be partly realized via regulation and inspection, as is referred to sometimes in this report, but probably also needs intervention via economic drivers.

The summary in Chapter 4.3 provides results for the prioritized measures per infrastructure type or sector per group of adaptation activities. The costs mostly concern the cost of realizing an adaptation activity, as well as monitoring and maintenance over the lifetime of these protective facilities. Benefits consist of (1) reduced physical damage and associated repair cost, (2) reduced costs of (temporary) limited functionality (of a home, hotel, transport infrastructure), (3) reduced or avoided deterrence effects to tourism, and (4) reduced numbers of casualties and fatalities. Many of the measures seem to produce sufficient benefits to justify the investment and operational costs.

Even though results are shown by infrastructure type or sector, there is significant interaction and synergy between the measures within and between different areas of the island of Ischia. Such effects could be accounted for to a limited extent. An exception is the interaction between effects of heliport availability and limitations on hospital functionality (activities 20 and 25), which was accounted for.

Investment recommendations

The investment recommendations in this report focus on project schemes that are currently not being managed by the Struttura Comissariale. Generally, it can be stated that the measures currently managed by the Struttura Comissariale are able to mitigate the natural hazard risk both under current conditions and under conditions of climate change in case they are properly designed. Therefore, only few adaptation activities are presented for Casamicciola Terme in this report, but it is recommended to follow the proposed design criteria of Chapter 3.10 in the current projects.

The investment recommendations have been divided into two categories, short-term and medium/long-term investments, based on the score from the cost and benefit analysis and the criticality of the investment, based on expert judgement. Some of the recommended investments were not included in the cost benefit analysis due to lack of information or otherwise not being suitable for the CBA, as is the case for the further studies that are required to gain additional information for more precise adaptation activity planning and the vineyards pilot projects.

Where the selected CBA scoring (BCR) resulted in a value of less than 2, expert judgement has also been used to determine whether the adaptation activity investments should be included in the short term or medium/long term investments. Expert judgement has also been used in the cases where the CBA was not carried out for an adaptation activity recommendation.

It should be noted that some of the investments can be combined to provide synergies, but possible synergies have not been considered in this study. For example, a road investment could provide synergy for other associated infrastructure like sewerage systems, proximal slopes, or coastal protection.

Short-term investment recommendations

Short term investment recommendations with cost estimations are considered the most critical and beneficial for the island of Ischia based on the criticality assessment of each adaptation activity and the cost benefit analysis. More details on the short-term investment recommendations are presented in Chapter 6.1. Table 0-2 below presents the recommended short-term investments.

Table 0-2. Recommended adaptation activities for short term investments sorted according to the CBA BCR with the largest number having the highest priority.

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Cost estimate [M€]
21	Ischia	Buildings	Wildfire	Vegetation control to create a buffer zone next to populated areas of Ischia	0,50 M€
22	Barano d'Ischia	Buildings	Wildfire	Vegetation control to create a buffer zone next to populated areas	0,50 M€
29	Barano d'Ischia	Water	Common	Combine existing water supply network to a circular network	0,31 M€
32	All	Water	Flooding	Connecting the two main drinking water network lines into one circular network	0.31 M€
31	All	Water	Landslide	Rerouting drinking water pipelines from areas prone to landslides to areas with lower risk	3.78 M€
25	Casamicciola Terme	Buildings	Sea level	Coastal erosion protection for Island heliport. Island heliport structures are reportedly crumbling.	5 M€
24	Lacco Ameno	Tourism	Landslide	Negombo hot spring resort erosion protection	1,00 M€
18	Ischia	Ports	Sea level	Raise of the quay level in Ischia Porto with a protective concrete wall along the edge of the actual quays on the restaurants section, with wooden deck on top.	3,00 M€
23	Forio	Tourism	Landslide	Poseidon hot spring resort site erosion protection	1,67 M€
38	All	Common	Common	Natural Hazard Monitoring, Early Warning and Alarming system	2,8 M€
14	Casamicciola Terme	Roads	Landslide	Steel nets need to be replaced near the heliport, possible partially with retaining walls. Length 150m, height 15m. Hydraulic structures (drainage system) will be needed, if wall is chosen.	1 M€
15	Casamicciola Terme	Roads	Landslide	Steel nets need to be replaced, possible partially with retaining walls. Length 250m, height 10-15m. Hydraulic structures	1,5 M€
20	Casamicciola Terme	Buildings	Landslide	Several activities for the Ischia Hospital	6,50 M€
11	Ischia	Forestry	Landslide	Monte Vezzi forested area management	0,11 M€
12	Ischia, Barano d'Ischia	Forestry	Landslide	Cretao forested area management	0,14 M€
13	Casamicciola Terme, Barano d'Ischia	Forestry	Landslide	Casamicciola Terme Monte Epomeo forest management	0,41 M€
16	Casamicciola Terme	Water	Flooding	Drainage upgrading, mixed sewer into separate. Increased capacity for the storm water.	1,00 M€
26	Casamicciola Terme	Water	Flooding	Redesign of a collector drain in Casamicciola Terme	0.43 M€

30	All	Water	Flooding	Enlarging the stormwater drainage system crossing areas prone to floods by 50 mm	11,9 M€
33	All	Water	Landslide	Transforming mixed sewer system at high landslide risk into a separated sewer system	2.77 M€
34	All	Water	Landslide	Transforming mixed sewer system at medium landslide risk into a separated sewer system	1.45 M€
19	Forio	Roads	Sea level	Stabilization of the cliff in Forio against coastal erosion with retaining wall coupled with the installation of natural rocks breakwater at the toe of the wall	15,0 M€

Medium/long term investment recommendations

Medium/long term investment recommendations with cost estimations are considered less critical and/or beneficial for the island of Ischia based on the criticality assessment of each adaptation activity by the sectoral experts and the cost benefit analysis. In some cases, it was not possible to assess the criticality without further data; the investments were therefore listed in the medium/long term investments. More details on the medium/long term investment recommendations are presented in Chapter 6.2. Table 0-3**Errore. L'origine riferimento non è stata trovata.** below presents the recommended medium/long term investments.

Table 0-3. Medium / long term investments for Ischia Island climate resilience

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Cost estimate [M€]
4	Ischia	Common	Landslide	Various landslide and hydrology related works in the Monte Vezzi area. Cost estimation is based on the local data.	14,6 M€
5	Casamicciola Terme, Ischia, Barano d'Ischia	Common	Landslide	Various landslide and hydrology related works in the Cretaio area. Cost estimation is based on the approximate area cover compared to Vezzio investment estimation.	15 M€
6	Casamicciola Terme, Serrara Fontana, Forio	Common	Landslide	Various landslide and hydrology related works in the Forio area. Cost estimation is based on the approximate area cover compared to Vezzio investment estimation.	30 M€
28	Lacco Ameno	Energy	Flooding	Possible Lacco Ameno cable connection point flood protection	Not defined
27	Ischia	Energy	Sea level	Possible Ischia electricity substation flood protection	Not defined
3	Lacco Ameno	Roads	Landslide	Securing and consolidating the ridge overlooking via Cava Pannella	1,59 M€
7	Lacco Ameno	Tourism	Landslide	Safety and consolidation of the ridge overlooking Varulo beach	1,23 M€

1	Lacco Ameno	Tourism	Sea level	Completion of the safety and consolidation intervention on the eastern ridge of Montevico - northern ridge	2,00 M€
35	All	Water	Landslide	Transforming the mixed sewer system in areas with low or no landslide risks into a separated sewer system	5.53 M€
17	Forio	Roads	Landslide	Slope stability. Using Biotextile and steel nets in various location in the Forio mountain area.	0,50 M€
9	Barano d'Ischia	Tourism	Flooding	Extremely urgent works to make the ribs safe and restore the hydraulic functionality of the Alveo Cava Ponte/Nitrodi/Olmitello	6,08 M€
10	Barano d'Ischia	Tourism	Flooding	Extremely urgent works to restore the hydraulic functionality of the Cava Rosato/Cavone Martoccio riverbed	1,60 M€
8	Barano d'Ischia	Tourism	Landslide	Works to improve the safety of the Maronti beach ridges	4,47 M€

Recommendations to strengthen project management

During the assignment, the consultants had several meetings with the Ischia Struttura Commissariale team of different configurations. During the meetings, it was observed that the Struttura Commissariale team is highly skilled in structural engineering related (buildings) matters and is supported by the Università degli Studi di Napoli Federico II and the Università degli Studi del Sannio di Benevento for issues related to geology, hydrology, hydraulics, landslides, and nature-based solutions (forestry).

As this assessment has considered also other sectors outside the abovementioned ones, we recommend that the Struttura Commissariale team could be further strengthened with experts with knowledge on water supply and wastewater treatment, coastal structures and with transportation (roads, ports) and energy networks and with a technical climate adaptation expert.

The assignment team is aware of a Technical Assistance project, provided by the EIB, which already covers capacity issues related to procurement and tendering.

It is recommended that a small group of people, preferably a technical unit, would be set up to direct the climate risk adaptation related investments. The unit could work directly under the special commissioner and the surveillance of the deputy commissioner.

The abovementioned technical unit should create a roadmap for the investments based on their priority to enable to implementation of the climate investments. The team should also develop the objectives of a monitoring program and follow the progress of the implementation based on suitable indicators supporting the objectives.

Introduction and objectives

In November 2022, extreme rainfall hit the Italian island of Ischia. Torrential rain caused landslides and flooding. The island suffered several casualties and damage to its infrastructure. The Italian government declared a state of emergency for the area and approved funds for recovery and rescue operations.

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- the formulation of recommendations for public sector adaptation investments and actions, and of adaptation and design recommendations to be integrated in the technical design of infrastructure investments foreseen in the island's reconstruction plan, which will be tendered by the relevant authorities;
- the elaboration of a Climate Change Adaptation Investment plan, including selected adaptation options and cost estimates;
- the compilation of recommendations to strengthen project management capabilities, project planning and execution monitoring, as well as risk management.

For the identification of key climate hazards and their impacts, and the development of recommendations for adaptation activities, the assignment made use of the following sources of information:

- data, information and analyses compiled by the Struttura Comissariale;
- information material on assessments carried out by other Italian entities;
- climate model data of the most recent high-resolution climate science results, in accordance with relevant national climate adaptation strategies;
- fact-finding missions to visit relevant areas of the island of Ischia and collect local information;
- stakeholder consultation events, with the Struttura Comissariale and other relevant entities;
- literature on climate change impacts and climate adaptation in similar contexts;
- calculations and numerical simulations to improve the knowledge on climate hazards and their impacts, and to formulate and prioritize recommendations for adaptation activities.

Missions to collect local information and data, were planned together with the main local stakeholder, the Struttura Comissariale, but also included contacts with other relevant groups. The inclusion of stakeholders throughout the project execution aimed not only to ensure successful collection of local information, but also to facilitate an active involvement and positive uptake of the results of the assignment.

This report provides a summary of the collected data, the conducted analyses and the main results as the main deliverable for EIB and the Struttura Comissariale. Part 1 of this report provides an island-wide climate risk and vulnerability assessment for the most relevant infrastructure and economic sectors, including the assessment of key physical climate risks and recommendations for climate adaptation activities. Part 2 focuses on economic and financial assessments, with a cost-benefit analysis and subsequent prioritization of adaptation activities and finally recommendations on strengthening the project management in the island of Ischia.

Even though there are numerous adaptation recommendations provided as a result of this assignment, the list is not to be considered exhaustive. Further studies to identify appropriate adaptation options for several areas at risk are recommended as part of the results of this assignment. The GIS analysis maps presented in this report will also be provided as separate files for better assessment and further studies.

PART 1: Climate risk and vulnerability assessment of the island of Ischia

The first part of this report summarizes the results of the Climate Risk and Vulnerability Assessment (CRVA) for the island of Ischia. The analyses in this assessment follow the principles formulated in the EIB Group Climate Bank Roadmap 2021-2025[1] and the EIB Environmental and Social Standard 5[2]. With reference to the EU "Technical guidance on the climate proofing of infrastructure in the period 2021-2027"[3], the assessment at the scale of the entire island can be regarded as a vulnerability analysis. The formal approach to a climate vulnerability classification proposed by the EU Technical guidance in a screening phase is followed, with some sectoral analyses going into more detail, to allow more specific recommendations of adaptation activities.

The CRVA includes the following steps:

- **Climate analysis**, which includes both, an assessment of the historical and current climate for the baseline period of 1981-2020 ("around 1995"), and of climate projections for the of 2036-2065 period ("around 2050"). They are performed for the most relevant climate variables and climate hazards identified.
- These analyses allow an island-wide evaluation and classification of the expected **change in climate hazards** under future climate conditions.
- A sectoral assessment of the considered **key sectors** (Roads, buildings, ports and coastal infrastructure, water supply and wastewater, energy supply, tourism, agriculture, and forestry and nature-based solutions). The specific **exposure** of the most relevant assets and operations to key climate hazards, considering their location on the island, is evaluated, and categorized. In parallel, the climate **sensitivity** of each sector is analysed and ranked.
- The combination of the evaluation of exposure and sensitivity results in the identification and ranking of the key **climate vulnerabilities** for each sector.
- Based on the main climate vulnerabilities, more detailed risk assessments (where possible and required), analyses of past damages and review of existing plans for reconstruction and recovery, **climate adaptation activities** are recommended.

For the climate analyses, carried out by experts of the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), the consideration of baseline climate data is crucial to describe the current climate. They serve as a benchmark against which recent or current observations can be compared, including for providing a basis for many anomaly-based climate datasets and for projecting future change in climate. The baseline climate references the period of 1981-2010, which represents the most recent period we can consider when using CMIP5 climate scenarios. Climate projections are calculated as the difference between the temporal mean values of the selected indicator in the scenario period (decided to be 2036-2065) and in the historical period, by considering the IPCC scenarios selected.

The selected IPCC scenarios include:

- RCP2.6: A pathway where radiative forcing peaks at approximately 3 W m-2 and then declines to be limited at 2.6 W m-2 in 2100 (the corresponding Extended Concentration Pathway, or ECP, has constant emissions after 2100).
- RCP4.5: An intermediate stabilization pathway in which radiative forcing is limited at approximately 4.5 W m-2 in 2100 (the ECP has constant concentrations after 2150).
- RCP8.5: A high pathway which leads to >8.5 W m-2 in 2100 (the corresponding ECP has constant emissions after 2100 until 2150 and constant concentrations after 2250).

These scenarios include both very optimistic assumptions with regard to the reduction of greenhouse gas reduction (RCP2.6) and relatively pessimistic high-emission assumptions (RCP8.5). These three scenarios

[1] https://www.eib.org/en/publications/the-eib-group-climate-bank-roadmap
[2] https://consult.eib.org/consultation/essf-2021-en/user_uploads/standard_5.pdfw
[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.C_.2021.373.01.0001.01.ENG

are the same scenarios as considered at the national level in the National Climate Adaptation Plan ("Piano Nazionale di Adattamento ai Cambiamenti Climatici", PNACC), recently published at the time of writing this report.

Also, the selected climate variables have been chosen from a long-list of variables that are included in the PNACC, in consideration of the 'slow onset', chronic and acute, 'shock' climate-related hazards liable to cause the most material impacts on the assets and economic activities of the key sectors in Ischia. The considered climate variables, as listed in Table 0-3, were identified in discussion between the climate scientists of the Consultant consortium, EIB and the Struttura Comissariale.

Table 0-3: Selected climate indicators and variables

Indicator	Variable	Units	Definition
Temperature	Mean Temperature	°C	Mean of the daily mean temperature.
	Summer days	day	Number of days with daily maximum temperature greater than 29.2°C. This indicator has been defined for Italy (PNACC).
	Warm Spell Duration Index	day	Total number of days per period (annual or seasonal) in which the daily maximum temperature is greater than the 90th percentile of the daily maximum temperature in intervals of at least 6 consecutive days.
	Cooling Degree Days	DD	Sum of mean temperature minus 21°C if mean temperature greater than 24°C.
	Heating Degree Days	DD	Sum of 18°C minus daily mean temperature if daily mean temperature less than 15°C.
	Tropical Nights	day	Number of days with daily minimum temperature greater than 20°C.
Precipitation	Average Precipitation in Wet Days	mm	Daily precipitation sum in wet days (days with precipitation greater than or equal to 1 mm).
	Very Heavy Precipitation Days	day	Number of days with daily precipitation greater than or equal to 20 mm.
	Maximum 1-Day Precipitation	mm/day	Maximum 1-day precipitation amount.
	Consecutive Dry Days	day	Largest number of consecutive days with daily precipitation less than 1 mm.
Wind	Extreme Wind Speed	m/s	98th percentile of daily maximum wind speed.

The analysis of the climate variables and climate-related hazards was performed over an annual and seasonal timescale, including winter (DJF; December, January, February), summer, (JJA; June, July, August), spring (MAM; March, April, May) and autumn (SON; September, October, November).

In addition to these climatic indicators and variables, hazards triggered by weather events, like the hydro-geo hazards landslides and floods, but also wildfires, were considered. Oceanographic processes and their changes, like sea level rise, storm surges and wind and wave set-up, and the resulting coastal flooding, which are highly relevant for a small island like Ischia, were also analysed.

Sectoral assessments, including analyses of locations and status of the main relevant assets and operations, past damages to those assets and potential climate impacts, the sectoral climate vulnerabilities and recommended adaptation activities are provided for the following key sectors:

- Roads
- Buildings, including hospitals
- Ports and coastal infrastructure
- Water supply and wastewater

- Energy supply
- Tourism
- Agriculture
- Forestry and nature-based solutions

Analyses of the baseline climate are provided in Chapter 1 and climate change projections and their impacts on climate hazards are described in Chapter 2.

The sectoral vulnerability assessments and description of possible adaptation activities, including also cross-sectoral measures and cost-benefit analyses, are provided in Chapter 3 of this Part 1 of the Report.

1 Historical and current climate conditions and events

The following chapters provide an overview of the historical and current climate conditions and observed weather events. The analysis is based on ERA5@2km, also known as VHR-REA_IT, which stands for Very High-Resolution ReAnalysis for Italy (Raffa et al. 2021[4]). ERA5@2km is a simulation for recent climate conditions over the entire Italian territory, obtained through the dynamic downscaling of the global ERA5 reanalysis at a resolution of approximately 2 km for the period 1981-2020 with hourly resolution. The use of this dataset in this work is expected to enable the capture of more localized climate characteristics.

The use of climate reanalyses allows for a consistent description of the atmosphere's state since their data are constrained by observations (which are incorporated into the reanalysis through data assimilation techniques). This is used to compensate for the lack of local observed data for the atmospheric variables of interest. Furthermore, reanalyses provide gridded data on atmospheric information even in areas where observations are limited or unavailable. Unlike the PNACC, where the baseline was based on the gridded E-OBS dataset (with a resolution of about 9 km), the use of this higher-resolution reanalysis became necessary for Ischia due to the size of the area. Otherwise, it would not have been possible to reconstruct the baseline. Additionally, the available in-situ observations do not cover a period long enough to allow for a 30-year climate reconstruction. Nevertheless, to confirm the quality of the reanalysis used, a dedicated assessment of its performance was conducted by comparing the data with in-situ observations.

Furthermore, specific precipitation analysis was conducted based on the four local stations on the island of Ischia. Rainfall analyses related with the occurrence of landslides are described in Chapter 1.4.3. Existing analyses of extreme precipitation for short durations, as reported in the "Piano commissariale di interventi urgenti per la sicurezza e la ricostruzione" (2023), are decribed in Chapter 1.4.4. Detailed analyses of observed spatial precipitation patterns during extreme events are presented in Appendix 1. More detailed maps on the climate indicators below can be found in Appendix 2.

1.1 Temperature

1.1.1 Mean temperature

The annual average daily mean temperature across Ischia is 17°C. Areas that experience the greatest annual mean temperatures are located on the western, northern and eastern coastlines of the island (Figure 1-1). For example, the Campagnano area's annual daily mean temperature is 17.4°C and Forio's is 17.2°C, while the interior of the island experiences lower temperatures, for example the average mean temperature of Fontana is 16.2°C, which is the lowest recorded temperature on the island.

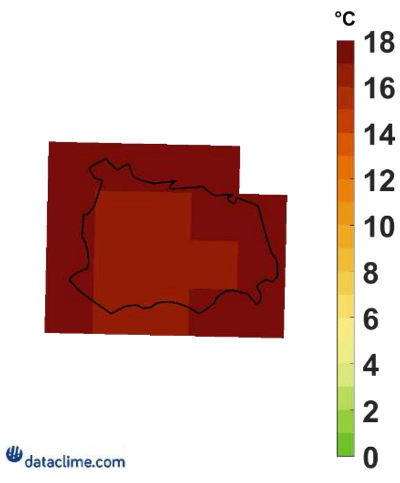


Figure 1-1: Mean Temperature across Ischia, using baseline climate data. Source: Dataclime

[4] Raffa, M.; Reder, A.; Marras, G.F.; Mancini, M.; Scipione, G.; Santini, M.; Mercogliano, P. VHR-REA_IT Dataset: Very High Resolution Dynamical Downscaling of ERA5 Reanalysis over Italy by COSMO-CLM. Data 2021, 6, 88. https://doi.org/10.3390/data6080088

During the year, the daily mean temperature ranges from an average low of 10.5°C in the winter, to a high of 24°C in the summer. During spring the mean temperature is 14.8°C and during autumn it is 18.7°C (Table 1-1).

Table 1-1: Baseline climate data for mean temperature (°C). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	17	10.5	14.8	24	18.7

1.1.2 Summer Days

The number of summer days in Ischia, which is the number of days per year when the daily maximum temperature exceeds 29.2°C, on average is 25. The area that experiences the greatest number of summer days a year is northeast of the island, in the area around Cretaio, where the number of days when the daily maximum temperature exceeds 29.2°C, is 66 (Figure 1-2).

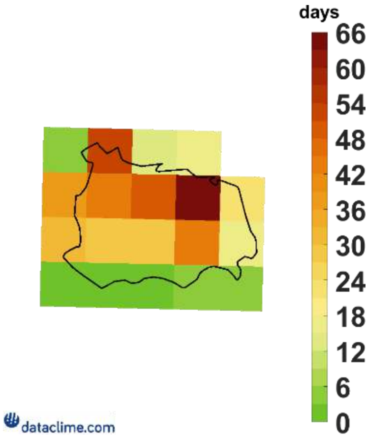


Figure 1-2: Summer Days across Ischia, using baseline climate data. Source: Dataclimte

The season that experiences the greatest number of summer days during the year is of course summer, where temperatures exceed 29.9°C for on average 23 days. During autumn they occur for 2 days, while daily maximum temperatures on average do not exceed 29.2°C during winter or spring (Table 1-2).

Table 1-2: Baseline climate data for Summer Days (days). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	25	0	0	23	2

1.1.3 Warm Spell Duration Index (WSDI)

The Warm Spell Duration Index represents the annual (or seasonal) count of days contributing to "warm spells", when the maximum temperature (TX) remains above its climatological 90th percentile. The 90th

percentile value is calculated over 5-day windows centred on each calendar day, so that the WSDI detects warm periods in the relative sense, which can happen in any season.

A relatively warm period must consist of at least 6 consecutive days above the threshold to be qualified as a "warm spell". The unit of measurement is [days]. In Ischia's past and current climate, warm spells occur for, on average, 5 days a year. Note that while each counted warm spell must at least include 6 days, the 30-year mean also includes years without warm spell, so that the mean value can be lower than 6 days. The area that experiences the greatest warm spell duration index is southeast of the island, in areas just south of Piano Liguori, where this occurs 6 days a year (Figure Figure 1-3).

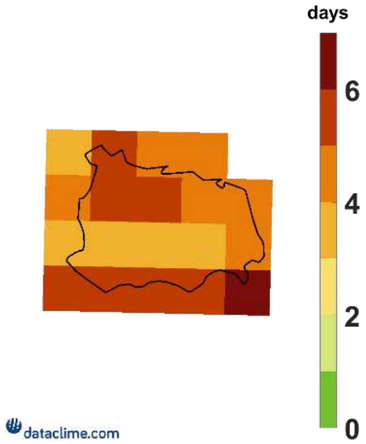


Figure 1-3. Warm Spell Duration Index across Ischia, using baseline climate data. Source: Dataclime

Over the year, the number of times when the daily maximum temperature is greater than the 90th percentile of the daily maximum temperature, in intervals of at least 6 consecutive days, occurs on average once during each season (*Table 1-3*).

Table 1-3. Baseline climate data for Warm Spell Duration Index (days). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	5	1	1	1	1

1.1.4 Cooling Degree Days

The annual average cooling degree days, which is the sum of the mean temperature minus 21°C if the mean temperature is greater than 24°C, is 262. Areas that experience the greatest cooling degree days are situated on the eastern, western and northern coastlines of the island. For example, areas north of Cretaio experience 349 cooling degree days, areas northwest of Lacco Ameno experience 341 and Forio 318 (Figure).

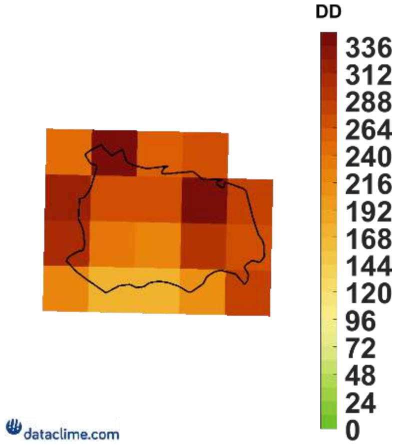


Figure 1-4. Cooling Degree Days across Ischia, using baseline climate data. Source: Dataclime

Over the year, the season that experiences the greatest cooling degree days is summer, with 240. During autumn the cooling degree days is 22, during spring 1 and it is 0 during the winter (Table 1-4).

Table 1-4. Baseline climate data for Cooling Degree Days (DD). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	262	0	1	240	22

1.1.5 Heating Degree Days

The annual average heating degree days, the sum of 18°C minus daily mean temperature if daily mean temperature is less than 15°C, is 1058. Across Ischia, areas that experience the greatest heating degree days are situated in the interior of the island, areas around Fontana and Majo experience 1277 and 1242 heating degree days, respectively (Figure 1-5).

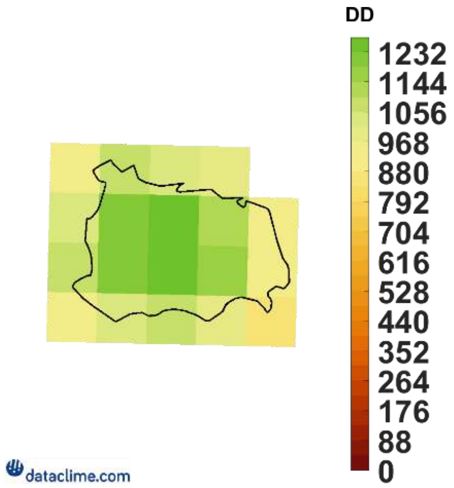


Figure 1-5: Heating Degree Days across Ischia, using baseline climate data. Source: Dataclime

Over the year, the season that experiences the greatest heating degree days is winter, with 674. During spring the Heating Degree Days is 286.8, during autumn it is 91.4 and it is 0 during the summer (Table 1-5).

Table 1-5: Baseline climate data for Heating Degree Days (DD). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	1058	674	287	0	91

1.1.6 Tropical Nights

The average number of tropical nights, which is the number days when the daily minimum temperature is greater than 20°C, occurs for on average 95 days a year. Across Ischia, areas that experience the greatest number of tropical nights a year are situated on the coastline of the island, while the interior experiences a lower number of tropical nights. For example, areas around Fontana experience 69 days, while areas south of Piano Liguori experience 119 days a year (Figure 1-6).

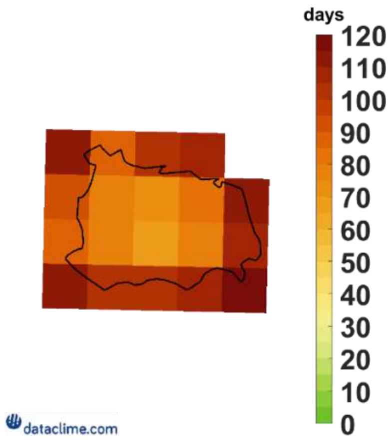


Figure 1-6: Tropical Nights across Ischia, using baseline climate data. Source: Dataclime

Over the year, the number of tropical nights is greatest during the summer, where it occurs for 71 days, and following this for 23 days during autumn. During spring this occurs for 1 day and there are on average no days when this occurs in winter (Table 1-6).

Table 1-6: Baseline climate data for Tropical Nights (days). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	95	0	1	71	23

1.2 Precipitation

1.2.1 Average Precipitation in Wet Days

The annual average precipitation sum in wet days, for days with precipitation greater than or equal to 1 mm, is 446 mm. Across Ischia, the northeast of the island experiences the greatest levels, while the southwest experiences lower levels. For example, the area around Cretaio receives around 468 mm, while areas southwest of Panza receive around 420 mm (Figure 1-7).

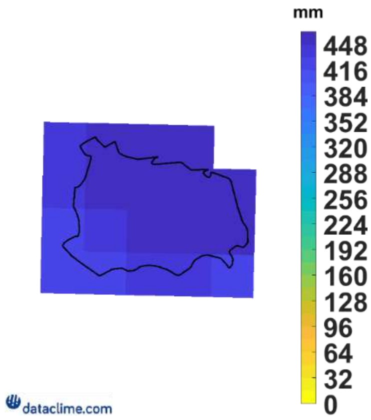


Figure 1-7: Average Precipitation in Wet Days across Ischia, using baseline climate data. Source: Dataclime

Over the year, winter experiences the greatest precipitation sum in wet days with a total of 168 mm. During autumn 146 mm is recorded, 109 mm is recorded during spring and during summer it's at its lowest at 24 mm (Table 1-7).

Table 1-7: Baseline climate data for Accumulated Precipitation in Wet Days (mm). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	446	168	109	24	146

1.2.2 Very Heavy Precipitation Days

The average number of days per year when daily precipitation is greater than or equal to 20mm is 4 days. Across the island, the number of very heavy precipitation days year is fairly uniform, at 4 days, except for one area located to the west of the island that records 3 days a year, which is just west of Cuotto (Figure 1-8).

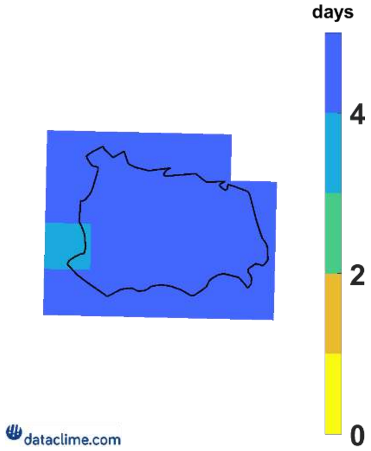


Figure 1-8: Very Heavy Precipitation Days across Ischia, using baseline climate data. Source: Dataclime

Over the year the number of very heavy precipitation days is highest in both autumn and winter at 2 days, and following this, during spring with 1 day. There is on average no days in summer when daily precipitation is greater than or equal to 20mm (Table 1-8).

Table 1-8: Baseline climate data for Very Heavy Precipitation Days (days). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	4	2	1	0	2

1.2.3 Maximum 1-Day Precipitation

The annual average maximum 1-day precipitation on Ischia is 46 mm/day. Across the island, maximum 1-day precipitation levels increase from 42 mm/day in the southwest of the island to 52 mm/day in the northeast (Figure 1-9).

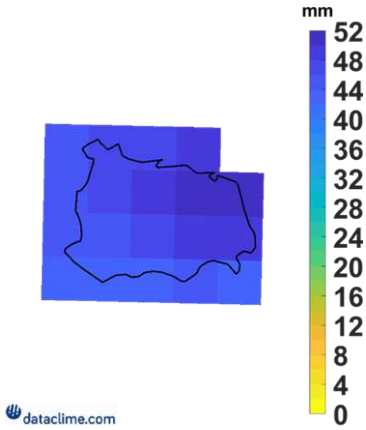


Figure 1-9. Maximum 1-Day Precipitation across Ischia, using baseline climate data. Source: Dataclime

Over the year, the season that experiences the greatest maximum 1-day precipitation is autumn with 37 mm/day and following this, winter with 30 mm/day. During spring it is on average 26 mm/day, and during summer 13 mm/day (Table 1-9).[5]

Table 1-9. Baseline climate data for Maximum 1-Day Precipitation (mm/day). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	46	30	26	13	37

Additional analyses of the spatial distribution of rainfall over the island of Ischia during selected extreme precipitation events, as shown in the ERA5@2km data, were performed. The objectives of these analyses were to evaluate the information provided in the reanalysis data against local station observations, but also to gain insight into spatial patterns of extreme rainfall over the island. These detailed analyses are described in Appendix 1.

1.2.4 Consecutive Dry Days

The number of consecutive dry days, when daily precipitation is less than 1mm, a year on average is 66 days. Across the island this number varies from around 62 days in the northwest (areas southwest of Lacco Ameno), to 67 and 69 days in the southeast and southwest of the island (Figure 1-10).

[5] During the November 2022 rainfall event, it is important to note that up to 155 mm of rain fell over the course of just six hours.

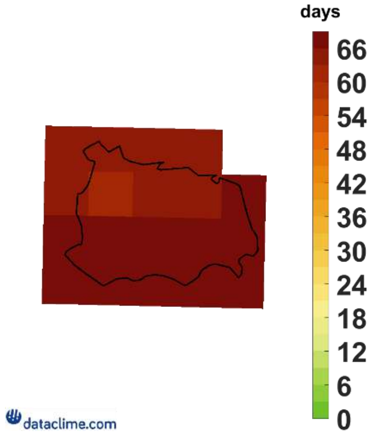


Figure 1-10: Consecutive Dry Days across Ischia, using baseline climate data. Source: Dataclime

Over the year the season that experiences the greatest number of consecutive dry days is summer, with 57 days. Following this, during autumn the number of consecutive dry days is 24 while in spring and winter this occurs for 21 days (Table 1-10).

Table 1-10: Baseline climate data for Consecutive dry days (days). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	66	21	21	57	24

1.3 Wind

1.3.1 Extreme Wind Speed

The annual extreme wind speed, that is the 98th percentile of the daily maximum wind speed, is on average 13 m/s. Across the island, extreme wind speeds are lower within the interior of the island, with extreme wind speeds reaching 10 m/s, while the south coast of the island experiences the greatest wind speeds, of up to 15 m/s (Figure 1-11).

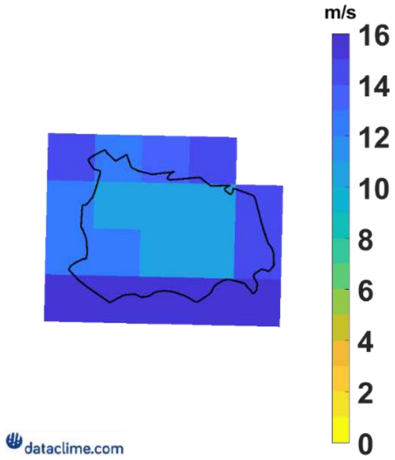


Figure 1-11: Extreme Wind Speed across Ischia, using baseline climate data. Source: Dataclime

Over the year, extreme wind speeds are greatest during winter, at 14 m/s, which is greater than the annual average value. During summer extreme wind speeds are at their lowest, at an average of 10 m/s and during spring and autumn extreme wind speeds are 13 m/s (Table 1-11).

Table 1-11: Baseline climate data for Extreme Wind Speed (m/s). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	13	14	13	10	13

1.4 Hydro-Geological Hazards

The island of Ischia is prone to hydro-geological hazards such as landslides, earth and debris flows, rockfalls and different types of floods. Especially the slope morphology, pyroclastic soils and potential extreme rain events focusing on winter, spring and especially autumn, make the island vulnerable to these types of natural hazards. To improve the readability of this report, gravitational mass flows such as landslides, earth and debris flows or rockfalls are summarized as landslides. However, in some specific chapters, rock falls are considered separately.

Drivers of hydro-geological hazards are slope morphology, lithology, land-use (changes), anthropogenic interventions, and extreme weather events. Ultimate triggers are rainfalls (extremes on different temporal scales), rapid snowmelt (especially in alpine regions) or earthquakes (Tichavsky et.al., 2019). Rainfall triggers both landslides and floods and can be linked to climate conditions and climate change, which is the focus in this report.

In general, long-lasting wet periods (i.e., antecedent rainfalls) and/or short-term intense rainfall induce slope failures (Tichavsky et.al., 2019 and references therein). In case of pyroclastic soils, as on the island of Ischia, it depends on the soil cover (shallow or not) and grain size whether antecedent conditions or short-term extreme rainfalls trigger slope instabilities (Uzielli et. al., 2018 and references therein). Especially the disaster on November 26th 2022 was triggered by a very extreme daily rainfall event (De Falco et. al., 2023 and Romeo et. al., 2023), which was then connected to climate change in public discussions. It needs to be mentioned that most landslides occur in combination with flood events, meaning that both are triggered by heavy rainfall events.

The following chapter:

1. gives a general overview of geomorphology, geology, and seismicity which is a base driver for geological hazards;
2. lists reported events in the context of hydro-geological hazards;
3. provides an island-wide overview of landslide hazard zones;
4. provides an island-wide overview of flood hazard zones.

1.4.1 Geomorphology, Geology and Seismicity

Geomorphologically, the island's structural high is Mount Epomeo (789 masl), which is a tectonic horst with a steep northern to northwestern mountainside and a flatter southern mountainside. There are also smaller peaks on the island, such as Mount Vezzi (394 masl) at the southeastern part of the island as well as Mount Rotaro (307 masl). The coastline, especially in the south of the Island, features steep cliffs.

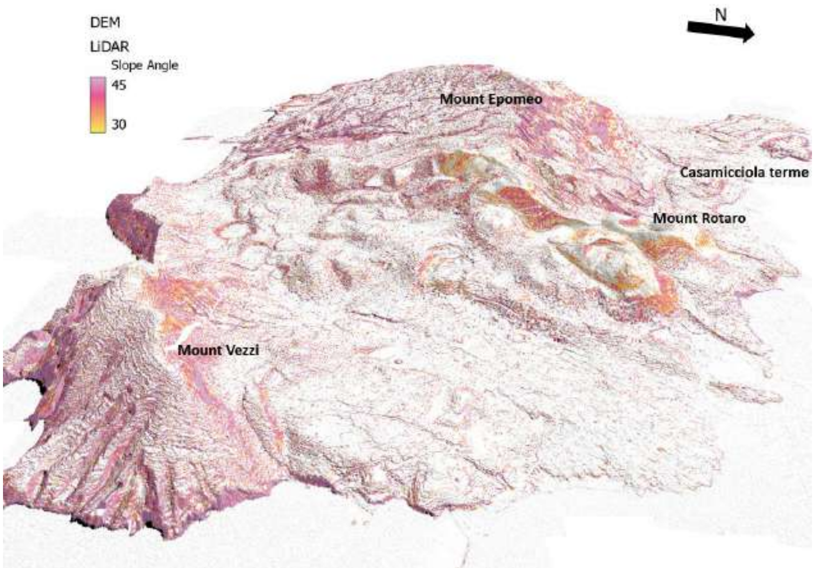


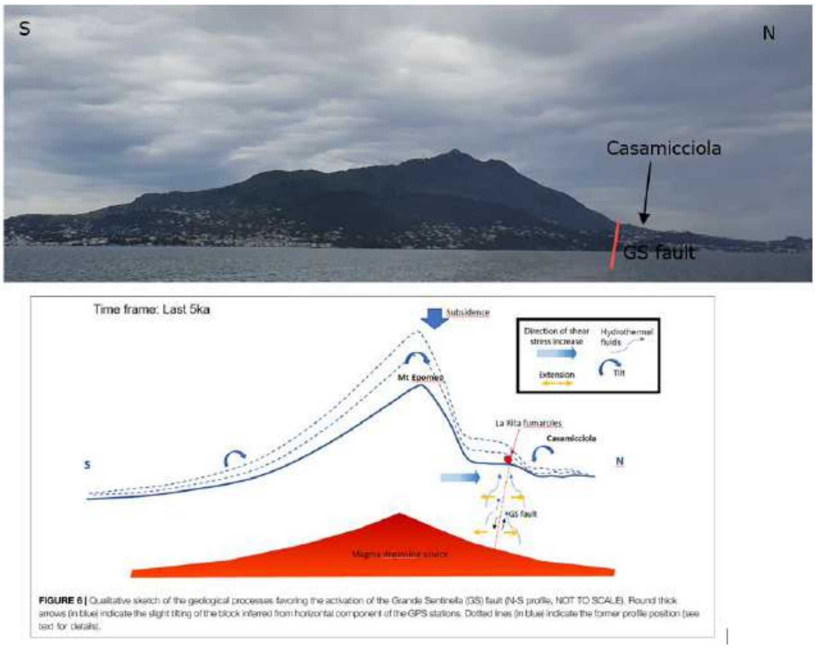
Figure 1-12: 3D-view of Ischia with visualized slopes above 30°, Vertical Scale x 1,5

Geologically, the island is dominated by Mount Epomeo green tuff, and different pyro- and epiclastic rocks of varying grain sizes ranging from ash to bombs and lavatic rocks. The mountain sides, especially around Mount Epomeo, are covered by loose material and pyroclastic soils (Carta Geologica, 2011). Especially, the Mount Epomeo green tuffs favor slope instabilities.

The green tuff generally has a relatively high connected porosity, meaning water can easily infiltrate this lithology applying pore pressure and destabilizing of the rock mass. The Mount Epomeo green tuff also contains swellable clay minerals of the smectite group, which is a weathering product of basaltic rocks (D'Antonio et al, 2021[6]). These clay minerals increase their volume when they come in touch with water, adding to the pore pressure which is one of the drivers of landslides on a microscopical level.

Figure 1-13: Mount Epomeo green Tuff (date of photo: 05/10/2023).

The volcanism originates from and along steep faults, which define and from volcanic blocks (Carlino et al, 2022[7]). According to Carlino et al. 2022, the subsidence of the island since the last 5.000 years – a gravitational sinking – happens along the same geological faults, which are activated in the process, creating shear stress along them and eventually, causing earthquakes (Figure 1-14). This is especially the case in the northern part of the island around Casamicciola Terme along the Grande Sentinella (GS) fault. The authors also determine a slight tilt of the Mount Epomeo block towards north, creating further shear stress on the GS fault.



[6] D'Antonio, Massimo, Arienzo, Ilenia, Brown, Richard J., Petrosino, Paola, Pelullo, Carlo, Giaccio, Biagio. (2021) "Petrography and Mineral Chemistry of Monte Epomeo Green Tuff, Ischia Island, South Italy: Constraints for Identification of the Y-7 Tephrostratigraphic Marker in Distal Sequences of the Central Mediterranean." Minerals 11(9):955

[7] Carlino Stefano, Alessandro Sbrana, Nicola Alessandro Pino, Paola Marianelli, Giuseppe Pasquini, Prospero De Martino and Vincenzo De Novellis. (2022): "The Volcano-Tectonics of the Northern Sector of Ischia Island Caldera (Southern Italy): Resurgence, Subsidence and Earthquakes." Front. Earth Sci., Sec. Volcanology, 10, https://doi.org/10.3389/feart.2022.730023

Figure 1-14: Top: Photo of Ischia from a ferry. Bottom: Latest volcanic and seismic phase of the island in a section from South to North, directly through Casamicciola (Carlino et al, 2022)

1.4.2 Reported events in the context of hydro-geological hazards

In recent years, several natural disasters have been reported in Ischia. On August 21st, 2017, an earthquake with rather moderate magnitude of M_W 3.9 – M_d 4.0 caused two fatalities, 42 injuries, and extensive damage to the Casamicciola Terme town and its surroundings, with 2500 displaced people (De Falco et. al., 2023[8], De Novellis et. al., 2018[9]). Furthermore, three severe landslide events have occurred in Casamicciola Terme within the last about 20 years: On April 30th, 2006, a landslide with one fatality occurred near Mount Vezzi (De Vita et. al., 2007[10]). Also, on November 10th, 2009 (Santo et. al., 2012[11]) and on November 26th, 2022 (De Falco et. al., 2023 and Romeo et. al., 2023[12]) heavy rainfalls triggered flash floods, debris flows and flow-like landslides resulting in a total of 13 fatalities (De Falco et. al., 2023).

During the first fact finding mission (3rd – 5th May, 2023), the Consultant had the opportunity to visit the area which was heavily affected by a disastrous event on November 26th 2022. This site visit gave important insights into the ongoing mechanism and characteristics of extreme landslide events in Ischia. In Appendix 3, the appraisal during and shortly after the site visit is documented in detail. However, in the meanwhile two scientific papers (De Falco et. al., 2023 and Romeo et. al., 2023) have been published, drawing a more detailed, yet similar picture of the event.

In addition to the three well-documented events mentioned above, scientific databases contain additional information on about 910 landslides registered in the past. The databases of historical landslide events were screened. A merge of the ITALICA (Peruccacci et al. ,2023[13]), CAFLAG (Esposito and Matano, 2023[14]), IFFI (Italian Landslide Inventory by ISPRA, 2023[15]) and LaICa (Fusco et. al. 2023[16]) datasets identified 910 landslides from 1828 to 2022 on the island of Ischia (Figure 1-15). The different datasets contain information on location, date, landslide characteristics (e.g., movement type, friction angle, triggers) and damage. Unfortunately, this information is not consistently available. For instance, the exact date of occurrence is not always available within the datasets. Yet, this information is very important to relate landslides to rainfall events. Furthermore, information regarding intensities (runout, energy, volume or velocities) is very sparse or not available. However, based on the events documented in detail, it is possible to identify three qualitative impact categories (moderate, severe, extreme). In the absence of information on intensities, the focus is on **serious landslides** which are defined as follows:

- it is assumed that events with reported exact dates were serious events, which need to be considered in the landslide risk assessment for the island;
- direct or indirect impact on the population;
- have the potential to cause damage to infrastructure or to hurt/kill people;
- independent of the intensities (e.g., even a landslide with small intensity can cause impacts);
- All types: complex, debris or earth flows, rock falls and shallow landslides.

For the period 2002 – 2022, 20 events are listed with exact dates, of which 19 have been triggered by rainfall and one was triggered by an earthquake (see Figure 1-15 and Table 1-12). No deep-seated landslides, although they exist on the island, have been reported. As far as possible, the selected landslides

[8] De Falco Melania, Giovanni Forte, Ermanno Marino, Luigi Massaro & Antonio Santo (2023): UAV and field survey observations on the November 26th 2022 Celario flowslide, Ischia Island (Southern Italy), Journal of Maps 19(1), DOI: 10.1080/17445647.2023.2261484
[9] De Novellis, V., Carlino, S., Castaldo, R., Tramelli, A., De Luca, C., Pino, N. A., et al. (2018). The 21 August 2017 Ischia (Italy) earthquake source model inferred from seismological, GPS, and DInSAR measurements. Geophysical Research Letters 45, 2193-2202. https://doi.org/10.1002/2017GL076336
[10] De Vita et. al., (2007): Engineering geological model of the initial landslides occurred on the April 30th, 2006, at the Mount Vezzi (Ischia Island, Italy), Italian Journal of Engineering Geology and Environment (2), 119-141. https://doi.org/10.4408/IJEGE.2007-02.O-08
[11] Santo et. al., (2012): The Ischia island flash flood of November 2009 (Italy): Phenomenon analysis and flood hazard, Physics and Chemistry of the Earth 49,3-17. https://doi.org/10.1016/j.pce.2011.12.004
[12] Romeo et. al., (2023): Investigation and preliminary assessment of the Casamicciola landslide in the island of Ischia (Italy) on November 26, 2022. Landslides 20, 1265-1276. https://doi.org/10.1007/s10346-023-02064-0
[13] Peruccacci et al. (2023): ITALICA, an extensive and accurate spatio-temporal catalogue of rainfall-induced landslides in Italy. Earth System Science Data 15, 2863-2023. https://doi.org/10.5194/essd-15-2863-2023
[14] Esposito, G. and Matano, F. (2023): A geodatabase of historical landslide events occurring in the highly urbanized volcanic area of Campi Flegrei, Italy. Earth System Science Data 15, 1133-1149. https://doi.org/10.5194/essd-15-1133-2023
[15] https://www.isprambiente.gov.it/en/projects/soil-and-territory/iffi-project
[16] Fusco, F., Tufano, R., De Vita, P. et. al. (2023): A revised landslide inventory of the Campania region (Italy). Scientific Data 10, 355. https://doi.org/10.1038/s41597-023-02155-6

were validated by Internet research and scientific papers. Thus, in the observation period of 21 years the historical occurrence probability of a **serious** landslide was 90 % within one year.

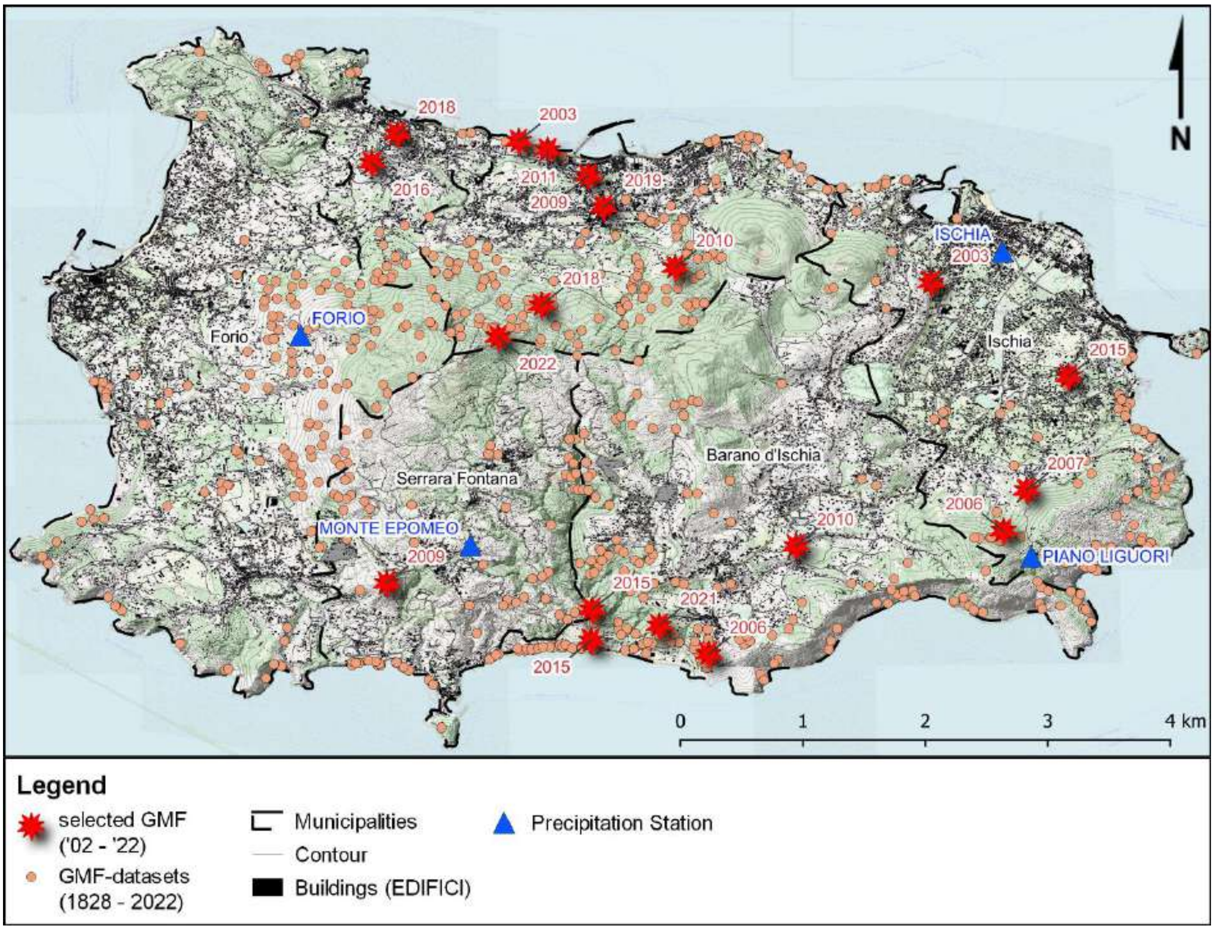


Figure 1-15 Island of Ischia: Overview of historic Gravitational Mass Flows (GMFs) and rainfall stations.

Table 1-12 Selected serious GMFs (2002 – 2022) with additional information (date, rainfall at and 59 days prior the event).

Date			**Rainfall @ Monte Epomeo**		**Date**			**Rainfall @ Monte Epomeo**	
year	**month**	**day**	**day of event [mm/d]**	**59 days prior event [mm/59d]**	**year**	**month**	**day**	**day of event [mm/d]**	**59 days prior event [mm/59d]**
2003	2	4	9.8	315	2015	2	22	44	388
2003	9	9	29.2	53	2015	2	25	19.6	447
2006	4	30	32.8	95	2015	2	26	19.6	456
2006	7	7	32.2	47	2016	10	9	5.2	263
2007	10	6	71	101	2018	2	20	9	154
2009	1	14	14	389	2018	2	24	18.8	216
2009	11	10	44	311	2019	11	25	19.6	420
2010	6	21	3.4	103	2021	12	11	7.6	409
2010	9	25	32.2	54	2022	11	26	145.4	199
2011	3	5	39.8	220					

1.4.3 Landslides

The following Geographical Information System (GIS) approach was applied to identify areas that are exposed to landslides on an island-wide scale (1:35,000):

1. Identification of geomorphologic homogenic zones based on slope information (derived from a high-resolution digital elevation model (Comm. Strutt., 2023) and a geological map.
2. Analysis of historic landslide cadastre and identification of hotspots based on heat maps.
3. Analysis of existing landslide hazard and risk map (i.e., ISPRA-map) based on (1) and (2)

The geomorphologic analysis leads to 11 geomorphological zones (GMZ). The zones are homogeneous areas regarding possible spatial extent (starting zone, travel path and runout area) of landslides. A qualitative estimation of landslide susceptibility was based on expert judgement (1 … moderate, 2 … medium, 3 … high and 4 … very high). Figure 1-16 shows the 11 zones. Naturally, GMZ with steeper terrain fall within a higher susceptibility category.

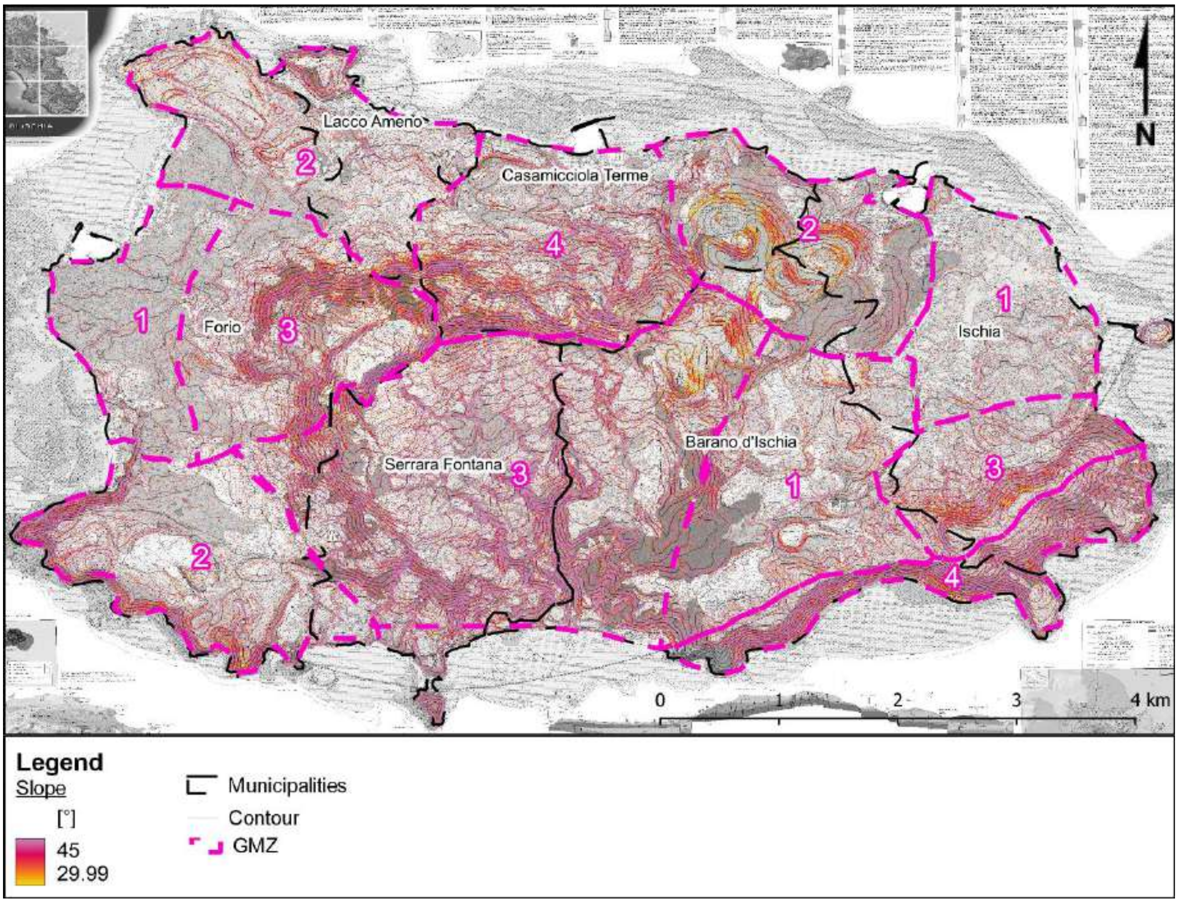


Figure 1-16 Island of Ischia: Geo-Morphologic Analysis leads to 11 geomorphological zones (GMZ).

Figure 1-17 visualizes the landslide cadaster described in chapter 1.4.2. Table 1-13 shows the landslides per municipality. Several hot spots exist: Casamicciola Terme and Barano d'Ischia are the municipalities with the highest landslide occurrence. Especially, Casamicciola Terme shows the largest number of landslides per km² and selected severe landslides. Also, the southern part (coastal part) is a center of landslides. Forio showed many landslides in the past, but no severe landslides in the recent years. Additional information from the ISPRA source reveals that most landslides in Forio are deep-seated landslides.

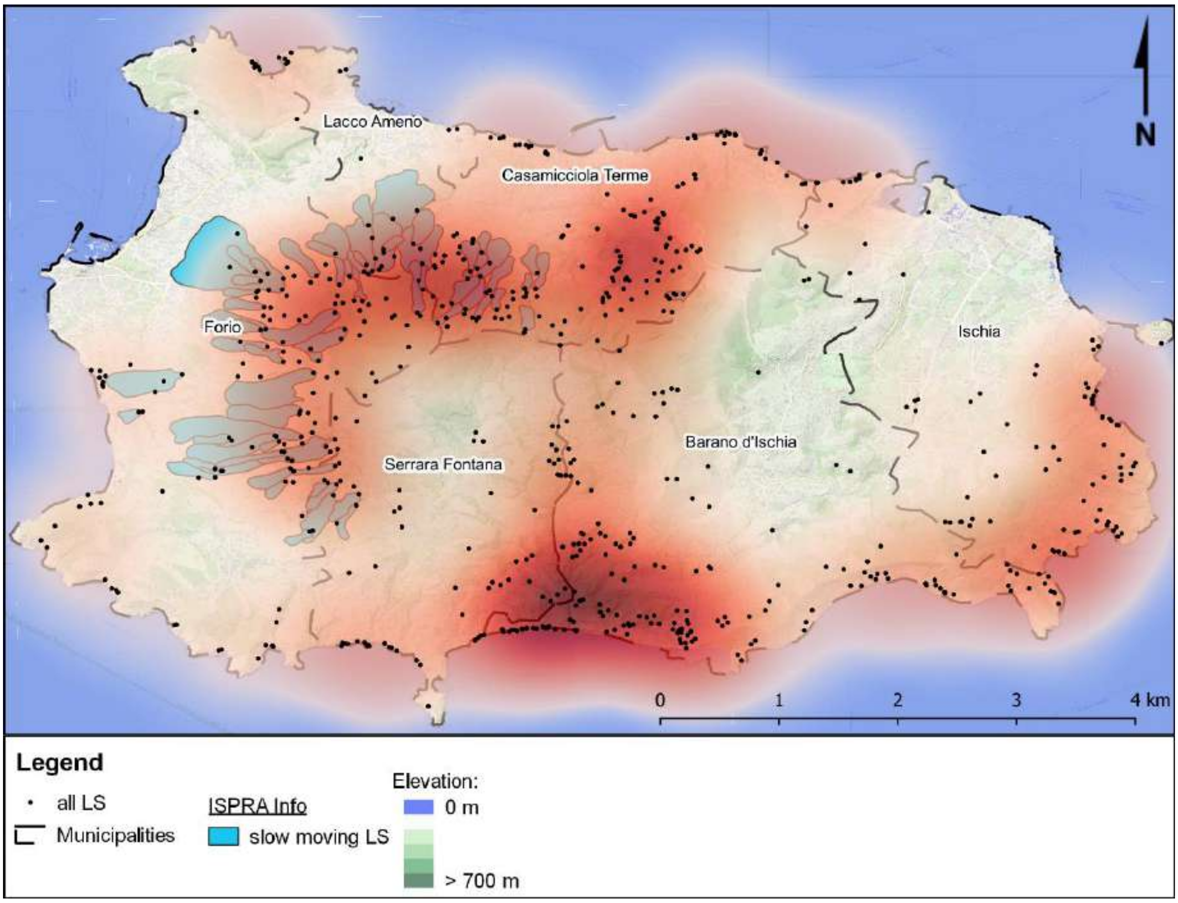


Figure 1-17 Island of Ischia: Heatmap of historic landslide densities. The red color identifies areas with increased landslide activity.

Table 1-13: Observed landslide events per municipality for different periods.

Municipality	total events (1828 - 2022)	events per km² (1828 – 2022)	serious landslides* (2002 - 2022)
Forio	196	15	0
Ischia	117	14	4
Lacco Ameno	38	18	3
Casamicciola Terme	214	37	7
Barano d'Ischia	233	21	4
Serrara Fontana	112	17	2

* Serious landslides are defined in chapter 1.4.2

Figure 1-18 shows the ISPRA landslide hazard zones, which are publicly available. The ISPRA map is a dataset providing categorized hazard zones (P1 … moderate, P2 … medium, P3 … high and P4 … very high). The discretization is rather course and the preparation and method of the delineation of these zones is unknown. Furthermore, a closer look on the map revealed that there are some weaknesses in the categorization. For instance, the northern slope of Mount Epomeo and the southern slope of Mount Vezzi have the same hazard zone category (compare Figure 1-19 left panel). Yet, energy potential in comparison is higher at Mount Epomeo due to higher altitudes and a longer steep sloping surface. Slopes at the southern part of Mount Epomeo shows lower hazard category (flatter slopes and terrasses). Another example is shown in Figure 1-19 - right panel: The spatial extent of the GMF event from November 26th, 2022 fits in general into the ISPRA hazard zones. However, the main GMF event cuts through a nonhazardous white area, which is surrounded by hazard zones from all sides. This is a gap in the ISPRA hazard map. This shows the importance of constantly updating, verifying and calibrating the hazard maps with new events. However, major runouts of landslides seem to be captured by the hazard map. The map shows hazard zones around the island's steep mountain sides and is considered as suitable for a scale of 1:35000.

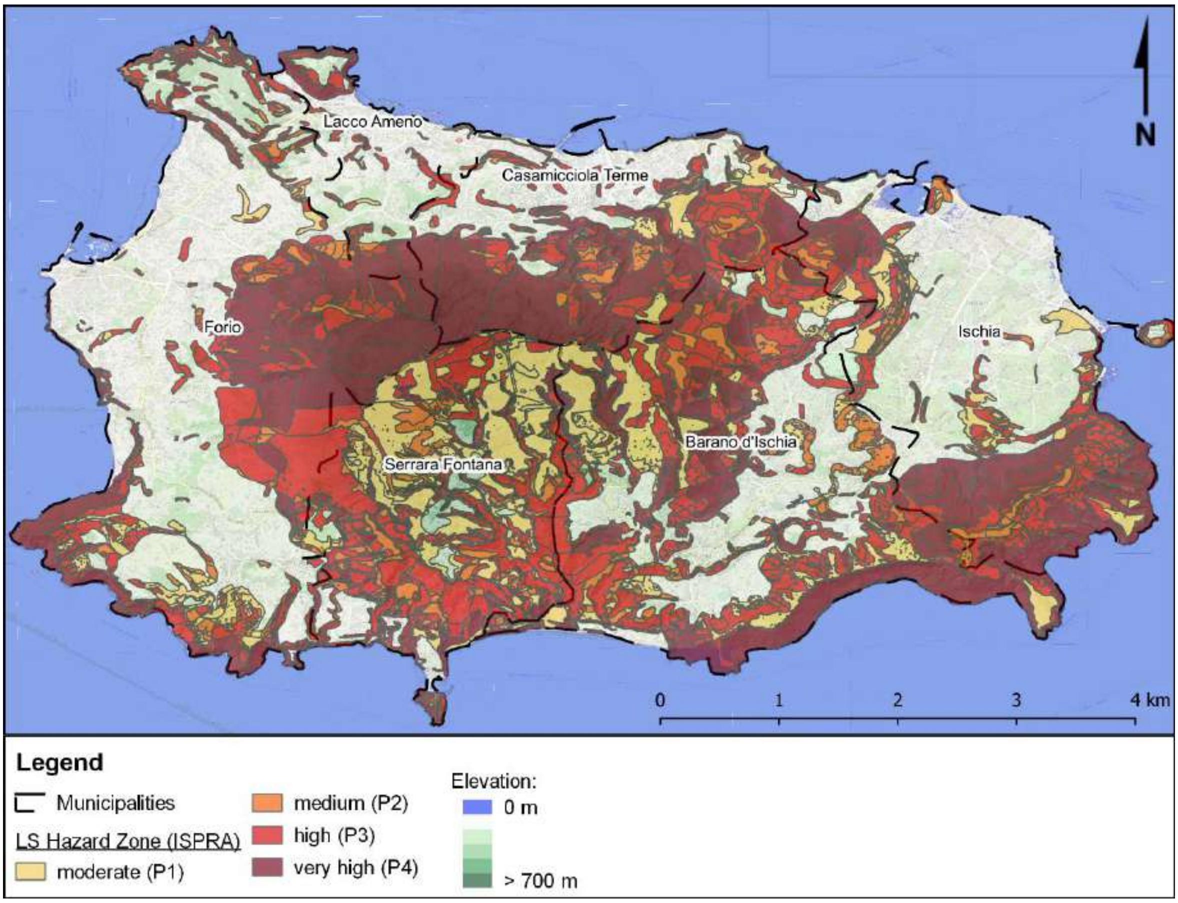


Figure 1-18 Island of Ischia: Existing landslide hazard map (source: ISPRA).

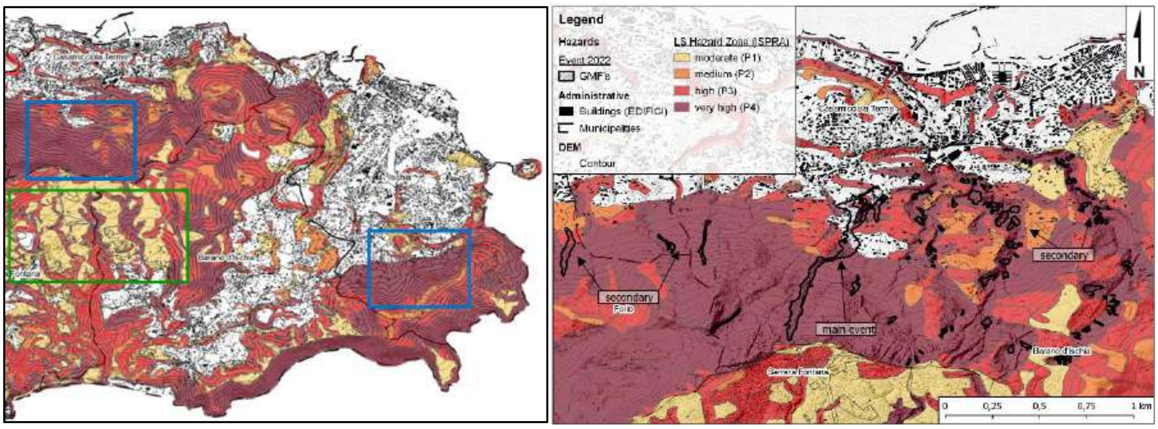


Figure 1-19 Examples for weak points of the existing landslide hazard map (source: ISPRA).

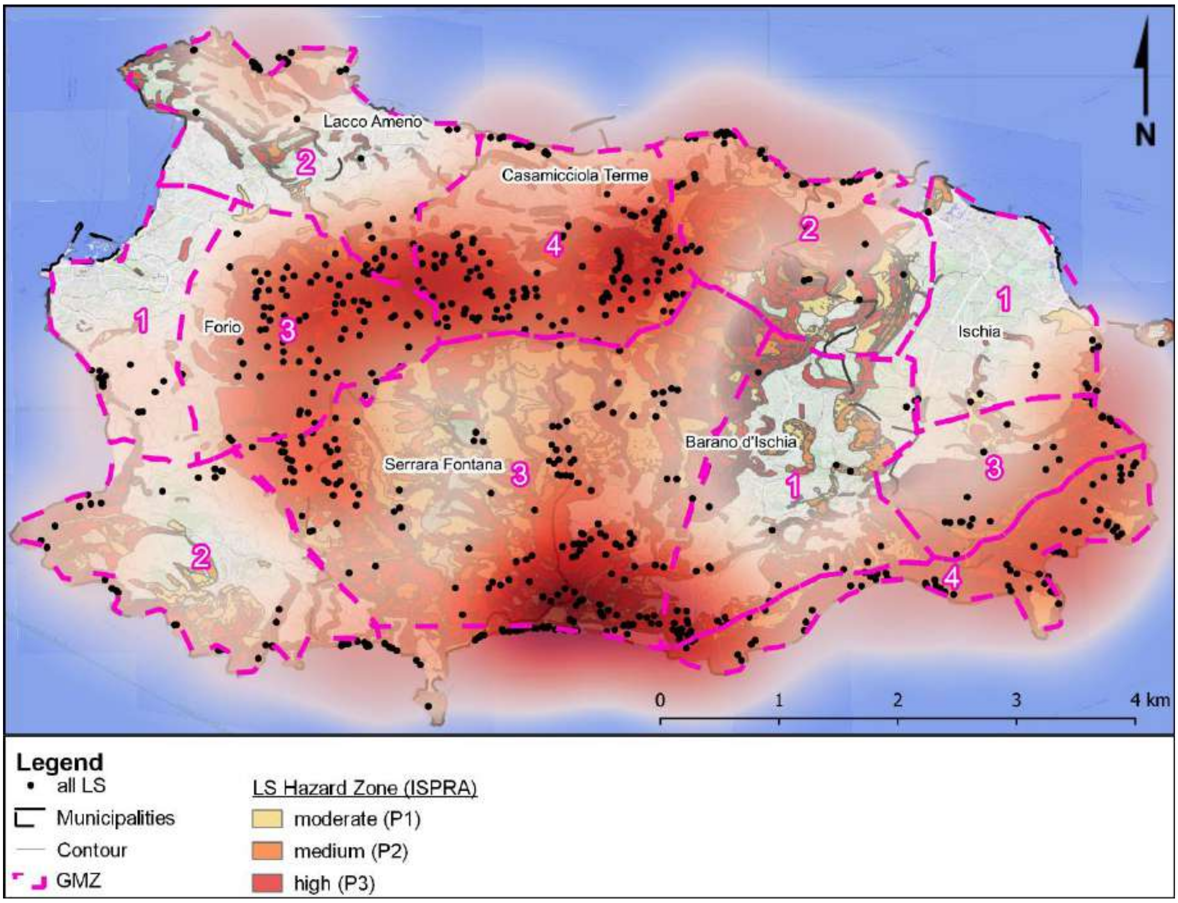


Figure 1-20 Island of Ischia: Overlay of existing landslide hazard map (source: ISPRA), identified geo-morphologic zones and historic landslide events.

In summary:

- ISPRA Hazard Map shows a good match (1) with the Heatmap of historic landslides and (2) with the geo-morphologic zones and the qualitative susceptibility index (compare Figure 1-20);
- Steep areas are categorized as high/very high hazard zones;
- Runout zones of landslides seem to be captured by the ISPRA map;
- Yet, the ISPRA-map shows some shortcomings: Energy potential at northern slopes of Monte Epomeo (Casamicciola) might be higher compared to other regions. White areas surrounded by hazard zones near Cretaio have less landslide density (less probability)

In the subsequent sections, the landslide risk for each sector will be obtained based on the created high-level landslide hazard map and its damage potential.

1.4.4 Floods

The main type of floods observed on Ischia are:

- Flash floods: triggered by extreme rainfalls with short duration leading to high water and debris flows in smaller catchments along trench and creeks;
- Pluvial floods: excessive rain leads to inundated flat areas that cannot absorb the rainwater or hillside water flows;
- Urban floods: excessive rain leads to an overtopping of urban drainage systems that cannot absorb the water;
- Coastal floods: storm surge and high winds force water ashore or sea level rise.

Developing a detailed **flood hazard map** including areas prone to flooding is a challenging task, which requires a detailed hydraulic simulation of the study area. However, for a first estimation of the areas at risk from flooding, a simpler, but also effective, method is available. In this study the estimation is based on a topographic analysis of the island which identifies areas due to their height above the nearest drainage or stream. Results are compared with data from the ISPRA-Portal which also provides a flood hazard map for the island.

The map in Figure 1-21 shows areas of flood risk on Ischia according to the ISPRA dataset. Areas along main river reaches as well as topographic depressions seem to be correctly identified and plausible. However, areas along the steep trenches in the highly elevated centre of the island and some circle shapes are not comprehensible as the topography does not allow an accumulation or lingering of water in these locations. The dots might indicate historic events but there is no additional information regarding their origin nor does these areas correspond to the actual areas of impact. Also, it seems that a few areas were not identified at all, especially in the lower parts of Ischia and Forio municipalities. Given the available information, it is not clear if this map was the result of a simulation, a manual classification, or some algorithm and on which data it is based. Thus, this information can only be used with reservation. Furthermore, no information on return periods for the identified flooded areas exists.

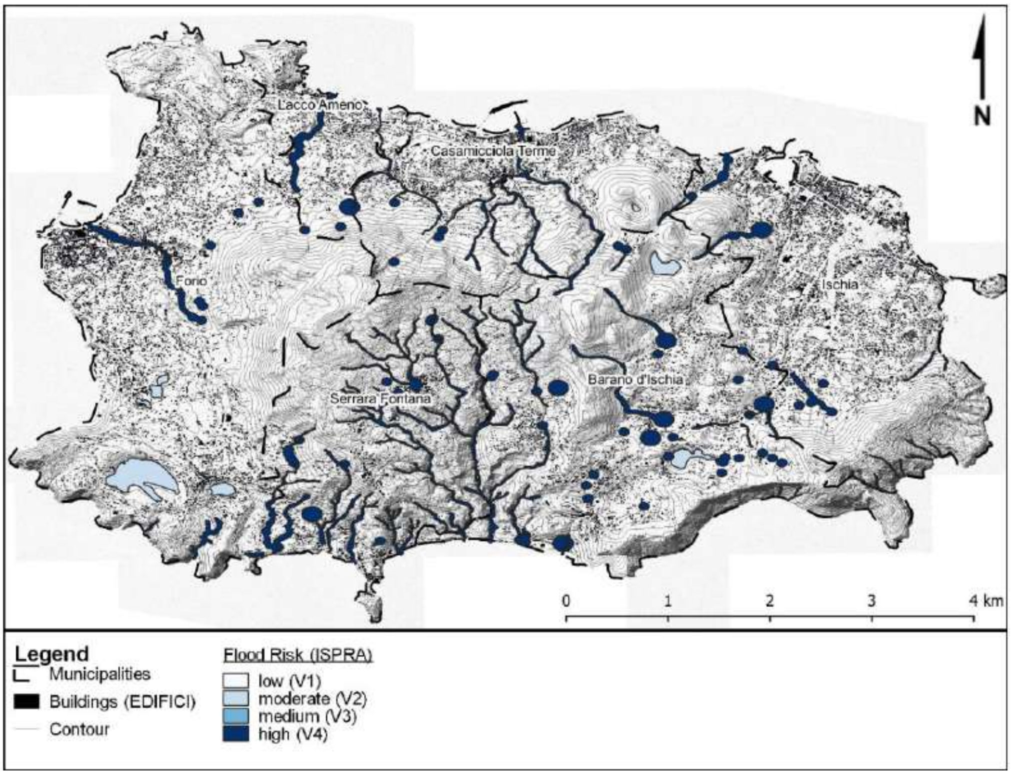


Figure 1-21 Areas at risk of flooding on Ischia according to the ISPRA flood hazard dataset.

At this stage, the approach to determine a preliminary flood-hazard map is based on a very rough topographic analysis. This analysis serves as a plausibility check of the ISPRA dataset and, in a second step, is combined with the ISPRA map. Figure 1-22 shows the result of the topographic analysis, which shows all areas that have a height above the nearest drainage (HAND) of equal or lower four meters. This means, that the map highlights areas that are 0 to 4 meters above the riverbed, which is a rough assumption of water levels during floods, based on expert judgement rather than hydraulic simulations.

It must be noted that this value is conservative and would have to be verified or refined by hydraulic flood simulations. However, in detail, the map is based on the high-resolution digital elevation model (DEM) derived from a laser scan. Based on this dataset, a GIS-algorithm calculated the flow accumulation, the flow directions, and the river network for the island. Based on these results a topographic analysis was conducted where for each drainage point along the river network the vertical distance to every pixel within the corresponding drainage area is calculated. A threshold of 0.5 km² for the minimum catchment area is set to ensure that considered areas can accumulate enough water for significant flooding.

Areas identified as being 0 to 4 meters above the riverbed seem to be consistent with the ISPRA dataset. In comparison to Figure 1-21 this approach does identify the same depressions, areas along larger streams and additional significant areas of flooding in the lower parts of Ischia and Forio. Furthermore, in case the ISPRA map identifies a flooded area, this area is a conservative estimate. However, no information regarding urban drainage or sewage systems were available at this stage and were therefore not considered when creating the map.

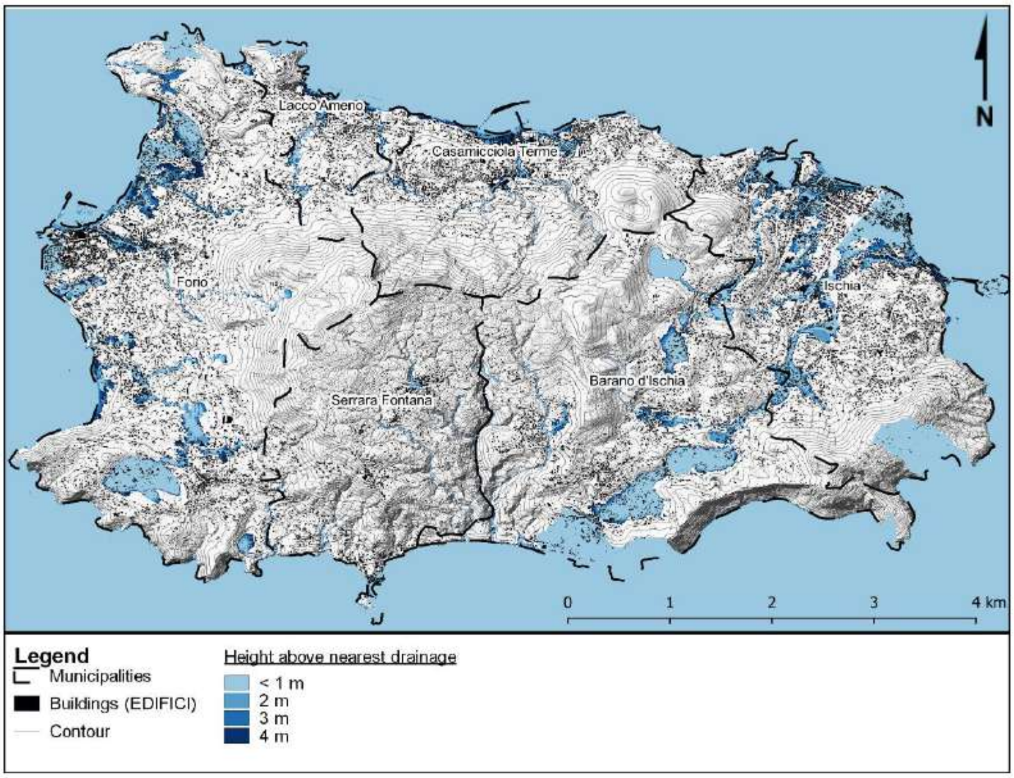


Figure 1-22 Height above nearest drainage. Highlighted areas were identified as more likely to be flooded due to their difference in elevation in relation to the nearest drainage point. Considered for the analysis were only drainage points with a catchment area greater than 0.5 km².

Figure 1-23 shows the high-level flood hazard map, which is a combination of the ISPRA map and the topographic analysis. In detail, (1) the circular polygons have been erased from the ISPRA-dataset and (2) the remaining dataset was merged with a modified HAND-dataset. The HAND-dataset was modified in a way, that areas prone to coastal floods have been erased and the water line of the 4 meters limit was polygonised.

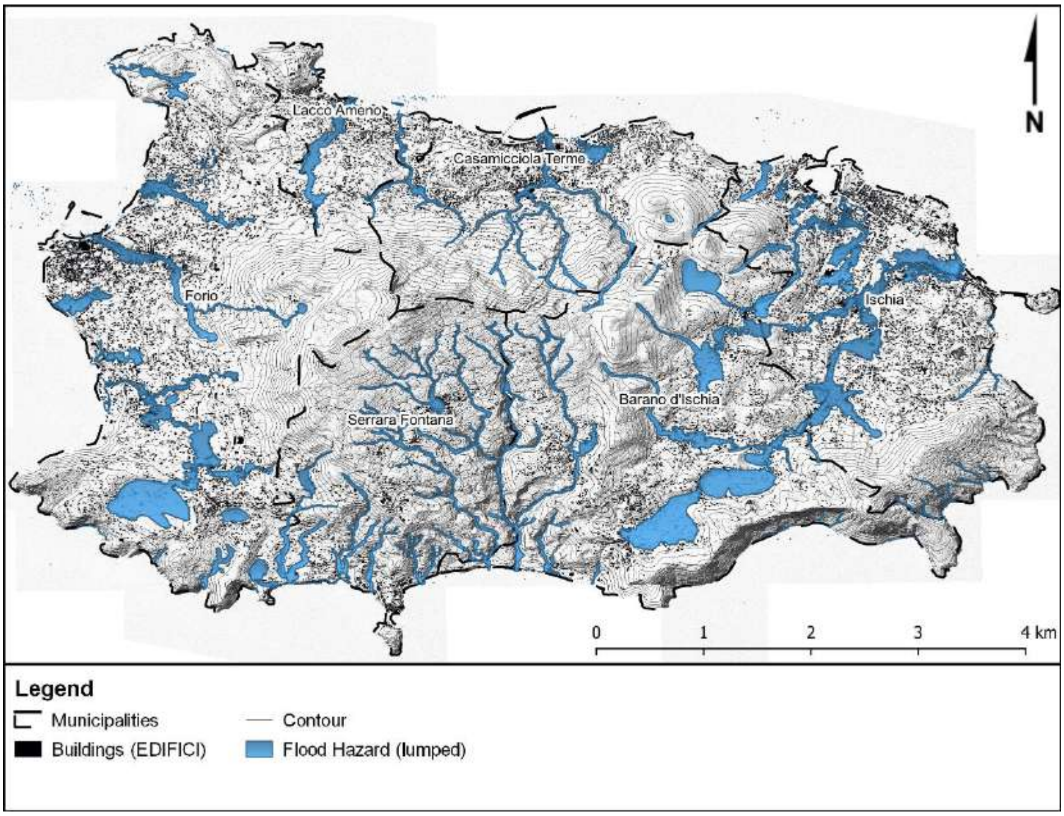


Figure 1-23 High-level flood hazard map of the island of Ischia. Combination of the ISPRA-flood risk map and height above nearest drainage analysis

One of the reasons for the high uncertainty in flood risk estimates for the island of Ischia is the specific topography, with many smaller creeks and ephemeral streams, but no larger rivers. Due to this disperse drainage network, no discharge observations are available, and the flood discharges related with extreme rainfall events are unknown.

After the November 2022 extreme event, a rainfall-runoff model was set up for two streams in Casamicciola Terme by the team of Prof. Domenico Pianese of the Department of Civil, Building and Environmental Engineering of the University of Naples Federico II. Their simulations are described in the "Piano commissariale di interventi urgenti per la sicurezza e la ricostruzione" (2023). Coupled hydrological and hydraulic models were set up for the catchment areas of two stream, as shown in Figure 1-24. These models were applied to simulate flood discharges generated by rainfall events of different return periods.

Figure 1-24. Catchment areas on the northern slopes of Monte Epomeo (dark blue streams) and channels draining through Casamicciopla Terme (light blue streams) considered in the hydrological and hydraulic models (view towards Casmicciola Terme from north towards south, source: Piano commissariale di interventi urgenti per la sicurezza e la ricostruzione, 2023)

For the definition of the rainfall input, extreme rainfall intensities at short time scales of a few hours were analysed in detail, and Intensity-Duration-Frequency (IDF) curves for the island of Ischia were derived. New IDF curves based on most recent local station observations were established and compared with previously calculated regional IDF curves. Figure 1-25 shows the comparison of the observations of November 26 at the four Ischia stations with the new IDF curves. The measurements for shorter durations were in the range of 20 to 100 years return periods, the longer durations of 5 to 12 hours were related with even higher return periods of up to 500 years, especially at Forio. It should be noted, however, that the observation record of around 20 years is very short for a reliable estimation of return periods, so that substantial uncertainty on the return period of the observations of November 26 remains.

The IDF curves were used to generate design rainfall input with different return periods, and the related design floods were modelled in the rainfall-runoff hydrological and hydraulic models. Figure 1-26 presents the simulation results, for one event and one of the modelled streams (Via Cava to the sea, on the right side in the above picture in Figure 1-24).

The described existing rainfall-runoff models for the northern slopes of Monte Epomeo and Casamicciola Terme will be used for the assessment of flood discharge under climate change. For this assessment, extreme precipitation IDF curves under climate change were developed based on climate model data, as described in Chapter 2.4.2.

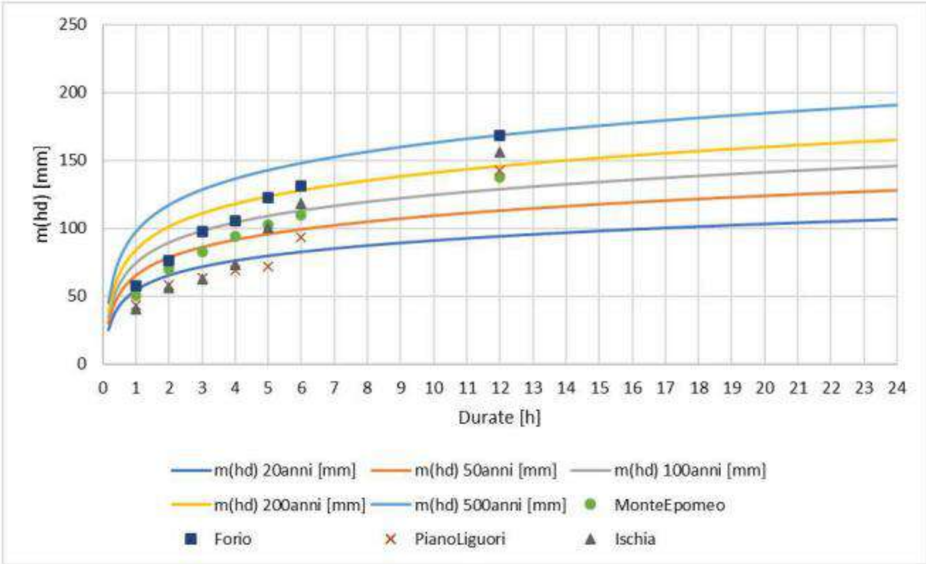


Figure 1-25 Comparison of the regional IDF curves for the island of Ischia with different return periods with the maximum rainfall for the November 26 event (source: Piano commissariale di interventi urgenti per la sicurezza e la ricostruzione, 2023)

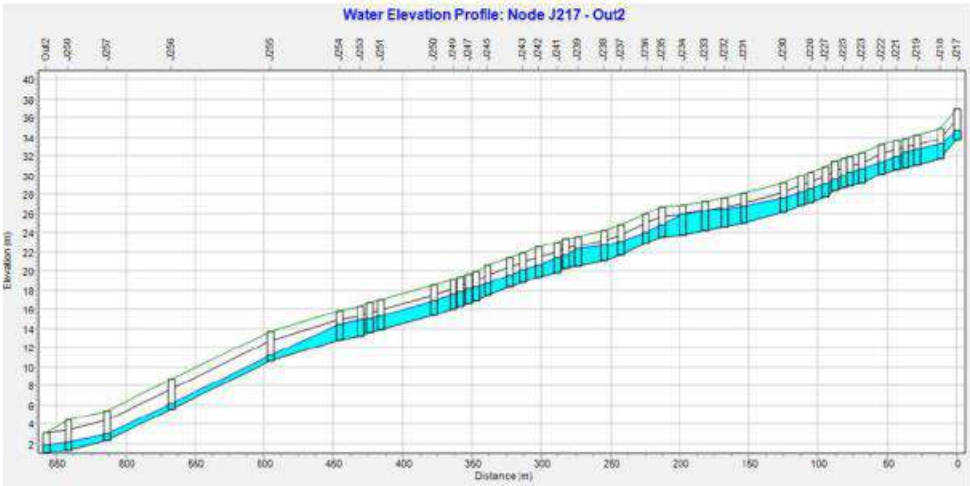


Figure 1-26 Longitudinal section of the water elevation during a 100-year flood event in the modelled stream of Via Cava to the sea, with a design discharge of 46 m³/s (source: Piano commissariale di interventi urgenti per la sicurezza e la ricostruzione, 2023)

In summary:

- The identified flood risk areas in the ISPRA flood risk maps are considered rather conservative. Yet, no information on return periods nor the methods used was available.
- The topographic analysis leading to the HAND-dataset is a simplified method to obtain potential flood areas. The manual adjustment and the union with the modified ISPRA-flood map leads to a high-level flood hazard map, as presented in this chapter.
- Coastal flooding is not considered in these maps, but is analysed and discussed in Chapter 1.6
- For two streams in Casamicciola Terme that were affected by flood flows in November 2022, rainfall-runoff model simulations are available that allow an estimation of flood discharges after extreme precipitation events.
- Further flood studies are required to increase the information on flood discharges and improve the level of confidence of flood risk maps. For instance, flow velocities and actual water heights (both indicators of intensities) cannot be considered by this high-level analysis.

- The high-level flood hazard map (i.e. at a scale of 1:35,000, shown in Figure 1-23) can be used to generally identify flood prone areas and can be used in the sector analysis.

1.5 Wildfires

The hills of Ischia are mostly forested, especially on the northern side. The EFFIS-database (https://effis.jrc.ec.europa.eu) shows that during the last years, some wildfires have been observed (Figure 1-27). Interestingly, all reported wildfires are from 2021 and 2022, while the database itself starts in 2008. However, the database might lack data since the wildfire signs shown in Figure 1-28 are not part of the database. Regardless of this, wildfires are an issue in the island and could be enforced by climate change.

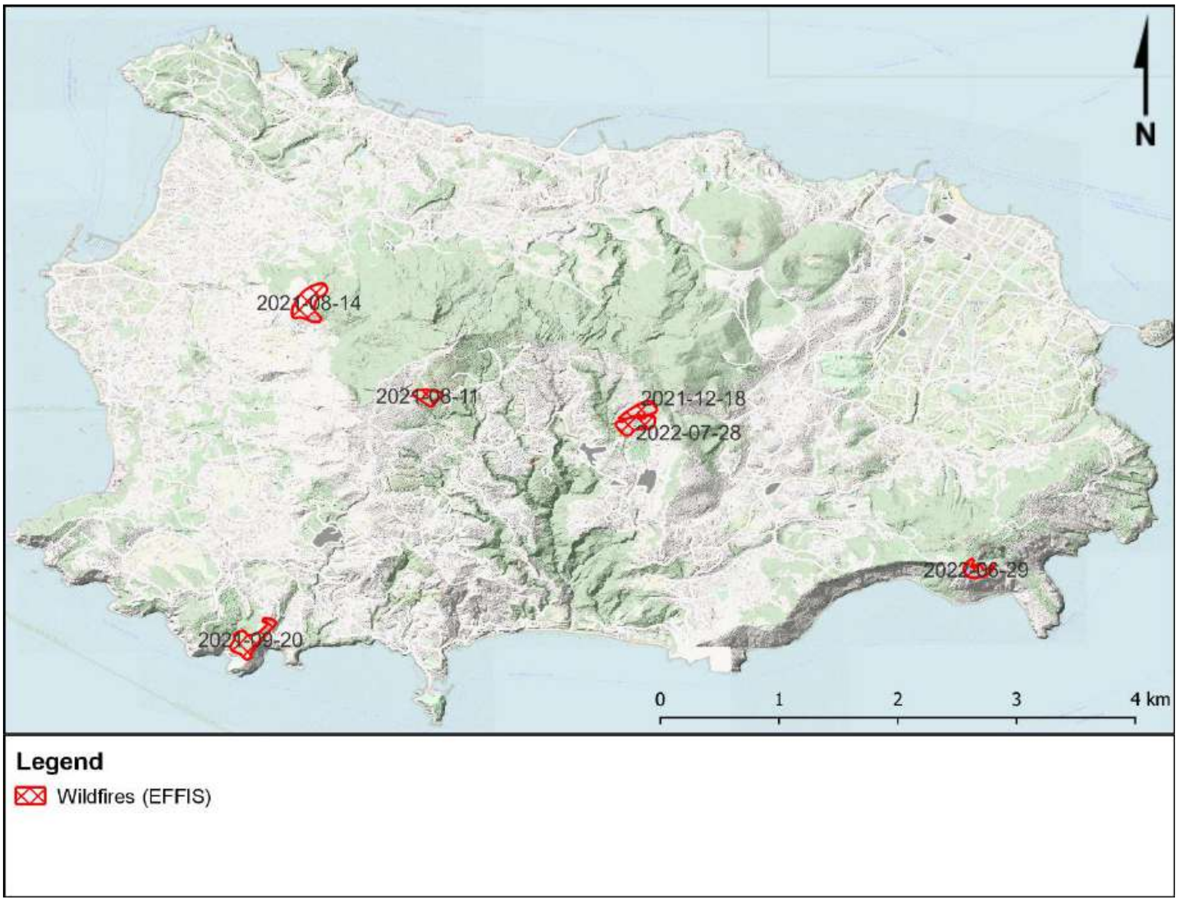


Figure 1-27 Overview of wildfires based on the EFFIS database (2008 – 2022).

Figure 1-28 Observed signs of a wildfire that occurred in 2022. The picture was taken during the scope finding mission (3rd – 5th May, 2023) from the bus station in Ischia viewing towards hill Montagnone.

1.6 Mediterranean oceanography

1.6.1 Sea level

Sea level fluctuations are a combination of astronomical and climatic factors, at different time scales (Figure 1-29). The different parameters are as follows:

- Astronomical tide (relatively low in the Mediterranean Sea);
- Storm surge (due to the combination of low-pressure and wind blowing on the surface of the sea);
- Wave set-up and run-up (in the wave breaking zone);
- Sea level rise due to global warming.

Except the astronomical tides, all the other parameters can be influenced by climate change. The different parameters (except sea level rise) are described in more detail in chapter 2.6.

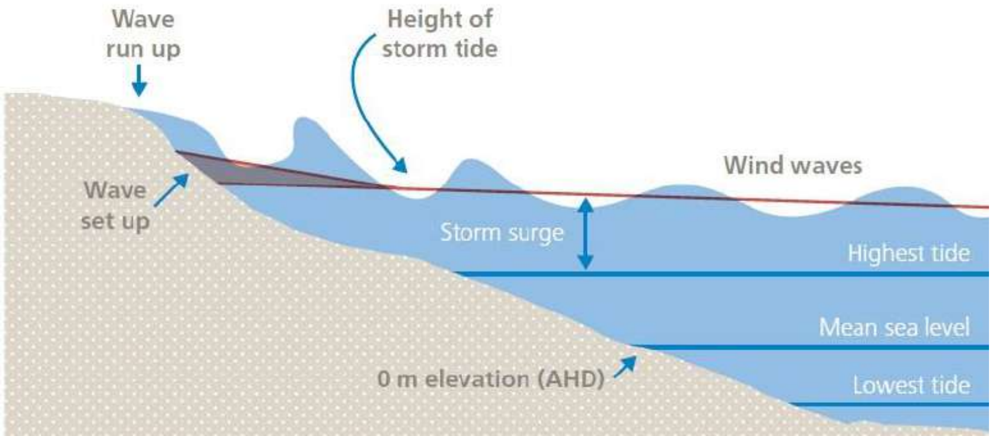


Figure 1-29. Illustration of the sea level parameters affecting a coastal zone

Sea level fluctuations are recorded by tide gauges all over the world. There is one tide gauge installed in Ischia Porto and one in Castellammare.

Tide gauges measurement in Ischia have been described and analysed in “Sea-Level Variability in the Gulf of Naples and the “Acqua Alta” Episodes in Ischia from Tide-Gauge Observations in the Period 2002–2019” by Berardino Buonocore, Yuri Cotroneo, Vincenzo Capozzi, Giuseppe Aulicino, Giovanni Zambardino and Giorgio Budillon.

The work presents an 18-year-long (2002–2019) tide-gauge dataset collected on the Island of Ischia (Gulf of Naples, Southern Tyrrhenian Sea) that can contribute to the analysis of the basic features of sea-level variability in this region. Analysis of tidal constituents shows that the Gulf of Naples is characterized by the absence of any amphidromic system. In this area, sea-level changes due to the **astronomical component** of the tide are generally **limited to ±20 cm** with respect to the mean sea level, but the impact of this variability is enhanced by global sea-level increase and the effect of regional atmospheric perturbations that might also triple sea-level variations.

The effects of these events, whose frequency has increased in recent decades, has been dramatic in coastal areas where intense social and economic activity occurs, e.g., in Ischia. **On interannual time scales, the results indicate that the relative sea-level rise in Ischia has a magnitude of 3.9 mm/year.** Special attention is dedicated to the "Acqua Alta" (AA) episodes and to their linkage with long-term sea-level trends and atmospheric forcing.

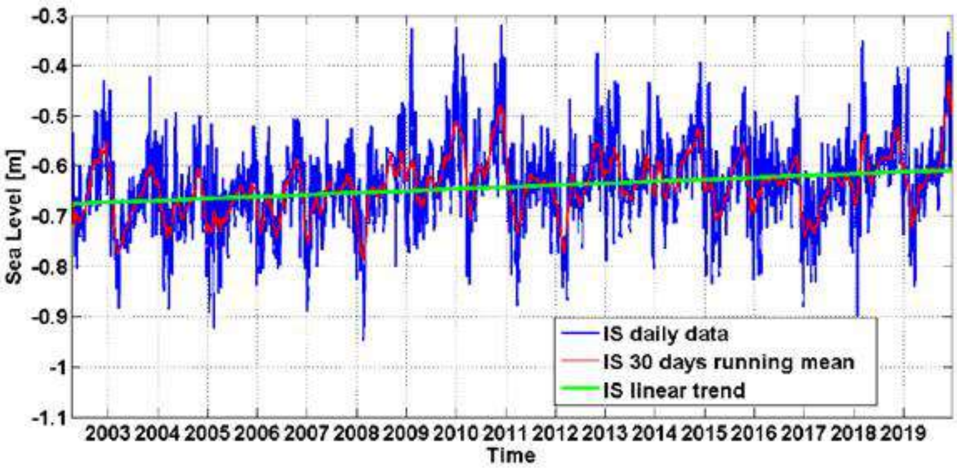


Figure 1-30. Daily tide-gauges data collected in Ischia from 2002 to 2019 (blue lines). A 30-day running mean (red line) and a linear trend of the data (green line) are also shown.

Gathering and statistical analysis of the raw data from tide gauge could allow isolating the astronomical components of the signal as well as the other components (storm surge particularly) in order to deduce the return period water levels.

"Acqua Alta" episodes in Ischia

The combined effects of the wind air pressure and tides can result in the rapid submersion of coastal areas, leading to catastrophic flooding and danger to life and economic activities. This phenomenon is known as "Acqua Alta" (AA), and it affects some Mediterranean areas, such as the city of Venice in the Northern Adriatic Sea and the island of Lipari in the Southern Tyrrhenian Sea.

Figure 1-31. « Acqua alta » events illustration Ischia Porto area (A) 2 March 2018 (B) 30 November 2019 and in Ischia Ponte right.

In Ischia, AA events cause water ingression over the piers in the Ischia Porto area and over the roads in the Ischia Ponte neighbourhood, where intense socio-economic activities, mainly linked to tourism, exist.

This phenomenon has gained the attention of the wider public in recent years, and its effects have been reported in several national and local newspapers.

In this work, the number, amplitude, and seasonal distribution of the AA events in Ischia Porto were studied through sea level data collected by the Ischia tide-gauge since 2002. For each year from 2002 to 2019, the total number of AA events is expressed as the percentage over the total number of hourly recorded.

After 2009, the AA episodes seem to have been more frequent, with only the years 2011 and 2017 having a percentage of single event lower than 1%. A higher number of AA episodes was registered in 2010 (8.7%), corresponding to about 762 submersion hours. During that year, the sea level height was registered at +32cm.

YEAR	H max [cm]	AA %	AA% > 5 cm	AA% > 10 cm	AA% > 20 cm	AA% > 30 cm
2003	12.0	0.82	0.74	0.02	0.00	0.00
2004	11.0	0.52	0.44	0.02	0.00	0.00
2005	5.5	0.38	0.27	0.00	0.00	0.00
2006	5.8	0.58	0.48	0.00	0.00	0.00
2007	6.5	0.35	0.32	0.00	0.00	0.00
2008	13.0	0.91	0.75	0.06	0.00	0.00
2009	26.0	4.50	4.20	0.91	0.08	0.00
2010	32.0	8.70	8.20	1.70	0.13	0.02
2011	13.0	0.41	0.35	0.01	0.00	0.00
2012	20.0	2.00	1.80	0.30	0.00	0.00
2013	18.0	3.00	2.70	0.17	0.00	0.00
2014	13.0	3.50	3.10	0.14	0.00	0.00
2015	12.0	2.10	2.00	0.06	0.00	0.00
2016	9.1	1.20	0.99	0.00	0.00	0.00
2017	7.2	0.47	0.39	0.00	0.00	0.00
2018	24.0	4.40	4.00	0.83	0.07	0.00
2019	24.0	4.30	4.10	1.20	0.14	0.00

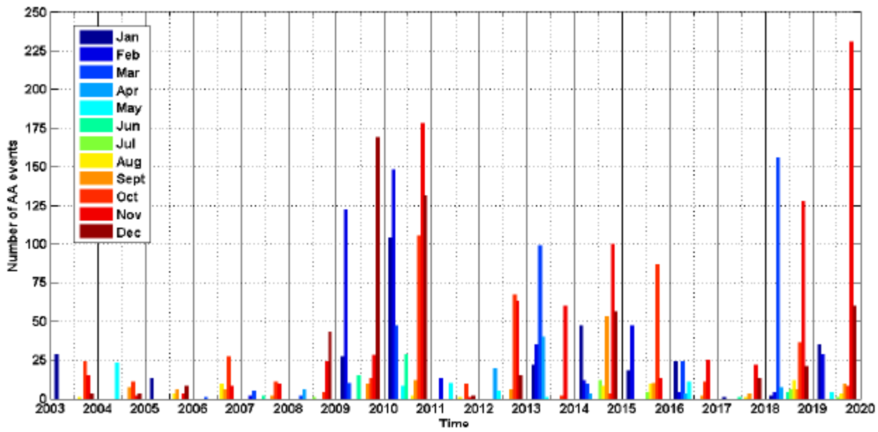


Figure 1-32. Maximum sea-level height (cm), total number of "acqua alta" events (%) and number of "alta aqua" events higher than 5, 10, 20 and 30cm over the pier from 2002 to 2019 (top table). Number of "aqua alta" events from 2002 to 2019, each event is defined as a single hourly mean sea level overpassing the "riva destra" pier edge (bottom figure).

1.6.2 Storm surge

Meteorological phenomena namely atmospheric pressure and wind may also affect the sea level in particularly during storm events. Pressure and wind effects are often combined during storms generating long waves, called storm surges, with a characteristic timescale of several hours to one day and a wavelength approximately equal to the width of the centre of the depression, typically 150–800 km. These storm surges produce significant variations of the sea level, up to 2–3 m at the shore depending on the shape of the coastline and the storm intensity. In practice, the term storm surge level is sometimes used loosely to include the astronomical tidal component and other meteorological effects.

Local low atmospheric pressures (depressions) cause corresponding rises in water level. Similarly, high pressures cause drops in water levels. This is the so-called inverse barometer effect.

Where the atmospheric pressure is higher than the mean value of 1013 hPa, the sea level decreases, provided that it can increase at another place where the atmospheric pressure is lower than the mean value.

Dynamic effects can cause a significant amplification of the rise in water level, however. When the depression moves quickly, the water level rise follows the depression. The height of these long waves may increase considerably as a result of shoaling in the nearshore zones.

1.6.3 Wind and waves set-up

Shear stress exerted by wind on the water surface causes a slope in the water surface, as a result of which wind set-up and set-down occur at downwind and upwind boundaries, respectively.

Operational systems used for the prediction of storm surges from meteorological forecasts are based on numerical flow models (either 2D or 3D) of the area considered. The model takes into account the stress at the sea surface due to the wind and the gradient of atmospheric pressure. Running such a numerical model with inclusion of tidal forcing is the recommended way to predict or model storm surges in real cases. This also applies to the dynamics of the meteorological forces, the effects of the bathymetry in shallow-water areas and the interactions between the tidal wave and the storm surge. The intensity of meteorological effects on the variation of MSL can be obtained by comparing the results of a simulation considering both tidal and meteorological forcings with the results of simulation considering tidal forcing only.

Wave set-up is localised near to the shoreline. It is mainly caused by energy dissipation caused by depth-induced breaking of the incoming waves.

1.6.4 Wind statistics

Wind and wave statistics were extracted from ERA5 and Copernicus models. ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate covering the period from January 1940 to present. ERA5 is produced by the Copernicus Climate Change Service (C3S) at ECMWF. ERA5 provides hourly estimates of a large number of atmospheric, land and oceanic climate variables. The data cover the Earth on a 30km grid and resolve the atmosphere using 137 levels from the surface up to a height of 80km. ERA5 includes information about uncertainties for all variables at reduced spatial and temporal resolutions.

Copernicus Marine Service is the marine service component of the Copernicus programme, delivering freely accessible oceanic operational data and information services. It is run by Mercator Ocean and its contractors on behalf of the European Union. The operational global ocean analysis and forecast system of Météo-France with a resolution of 1/12 degree is providing daily analyses and 10 days forecasts for the global ocean sea surface waves. This product includes 3-hourly instantaneous fields of integrated wave parameters from the total spectrum (significant height, period, direction, Stokes drift,...etc), as well as the following partitions: the wind wave, the primary and secondary swell waves.

Wind and waves statistics were extracted at two different points: one on the eastern side of Ischia Island and the other one of the western side as shown in Figure 1-33 on which wind and wave roses for those two points are presented. These wind and wave roses are also reproduced in larger pictures in Appendix 4.

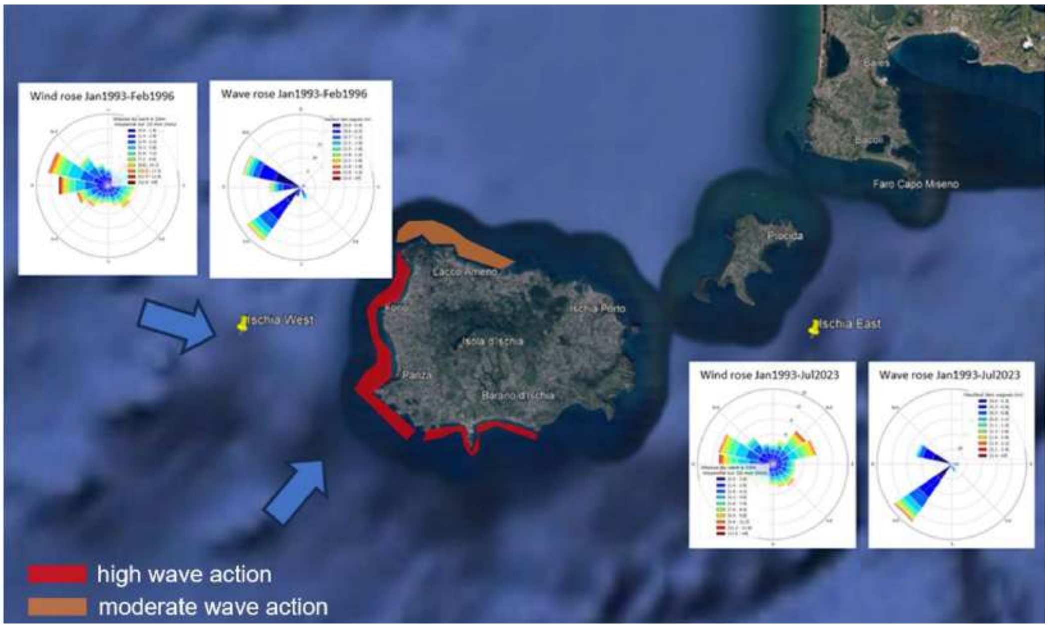


Figure 1-33. Wind and wave roses and two different locations around Ischia Island

Figure 1-34. Waves breaking on Spaggia dei Maronti

We can observe that due to the location of Ischia Island in the Mediterranean Sea, wind and waves are not completely correlated. Indeed, the island is only exposed to two main wave regimes: south-west and west-northwest whereas if the wind is also dominant on those sectors, we can also find winds from the East sector.

The western and southern coasts are then more exposed to wave attacks that the northern and eastern coasts (Figure 1-34).

Monthly statistics were also extracted (and presented in Appendix 3). The figures show that both wind and waves have their greatest intensity (i.e. wind speed and wave heights) during winter season between October and April which is typical of the northwest Mediterranean climate.

Interesting statistics to look at are the wind and wave trimestral average trends that were recorded from 1993 to 2023 on the east point. In 30 years, we can observe that all the parameters (wind and waves, separated in summer and winter graphs) vary around a constant average line. However, some years are clearly more energetic than the average and some other a lot less.

Cycles can be observed with 3 to 4 years in a row above or below the average. These graphs show that the average climate does not necessary change however they do not represent extreme isolate events that can occur.

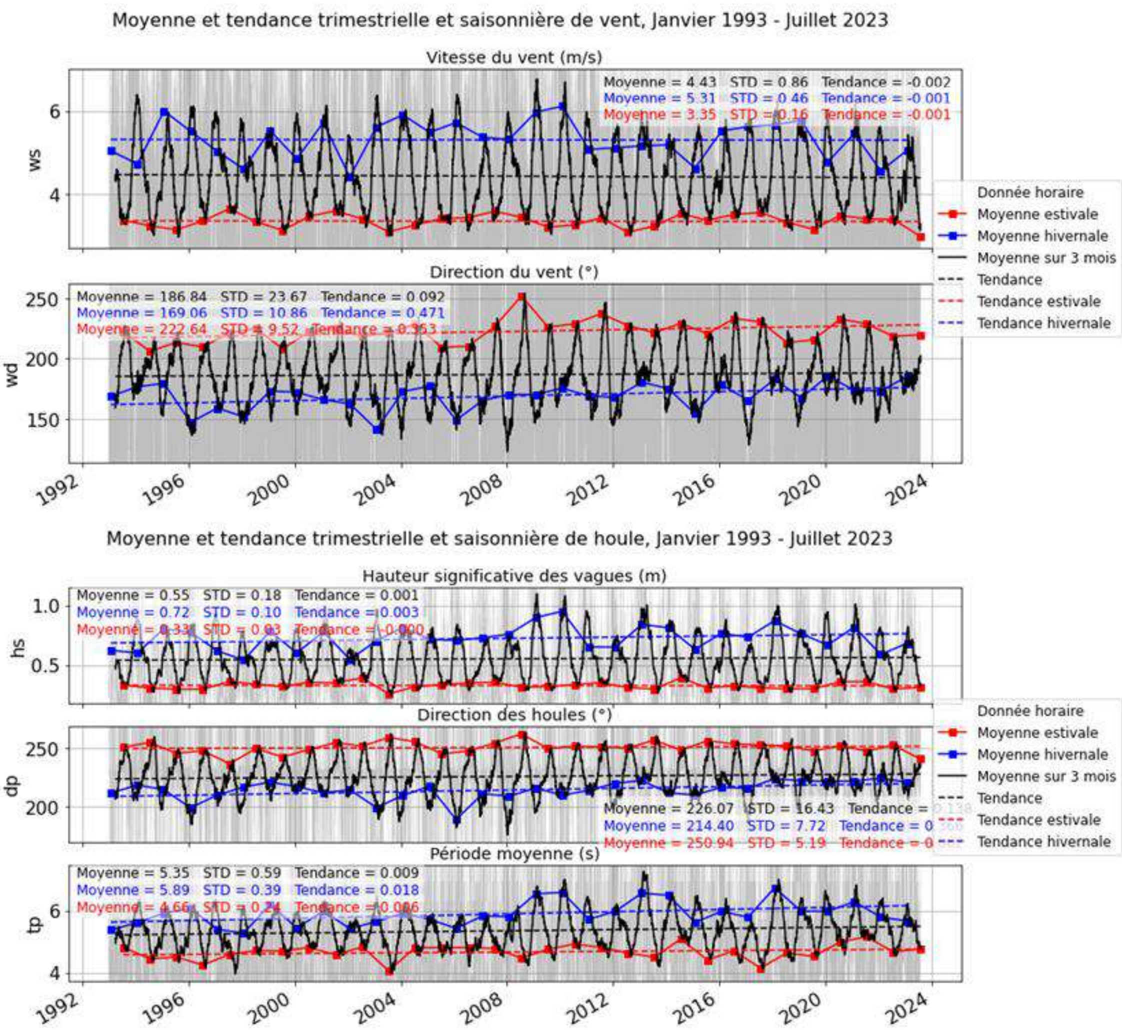


Figure 1-35. Wind and wave trimestral average trends from 1993 to 2023

Along the coasts of the Mediterranean Sea and especially on the island of Ischia, **storm surges and wind and wave set-up combined, can induce a local rise of the sea-level up to 1.0m (in a static level)**.

Wave action can also produce submersion with wave overtopping and flooding that can reach **+1.0m** in altitude above the sea level along the exposed coastline (in dynamic action).

These values are a rough estimate considering the addition of all the components. For design criteria, we advise a specific study on storm surge using the exploitation of the tide gauge data and other data if available.

2 Climate change projections for the island of Ischia

In order to study climate hazards in these limited areas, regional climate models are currently available with resolutions on the order of 10-15 km, allowing for a detailed characterization of atmospheric processes. Regional climate models enable an increase in spatial and temporal resolution compared to global circulation models and are better suited for formulating climate change scenarios for local impact analysis. Of particular significance at the European level are the Regional Climate Models produced by the international scientific community as part of the EURO-CORDEX program, with a resolution of approximately 12 km over Europe[17].

These models have been used in the present work to assess expected climate variations in the area of interest, also in accordance with what has been done within the framework of the Italian national adaptation plan (Piano Nazionale di Adattamento ai Cambiamenti Climatici, PNACC) approved in December 2023. Specifically, the EURO-CORDEX models adopted to perform the analysis are currently available for consultation on the Copernicus Climate Change Service (C3S) platform. For each of the 3 RCP scenarios considered, 14 climate simulations provided by different combinations of Global Climate Models (GCMs) and Regional Climate Models (RCMs) were used.

It is important to emphasize that the analyses produced by climate models are subject to uncertainties for various reasons, such as different assumed concentration scenarios, imperfect simulation of the climate system by the models, and the inherent complexity and non-linearity of the system (Collins 2007). For this reason, especially in decision support, a strategy is preferred that uses both different scenarios and an ensemble of modelling chains. This strategy, to perform climate change assessment with the EURO-CORDEX models, allows for the quantification of some of the sources of uncertainty associated with the models.

The measurement of model uncertainty with respect to the most reliable value, the ensemble mean, for each data point in this context is determined by the standard deviation. A greater standard deviation indicates greater model uncertainty. Note, however, that the standard deviation is also related to the absolute values of the parameter, i.e. that higher absolute values imply higher standard deviation values. This is because it implies that data points are spread further away from the ensemble mean, which is considered the most reliable value for assessing climate variation at that specific point. This methodology is consistent with what has been calculated analogously to the PNACC. For each point within the domain, a lower standard deviation value implies a higher level of agreement and conversely, a higher standard deviation suggests greater model variability, as referenced in Von Trentini et al., 2019[18]. Generally, higher model uncertainty (i.e. higher values of standard deviation in relation to the median change projections) is observed for precipitation-related projections than for temperature-related projections. Also the uncertainty for extreme values is higher than for average values.

The measures of uncertainty are provided in the below tables in brackets, to the right of the ensemble mean value. The ensemble mean value in the tables is shown in red, if the value shows a decrease, and in blue if it shows an increase. The provided values are average values over the island of Ischia. Maps showing the spatial distribution over the island are shown in Appendix 1.

Regarding the Sea Surface Height indicator, data is obtained from two sources. The CMIP6 climate model ensemble data available in the IPCC Atlas allows the analysis of uncertainty related with sea level rise projections. The NEMO ocean model applied to the Mediterranean Sea at a 7 km resolution and forced with atmospheric and hydrological data from the CMCC-CM climate model at ~80 km horizontal resolution (in agreement with the same approach used in the PNACC) provides projections of just one climate model, but at higher spatial resolution. The model configuration used in these simulations is referred to as MEDSEA. This indicator is available only for the RCP8.5 climate scenario.

[17] Jacob et al. (2014). EURO-CORDEX: new high-resolution climate change projections for European impact research. Regional Environmental Change 14(2), 563-578, http://doi.org/10.1007/s10113-013-0499-2
[18] Von Trentini et al. (2019). Assessing natural variability in RCM signals: comparison of a multi model EURO-CORDEX ensemble with a 50-member single model large ensemble. Climate Dynamics 53(3), 1963-1979. https://doi.org/10.1007/s00382- 019-04755-8

2.1 Temperature

2.1.1 Mean temperature

The mean temperature is projected to increase across all emissions scenarios by 2050, both annually and seasonally, with the level of increase depending on the emission scenario. The season that is projected to experience the greatest increase, changes. Under RCP2.6 the greatest increase is projected to occur during both summer and autumn with 1.2 days, under RCP4.5 the greatest increase is projected to occur during summer with 1.7 days, and under RCP8.5 it is projected to occur during autumn with 2.1 days (Table 2-1). For mean temperature, the uncertainty between models (standard deviation in brackets) is very low in relation to the change projections, i.e. all models agree on the sign and mostly on the extent of the temperature change. For the remaining temperature related variables, the uncertainty is slightly higher, but still markedly lower than for the precipitation-related variables.

Table 2-1. Projected climate data for mean temperature (°C). The standard deviation, and thus the model uncertainty, is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**17**	**10.5**	**14.8**	**24**	**18.7**
2050 RCP2.6 (variation)	*+1 (0.4)*	*+1 (0.4)*	*+0.8 (0.3)*	*+1.2 (0.3)*	*+1.2 (0.6)*
2050 RCP4.5 (variation)	*+1.4 (0.3)*	*+1.3 (0.4)*	*+1.0 (0.3)*	*+1.7 (0.3)*	*+1.5 (0.3)*
2050 RCP8.5 (variation)	*+1.8 (0.3)*	*+1.7 (0.3)*	*+1.4 (0.3)*	*+2 (0.3)*	*+2.1 (0.3)*

2.1.2 Summer days

The number of days when the daily maximum temperature exceeds 29.2°C a year is projected to increase across all emissions scenarios by 2050. Under RCP8.5 the annual number of days is projected increase by 14 days. The season that is projected to experience the greatest increase, across all emissions scenarios, is summer, while winter and spring are projected to experience no change in the number of summer days, across all emissions scenarios (Table 2-2).

Table 2-2. Projected climate data for summer days (days). The standard deviation, and thus the model uncertainty, is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**25**	**0**	**0**	**23**	**2**
2050 RCP2.6 (variation)	*+7 (11.7)*	*0 (0.0)*	*0 (0.1)*	*+6 (9.4)*	*+1 (2.4)*
2050 RCP4.5 (variation)	*+11 (14.8)*	*0 (0.0)*	*0 (0.3)*	*+9 (11.8)*	*+1 (3.0)*
2050 RCP8.5 (variation)	*+14 (17.4)*	*0 (0.0)*	*0 (0.2)*	*+11 (13.1)*	*+3 (4.7)*

2.1.3 Warm spell duration index

The number of days contributing to "warm spells", when the maximum temperature (TX) remains above its reference climatological 90th percentile, is projected to increase across all emissions scenarios by 2050, both annually and seasonally. The baseline annual value of 5 warm spell days is projected to increase by 89 days under RCP8.5. The season that is projected to experience the greatest increase, changes depending on the emission scenarios. Under RCP2.6 and RCP8.5, the greatest increase is projected to occur during autumn, while under RCP4.5 the greatest increase is projected to occur during summer (Table 2-3).

Table 2-3. Projected climate data for Warm spell duration index (days). The standard deviation, and thus the model uncertainty, is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**5**	**1**	**1**	**1**	**1**
2050 RCP2.6 (variation)	+37 *(22.0)*	+8 *(5.8)*	+5 *(3.7)*	+9 *(5.5)*	+12 *(9.8)*
2050 RCP4.5 (variation)	+59 *(23.1)*	+12 *(5.8)*	+8 *(4.2)*	+18 *(7.3)*	+16 *(11.5)*
2050 RCP8.5 (variation)	+89 *(27.7)*	+18 *(6.4)*	+14 *(6.7)*	+23 *(10.1)*	+26 *(12.2)*

2.1.4 Cooling degree days

Cooling degree days are projected to increase across all emissions scenarios annually, with up to 206 degree days under RCP8.5. The season that is projected to experience the greatest increase, across all emissions scenarios, is summer, with 154 days under RCP8.5. Spring is projected to experience an increase of 1 day under RCP4.5 and experience no change from baseline values under RCP2.6 and RCP8.5. Autumn is projected to experience an increase under all emissions scenarios, with up to 52 under RCP8.5, while winter is projected to experience no change from baseline values under all emission scenarios (Table 2-4).

Table 2-4. Projected climate data for Cooling degree days. The standard deviation is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**262**	**0**	**1**	**240**	**22**
2050 RCP2.6 (variation)	+107 *(83.0)*	*0 (0.0)*	*0 (0.6)*	+81 *(51.9)*	+26 *(39.9)*
2050 RCP4.5 (variation)	+159 *(95.3)*	*0 (0.0)*	+1 *(1.3)*	+125 *(63.1)*	+34 *(42.2)*
2050 RCP8.5 (variation)	+206 *(117.1)*	*0 (0.0)*	*0 (1.0)*	+154 *(69.8)*	+52 *(57.5)*

2.1.5 Heating degree days

Heating degree days are projected to decrease across all emissions scenarios, both annually and seasonally. The season that is projected to experience the greatest decrease, across all emissions scenarios, is winter, with a decrease of 173 under RCP8.5. Summer is projected to experience very little change from baseline values, with an average decrease of 1 day under all emissions scenarios (Table 2-5).

Table 2-5. Projected climate data for Heating degree days (DD). The standard deviation is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**1058**	**674**	**287**	**0**	**91**
2050 RCP2.6 (variation)	*-217 (60.5)*	*-100 (39.3)*	*-78 (18.3)*	*-1 (1.4)*	*-38 (17.2)*
2050 RCP4.5 (variation)	*-277 (47.3)*	*-138 (40.2)*	*-94 (14.5)*	*-1 (1.5)*	*-44 (17.9)*
2050 RCP8.5 (variation)	*-361 (44.6)*	*-173 (33.3)*	*-130 (21.8)*	*-1 (1.7)*	*-58 (18.1)*

2.1.6 Tropical Nights

The number of days a year when the daily minimum temperature is greater than 20°C is projected to increase across all emissions scenarios, by 21, 28 and 36 days under RCP2.6, RCP4.5 and RCP8.5 respectively. The number of days is projected to decrease during the winter months, across all emission scenarios, and similarly, during spring under RCP2.6, while under RCP4.5 and RCP8.5 it is projected that there will be no change. The greatest increase is projected to occur during the summer, across all emissions scenarios, followed by autumn (Table 2-6).

Table 2-6. Projected climate data for Tropical Nights. The standard deviation is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**95**	**0**	**1**	**71**	**23**
2050 RCP2.6 (variation)	*+21 (9.0)*	*-4 (13.1)*	*-1 (5.0)*	*+16 (16.2)*	*+9 (5.9)*
2050 RCP4.5 (variation)	*+28 (9.9)*	*-4 (13.2)*	*0 (5.0)*	*+20 (15.7)*	*+11 (6.7)*
2050 RCP8.5 (variation)	*+36 (10.9)*	*-3 (13.0)*	*0 (5.0)*	*+24 (15.9)*	*+15 (7.6)*

2.2 Precipitation

2.2.1 Average precipitation in wet days

The average annual daily precipitation sum in wet days (days with precipitation greater than or equal to 1 mm) is projected to increase under RCP2.6 by 4 mm, and projected to experience a decrease under both RCP4.5 and RCP8.5 (Table 2-7). Under RCP2.6 all seasons are projected to experience an increase, with winter projected to experience the greatest increase of 8 mm. Under RCP4.5 winter and autumn are projected to experience an increase, while spring and summer are projected to experience a decrease - the largest change is projected to occur in summer with a decrease of 16 mm. Under RCP8.5, the largest change is projected for spring and summer, with a decrease of 5 mm. Winter is projected to experience no change while autumn is projected to experience a small increase of 2 mm. The uncertainty related with average precipitation and all other precipitation-related variables is high, as the standard deviation of the model results is mostly higher than the median change.

Table 2-7. Projected climate data for average precipitation in wet days (mm). The standard deviation is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**446**	**168**	**109**	**23**	**146**
2050 RCP2.6 (variation)	*+4 (6.0)*	*+8 (14.4)*	*+2 (11.0)*	*+8 (27.4)*	*+2 (12.8)*
2050 RCP4.5 (variation)	*-2 (3.7)*	*+2 (8.8)*	*-3 (8.4)*	*-16 (36.0)*	*+1 (12.0)*
2050 RCP8.5 (variation)	*-1 (4.9)*	*0 (11.1)*	*-5 (9.9)*	*-5 (28.7)*	*+2 (12.7)*

2.2.2 Very heavy precipitation days

The number of days when daily precipitation is greater than or equal to 20mm, a year, is projected to increase under RCP2.6 and RCP8.5 by 1 day, under RCP4.5 there is projected to be no change. Across all seasons, under all emission scenarios, there is on average projected to be no change in the number of days when daily precipitation is greater than or equal to 20mm, apart from in winter under RCP2.6, where it is projected to experience an increase by a day (Table 2-8).

Table 2-8. Projected climate data for Very heavy precipitation days. The standard deviation is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**4**	**2**	**1**	**0**	**1.7**
2050 RCP2.6 (variation)	*+1 (0.9)*	*+1 (0.7)*	*0 (0.4)*	*0 (0.2)*	*0 (0.9)*
2050 RCP4.5 (variation)	*0 (0.7)*	*0 (0.4)*	*0 (0.3)*	*0 (0.2)*	*0 (0.6)*
2050 RCP8.5 (variation)	*+1 (0.7)*	*0 (0.4)*	*0 (0.3)*	*0 (0.2)*	*0 (0.7)*

2.2.3 Maximum 1-day precipitation

The annual maximum 1-day precipitation is projected to increase under all emissions scenarios, with up to an 8 mm/day increase under RCP8.5. The greatest increase is projected to occur during winter, across all emissions scenarios, with up to 7 mm/day under RCP2.6, 9 mm/day under RCP4.5 and 12 mm/day under RCP8.5. However, the greatest change is projected to occur during summer under RCP4.5, with a decrease of 16 mm/day. All other seasons are projected to experience an increase (Table 2-9).

Table 2-9. Projected climate data for Maximum 1-day precipitation (mm/day). The standard deviation is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**46**	**30**	**26**	**13**	**37**
2050 RCP2.6 (variation)	*+4 (9.3)*	*+7 (8.9)*	*+5 (14.4)*	*+4 (21.0)*	*+5 (14.5)*

2050 RCP4.5 (variation)	+6 (16.1)	+9 (11.3)	+4 (12.6)	-16 (24.0)	+8 (20.1)
2050 RCP8.5 (variation)	+8 (10.2)	+12 (10.4)	+2 (11.6)	+3 (24.0)	+8 (13.5)

2.2.4 Consecutive dry days

The number of consecutive days when daily precipitation is less than 1mm per year is projected to increase under both RCP4.5 and RCP8.5, while under RCP2.6 it is projected that there will be no change from the baseline value of 66. Under RCP2.6 spring and autumn are projected to experience the greatest increases of 1 day. Under RCP4.5 and RCP8.5 summer is projected to experience the greatest change with an increase of 3 and 2 days respectively (Table 2-10).

Table 2-10. Projected climate data for Consecutive dry days (days). The standard deviation is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**66**	**21**	**21**	**57**	**24**
2050 RCP2.6 (variation)	0 (4.1)	0 (1.9)	+1 (1.8)	0 (3.7)	+1 (1.9)
2050 RCP4.5 (variation)	+3 (3.5)	0 (1.3)	+1 (1.9)	+3 (3.7)	0 (1.7)
2050 RCP8.5 (variation)	+2 (5.4)	+1 (2.0)	+1 (2.5)	+2 (4.7)	+1 (1.5)

2.3 Wind

2.3.1 Extreme wind speed

Annual extreme wind speed (98th percentile of daily maximum wind speed) is projected to experience no relevant change. Median values under RCP2.6 and RCP4.5 show no change, while RCP8.5 shows a small decrease. Under RCP8.5, all seasons are projected to experience a decrease in extreme wind speed, under RCP4.5 winter and summer are projected to experience a decrease, summer is projected to experience no change from the baseline value while spring is projected to experience an increase. Under RCP2.6 winter is projected to experience a decrease in extreme wind speed, while spring, summer and autumn are projected to experience no change. The greatest change is projected to occur during summer under RCP4.5, as well as winter under RCP4.5 and RCP8.5, with a decrease of 2 m/s (Table 2-11). The model uncertainty (standard deviation in brackets) is in the range or slightly higher than the the median projections, indicating a substantial uncertainty. However, all projections agree on only minor changes in extreme wind speed.

Table 2-11. Projected climate data for Extreme wind speed (m/s). The standard deviation is presented in brackets. Source: Dataclime

	Annual	DJF	MAM	JJA	SON
Historical Period (absolute)	**13**	**14**	**13**	**10**	**13**
2050 RCP2.6 (variation)	0 (1.5)	-1 (2.1)	0 (2.2)	0 (4.0)	0 (3.1)
2050 RCP4.5 (variation)	0 (1.1)	-2 (1.7)	+1 (2.2)	-2 (3.6)	0 (3.4)

2050 RCP8.5 (variation)	*-1 (0.8)*	*-2 (2.2)*	*-1 (2.2)*	*-1 (3.5)*	*-1 (2.7)*

2.4 Hydro-Geological Hazards

The main hydro-geological hazards on the island of Ischia are landslides (i.e., various types of gravitational mass flows) and floods. Expected changes in these two hazards in the context of climate change are analysed in the following.

2.4.1 Landslides

To estimate the future landslide probability, the **following steps** were applied:

1. Analysis of historical data (2002 – 2022):

   a) Data analysis of historical severe landslides and rainfall datasets
   b) Establishing of a conditional probabilistic model (i.e., Bayes Model) describing historical landslide probability

2. Future projections (2040 – 2060)

   a) Analysis of projected changes of daily rainfalls (based on the EURO-CORDEX Regional Climate Model ensemble)
   b) Estimation of future landslide probability based on conditional probabilities and projected rainfall

In the **first step**, databases of historical landslide events were screened, and details can be found in chapter 1.4.2. This analysis of historical data revealed that in the baseline period of 21 years (2002 – 2022) the historical occurrence probability of a "serious" rainfall induced landslide was 90 % within one year.

Furthermore, historical rainfall measurements of four rainfall stations on the Island of Ischia were analysed (Figure 1-15). The station Mount Epomeo contains the longest record (2002 – 2022) and was considered in this study. Rainfall in Ischia has a clear seasonal pattern with a rainy season from September to February, peaking in November (150 mm/month), and a minimum from July to August (18 mm/month). Mean annual rainfall is around 870 mm/year. In 20 years of observation, 1696 days with a daily rainfall larger than 1mm/day have been observed. The mean rainfall event is 11 mm/day, while the maximum observed rainfall was 145 mm/day and occurred on November 26th, 2022.

Table 1-12 shows the selected landslide events in detail. Most of the events occurred during the rainy season, with two distinct peaks: one at the beginning (October/November with heavy short-term rainfall events) and one at the end of the rainy season (February with higher antecedent rainfalls, and thus most probably saturated soils). Triggering daily rainfall events were mostly smaller in February and larger in the remaining months. This is comprehensible considering the rather saturated soils at the end of the rainy season and potentially larger daily rainfall events in earlier rainy season months.

Table 1-12 also leads to the assumption that all considered landslides were triggered by rainfall events (as also supported by De Falco et. al., 2023). Even though other triggers such as earthquakes cannot be generally excluded, the well-documented disastrous events in 2006, 2009 and 2022 were triggered by heavy daily rainfall events. The 2022 event can be considered as very extreme, while the other two can be considered as severe (compare also Figure 2-1).

Figure 2-1 shows the daily rainfall events greater than 1 mm/day observed at Mount Epomeo, with rainfall events related to a landslide event marked in red – clearly, most events did not lead to a GMF event. The plot is divided into five classes: the first two classes ([1,20], [21,40]) are related to rainfall events that occur on an annual basis. The subsequent two classes ([41,60], [61,80]) can be associated to return intervals of five to ten years. The remaining class ([>80]) is unbounded and contains daily rainfall with return intervals of 20 years and more. These defined rainfall classes are essential in the applied Bayesian model, which is described in the following paragraph.

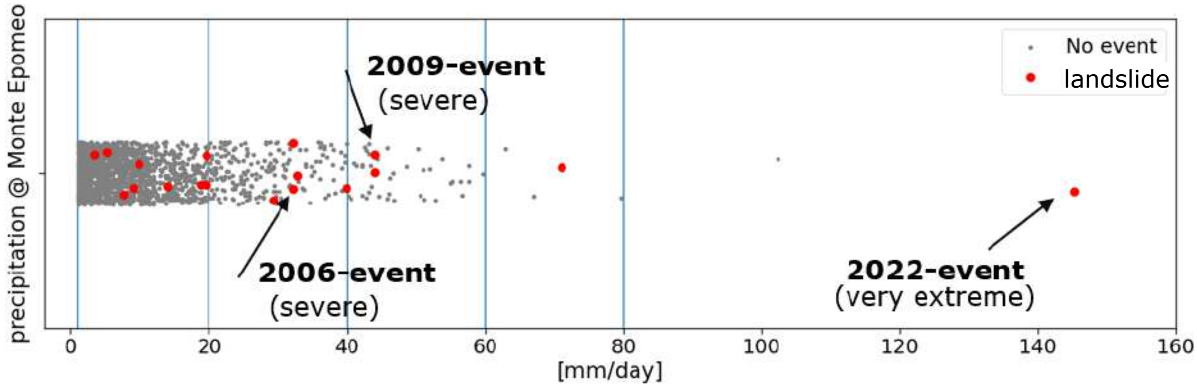


Figure 2-1 1D-scatter plot of rainfall events (> 1 mm/d) from 2002 to 2022 and associated landslide-events (red dots).

While rainfall is considered as a main trigger of landslides, they are not only determined by rainfall, which means that a similar amount of daily rainfall does not always lead to a landslide event. The question arises: at which threshold does a landslide happen? Berti et. al., 2012[19] suggest a probabilistic approach to evaluating rainfall thresholds and landslide occurrence based on a Bayesian model (conditional probability). To keep the Bayesian model simple and since most severe landslide events are most likely triggered by short and intense rainfall, the 1D-case as proposed by Berti et. al., 2012is used. The conditional probability *P(A|B)* is the probability of some event A (i.e., a landslide) happens given the occurrence of some other event B (i.e., daily rainfall sums). In other words, the conditional probability of A given B (also called posterior probability), is the probability of observing a landslide when a rainfall event of magnitude B occurs. In this study, B is considered as five rainfall classes (n) as shown in Figure 2-1. The conditional probability is provided by the Bayes' theorem:

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)}$$

where:

P(B|A) is the conditional probability of B given A (also called the likelihood), that is the probability of observing a rainfall event of magnitude B when a landslide occurs,

P(A) is the prior probability of A, that is the probability a landslide occurs regardless of whether a rainfall event of magnitude B occurs or not. In this study, the prior probability is 1.1 % (19 GMF's in 1696 rainfall events).

P(B) is the marginal probability of B, that is the probability of observing a rainfall within a certain rainfall class (n) regardless of whether a landslide occurs or not.

As an example, for a rainfall B_5 with an intensity I > 80 mm/day, it is $P(B_5|A) = P(I > 80|A) = 1/19 = 0.05$ and $P(B_5) = P(I > 80) = 2/1696 = 0.0011$ (2 out of the 1696 rainfall events fall in the considered range of intensity). The corresponding landslide probability is $P(A|B_5) = P(A|I > 80) = 0.05*0.011/0.0011 = 0.5$. Running the same analysis for different intensity classes n, a histogram of landslide probability is obtained (Figure 2-2). As described by Berti et. al., 2012 the intensity classes with the higher P(A|B) values are most susceptible to landslides. If the distribution of rainfall changes in the future due to climate change (e.g., towards more extreme events), it is possible to estimate changes in the occurrence of landslides on a statistical basis.

[19] M. Berti, M. L. V. Martina, S. Franceschini, S. Pignone, A. Simoni, and M. Pizziolo. (2012): "Probabilistic rainfall thresholds for landslide occurrence using a Bayesian approach." Journal of Geophysical Research: Earth Surface, https://doi.org/10.1029/2012JF002367

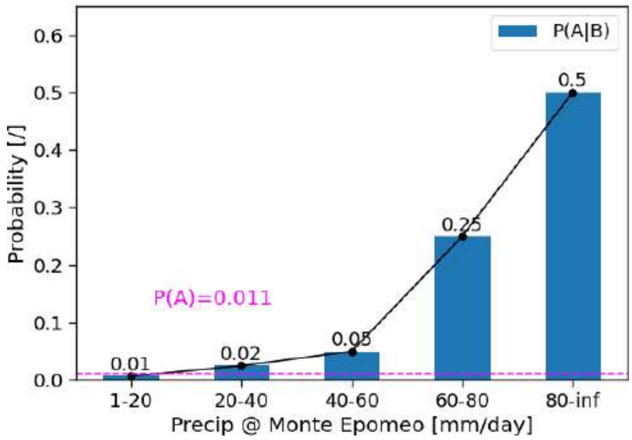


Figure 2-2 Conditional probability of GMFs per rainfall class based on historical data (2002 - 2022)

In the **second step**, climate change signals of daily rainfalls were assessed. EURO-CORDEX climate model data, as publicly available on the Copernicus Climate Change Service (C3S) platform, with a resolution of ~12 km over Europe (Jacob et al., 2014[20], Hennemuth et al., 2017[21]), were used in this study. The climate model ensemble considers three different emission scenarios (i.e., RCP2.6, RCP4.5 and RCP8.5) and 14 different climate models. In total, 42 time series of simulated daily rainfalls from 1981 to 2065 were analyzed.

To assess the changes in future rainfall, the following approach is used: First, the five historical rainfall classes, as shown in Figure 2-1 and Figure 2-2), are translated into percentiles. This means that each bin is defined by its percentile value based on the historical observations. Second, for each of the 42 climate model runs, the percentiles calculated from the observations are applied to classify the simulated rainfall timeseries for the historical period 2002 – 2022. Third, the absolute values derived from this classification, separately for each climate model, is used to classify the simulated future period (2040 – 2060). Fourth, the number of days per bin is counted for both, the historical and future periods simulation and changes are calculated relatively to each other.

This approach, based on relative values (percentiles) derived from the observed series, but using absolute values as classification range to calculate the change from historical to future period in the climate model simulations, allows the use of original climate model data without explicitly correcting the model bias.

Figure 2-3 shows the projected changes in number of days per defined rainfall class. Low rainfall intensities are likely to decrease, while medium intensities are likely to slightly increase, and high intensities to increase. Variations between different climate models increase with higher intensity.

[20] Jacob et al. (2014). EURO-CORDEX: new high-resolution climate change projections for European impact research. Regional Environmental Change 14(2), 563-578, http://doi.org/10.1007/s10113-013-0499-2

[21] Hennemuth et al. (2017). Guidance for EURO-CORDEX climate projections data use. Version1. 0-2017.08. https://www.hereon.de/imperia/md/content/csc/cordex/euro-cordex-guidelines-version1.0-2017.08.pdf

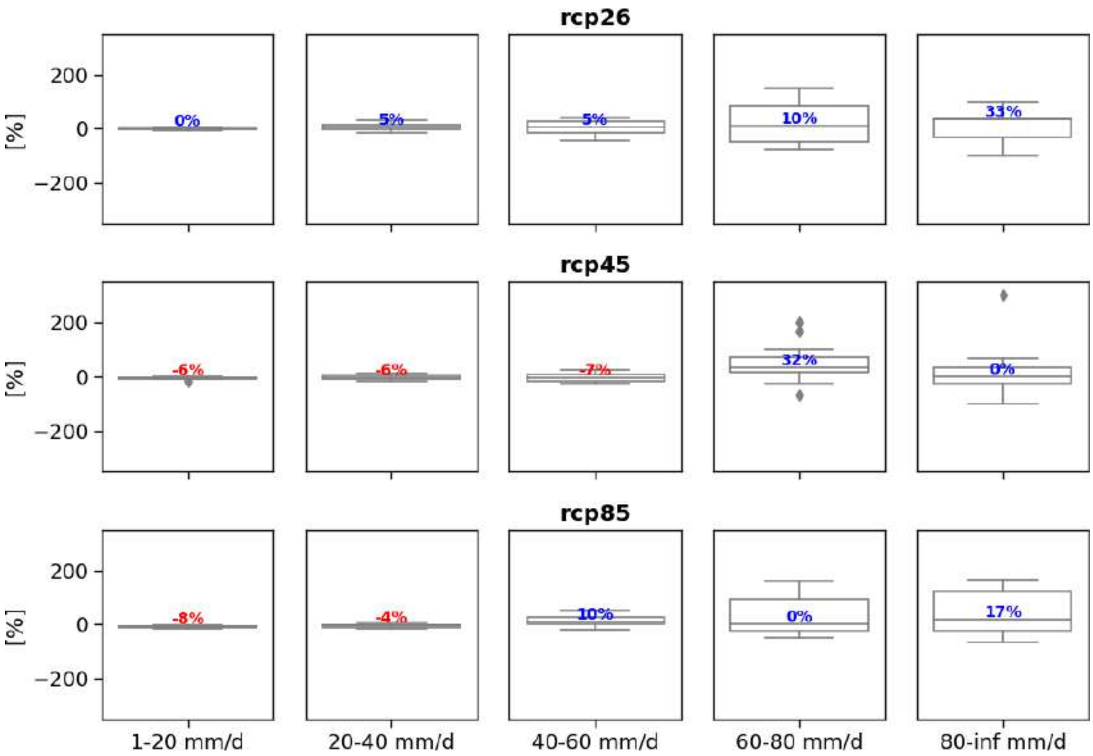


Figure 2-3 Box plots of simulated changes [%] in 14 CORDEX climate model simulations for three different emission scenarios and each rainfall class. The number (red for a decrease or blue for an increase) shows the median of the CORDEX-ensemble.

Under the premise that the conditional probabilities of rainfall and GMFs do not change in the future, the occurrence of landslides in the future was estimated based on the following approach. The climate change signals of each climate model and each rainfall class were applied to the historical observations. Then, the number of projected GMFs for the period 2040 – 2060 ($\#LS_{CC}$) was calculated based on the changed rainfall occurrences in each class and each climate model simulation ($\#rainfall_{i,CC}$) as follows:

$$\#LS_{CC} = \sum_{i}^{classes\ (n)} \#rainfall_{i,CC} * P(A|B_i)$$

The **results** are discussed in the following paragraphs. The left panel of Figure 2-4 shows the projected number of landslides and the related changes based on the CORDEX ensemble for different emission scenarios. Due to diverging climate change signals – decrease in the lower two rainfall classes and clear, yet uncertain, increase in the highest rainfall classes – the overall number of landslides will remain practically unchanged in the ensemble median. However, the box plots show a low model agreement: 18/10/14 models show an increase/no change/decrease of landslides in the future. The total number of projected GMFs (2040 – 2060) varies from 16 in the best to 23 in the worst case. Compared to 19 historical landslides events, the projection varies between -15 % to +20 %.

The right panel in Figure 2-4 focuses on extreme landslides (e.g., 2022-event) triggered by rainfall with very high intensities and shows that their probability is likely to increase under future climate conditions. There is a rather good model agreement, with 21/9/12 models showing an increase/no change/decrease of future landslides. Two climate models show a severe increase of extreme landslides from one historical landslide to four/five under future climate conditions.

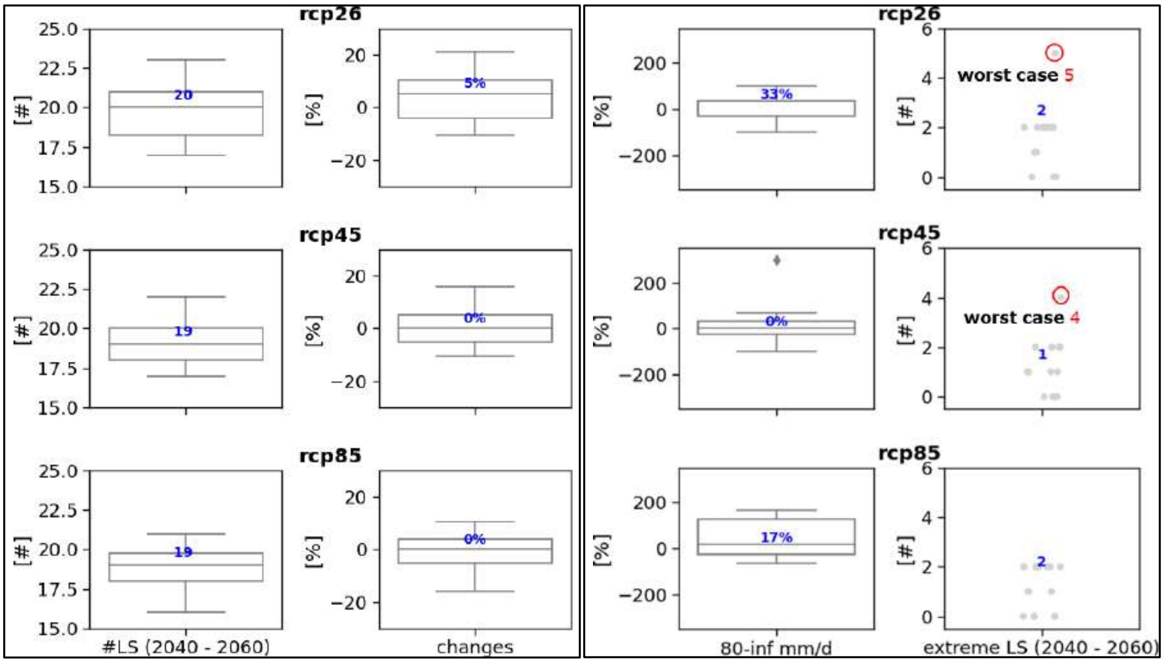


Figure 2-4 Results: left panel shows the total projected number of landslides (2040 – 2060) along the CORDEX ensemble as well as projected changes [%]. Right panel shows the projected changes in the highest rainfall class and associated number of projected extreme landslide-events for the period 2040 - 2060. Blue numbers show the median along the ensemble.

With respect to decision making, it is important to emphasize that the data produced by climate models is subject to uncertainties for various reasons, such as different assumed emission scenarios, imperfect simulation of the climate system by the models, and the inherent complexity and non-linearity of the system. Also, the climate models have a rather coarse resolution, which do not fully capture orographic effects of the island's topography. Climate models with very high resolution have been developed (e.g. Raffa et al., 2023[22]), but no large ensembles as required for the analysis of uncertainties are yet available. Therefore, climate model projections with higher temporal (e.g. hourly) and spatial resolution remain a subject for future research.

Additional uncertainty comes from the use of accumulated daily rainfall data that may not fully capture differences in triggering events of shorter duration. Future increases in rainfall intensities for events with durations of a few hours might be higher than for daily rainfall (Westra et al., 2014[23]), possibly implying more pronounced increases in GMF occurrence. Furthermore, the analysis is based on the Mount Epomeo rainfall station, which is considered as representative for all recorded landslides on Ischia, although local rainfall intensities triggering the specific landslide might have been different than observed at Mount Epomeo station.

Furthermore, the applied Bayesian model introduces uncertainties. For instance, many of the observed landslides fall into the two lowest rainfall intensity classes, where a decrease of rainfall days and therefore a decrease in landslides is projected. However, this could be misleading, as the antecedent rainfall is not considered. Antecedent rainfall and the related saturated soils might be relevant especially for landslides triggered by rainfall events with relatively low daily rainfall intensity (compare also e.g., Uzielli et. al., 2018[24]). Also, the combination of long dry spells followed by extremely wet conditions might trigger GMFs

[22] Raffa, M., Adinolfi, M., Reder, A. et al. Very High Resolution Projections over Italy under different CMIP5 IPCC scenarios. Sci Data 10, 238 (2023). https://doi.org/10.1038/s41597-023-02144-9

[23] Westra, S., et al. (2014). Future changes to the intensity and frequency of short-duration extreme rainfall, Rev. Geophys., 52, doi:10.1002/2014RG000464

[24] Uzielli, Marco, Guido Rianna, Fabio Ciervo, Paola Mercogliano and Unni K. Eidsvig. 2018. "Temporal evolution of flow-like landslide hazard for a road infrastructure in the municipality of Nocera Inferiore (southern Italy) under the effect of climate change." Nat. Hazards Earth Syst. Sci., 13, 2195–2207, doi:10.5194/nhess-13-2195-2013

and could be observed more frequently in the future (Tichavsky et. al., 2019[25]). Consideration of antecedent soil moisture conditions could be considered in a 2D Bayesian model (as proposed in Berti et. al., 2012). In addition, the assumption that conditional probabilities do not change in the future is only true if the earth surface system state remains unchanged (Berti et. al., 2012). For instance, an earthquake could change the conditions that triggered a GMF in the past and the prior probabilities may not be representative for the future anymore. However, after the 2017-earthquake, the reported landslides did not significantly increase. Therefore, no direct link to the earthquake can be established, indicating that the system might change slowly or that the magnitude of this earthquake was too weak.

In addition, the applied method has limitations in terms of spatial resolution. The computed probabilities refer to the whole island and cannot be linked to a specific location on the island. Furthermore, the landslide database includes all different landslide types, which were analyzed together to have a suitable sample. Also, the database is limited to marginal information on intensities of landslides, with only three landslide events documented in detail. For a more detailed view of the landslide hazard and risk on hot spots, more specific studies are required.

Despite the described uncertainties, the Bayesian model captures the basic physical relationship between daily rainfall and landslide occurrence. The use of probabilistic rainfall thresholds allows the consideration of climate change signals and provides a basis for discussion on how future GMFs might impact the society on the Island of Ischia. It raises attention to likely more frequent extreme events and highlights the importance of measures to reduce these hazards and/or avoid disastrous events in the future.

From this analysis, the following **conclusions** can be drawn: On the Island of Ischia, the occurrence probability of serious landslides is already high under the current climate. The analysis of historical events revealed that rainfalls with high intensities have the potential to trigger disastrous landslide events. The applied Bayesian model also showed that the probability of landslides during rainfall events with high intensities is higher compared to low intensities.

The analysis of projected changes in rainfall revealed that events with low intensities will rather decrease in the future, while high intensities will increase. Based on these climate change signals and conditional probabilities, **the occurrence probability of landslides is projected to change between -15 % and +20 % under a future climate for 2040-2060**. Furthermore, the analysis showed that **in two worst case scenarios, four to five landslides with the same disastrous potential as the 2022-event may happen in 22 years.**

In the light of recovery and reconstruction, the analysis clearly shows that the threat of landslide is evident and might be even more severe in the future, due to increased frequencies of extreme events. The study allows for reliable worst-case considerations that will serve as a base for discussion among different stakeholders. In subsequent studies (not part of this study), hot spots of potential slope instabilities should be investigated in more detail, to enable planning for adaptation activities to reduce the intensity of future landslide events.

2.4.2 Floods

The flood types observed on Ischia (see Chapter 1.4.4) are directly related to extreme precipitation events. The effect of changes in rainfall intensities on flood discharge can be assessed by applying rainfall-runoff simulations as carried out by the team of Prof. Pianese for Casamicciola Terme.

As rainfall-runoff models for this area have already been developed, and simulations with extreme rainfall for different return periods under historical climate conditions have been carried out, it was decided between the EIB, the Struttura Comissariale and Prof. Pianese that this model setup should be used to investigate climate change impact on floods. Therefore, projections for extreme rainfall under climate change scenarios were developed in the framework of this study.

[25] Tichavský, R., Ballesteros-Cánovas, J.A., Šilhán, K. et al. Dry Spells and Extreme Precipitation are The Main Trigger of Landslides in Central Europe. Sci Rep 9, 14560 (2019). https://doi.org/10.1038/s41598-019-51148-2

The applied data was coordinated in a way that the results can directly be used in the rainfall-runoff models of Prof. Pianese's team, and the impact of applying climate change scenarios of flood discharge can directly be assessed. As the rainfall-runoff model's rainfall input was mainly based on Intensity-Duration-Frequency curves (IDF curves, see Chapter 1.4.4), the analyses of extreme precipitation in the climate model data aimed at the generation of IDF curves under climate change.

IDF curves under climate change were generated based on analyses of annual maximum precipitation for different probabilities of occurrence on the island of Ischia. These variations have been calculated using the approach described in Padulano et al. (2019)[26]. While the analytical details are referenced in the work of Padulano et al. (2019), the approach requires as input the reference Intensity-Duration-Frequency (IDF) curve for the area-of-interest and at least two samples of 30 maximum daily precipitation returned by at least one climate model for the reference period and the future one. Through the reference IDF, the climate data are "corrected" and "perturbed" to provide the IDF curve for the future period consistent with the reference one.

Specifically, the reference IDF curve for the area-of-interest has been obtained from the VA.PI Campania as reported in the document "Piano Commissariale di Interventi Urgenti" (Commissioner's Plan for Urgent Interventions). Both the "traditional" curve used for the Ischia island (falling within subzone A1, now referred to as "original VA.PI") and the curve obtained by considering the annual maximum precipitations at different durations obtained from the analysis of the 4 rain gauges on the island over the last 15 years have been taken into account (now referred to as "modified VA.PI"), which are also described in Chapter 1.4.4.

As for the climate data, they are the same ones used to outline the local climatic profile of the Ischia island, derived from the CORDEX program for Europe (i.e., EURO-CORDEX). Specifically, various models and scenarios have been considered ("historical" experiment for the past period, which for these models extends to 2005, and the RCP2.6, RCP4.5, and RCP8.5 for the future period, which for these models spans from 2006 to 2100) to provide a clearer view about the spread among the different models and climate scenarios considered.

Regarding the assumed periods, they are 1981-2010 for the past and 2036-2065 for the future. It should be noted that for the past period, EURO-CORDEX data are derived from the so-called "historical experiment", obtained by running regional climate simulations over a historical period using observed CO_2 concentrations as forcing (which means they are not actual observations).

Before presenting the results, it is worth highlighting some of the main assumptions and limitations of the approach:

- Due to the current performance and skills of climate models, all elaborations have been made under the strong assumption that variations at the daily scale "work" for sub-daily durations.
- The analysis has been carried out by exploiting climate simulation chains only for the investigated area and then proposing a variation in growth factor (at specific return periods) that, strictly speaking, is valid only on the same local scale. The parameters of the growth factor are originally estimated in VA.PI. by considering much broader territorial contexts.

Table 2-12 provides the expected changes in Maximum Annual Precipitation (MAP) obtained under different RCP scenarios from the Ensemble Mean (EM) of the EURO-CORDEX models using the "modified VA.PI". The Tables also report the Standard Deviation (STD) between the different models to quantify the spread with respect to the Ensemble Mean of the EURO-CORDEX and the Coefficient of Variation (CV), defined as the ratio of STD against EM, which quantifies by how many times the standard deviation is greater than the mean.

Table 2-12: Maximum Annual Precipitation (MAP) variation for different return periods under different scenarios carried out by using the "modified VA.PI" curve as reference

[26] Padulano, R., Reder, A., & Rianna, G. (2019). An ensemble approach for the analysis of extreme rainfall under climate change in Naples (Italy). Hydrological Processes, 33(14), 2020–2036. https://doi.org/10.1002/hyp.13449

Maximum annual rainfall depth (mm) variation for different return periods									
T (years)	RCP2.6			RCP4.5			RCP8.5		
	EM (%)	±STD (%)	CV (-)	EM (%)	±STD (%)	CV (-)	EM (%)	±STD(%)	CV (-)
5	5.0	9.1	1.8	4.0	12.5	3.1	8.4	9.6	1.1
10	7.0	11.1	1.6	5.7	14.7	2.6	8.5	12.0	1.4
20	10.0	19.0	1.9	8.7	22.0	2.5	8.5	15.1	1.8
50	16.5	40.7	2.5	16.0	43.4	2.7	8.4	20.6	2.5
100	24.6	68.7	2.8	25.7	71.4	2.8	8.5	25.9	3.0

The variations in MAP are higher for the RCP8.5 scenario compared to the other scenarios for low return periods (higher frequency); an opposite behaviour is assessed for high return periods (lower frequency) with similar values for the RCP2.6 and RCP4.5 scenarios. A detailed overview of the values of individual models is provided in Appendix 5 for different RCP scenarios.

These above-mentioned elaborations have been further complemented by two additional analyses.

The first analysis involved conducting the 2-sample Kolmogorov-Smirnov statistical test for each climate model and scenario considered. This test aimed to assess whether the two samples related to the maximum daily precipitation for current and future periods are characterized by the same distribution. The analysis revealed that only model ID7 (under RCP2.6; see Appendix 5 for the model labels and related GMC-RCM combination) shows statistically significant variations. A possible explanation is the selected time horizon, which is relatively close to the current one.

The second analysis focused on assessing the past changes in annual maximum precipitation given by climate models, considering two past periods (i.e., 1971-1995 and 1996-2020). This analysis aims to assess potential variations in the annual maxima regime during the past period, comparing the annual maxima for the period the "VA.PI original" falls in with the period corresponding to the "VA.PI modified" Figure 2-5, left, shows that the climate models in the "historical" experiment already return an increase in annual maximum daily precipitation of about 8% in the period 1996-2020 compared to the period 1971-1995. This variation should be further considered in combination with the information provided in Table 2-12 if one intends to relate the result to the reference IDF provided by the "VA.PI original." Furthermore, the spatial pattern shown in Figure 2-6 is very similar to the pattern in changes in observations of extreme precipitation in Southern Italy (Avino et al. 2021[27]), confirming the general ability of the CORDEX climate models to represent changes in extreme precipitation.

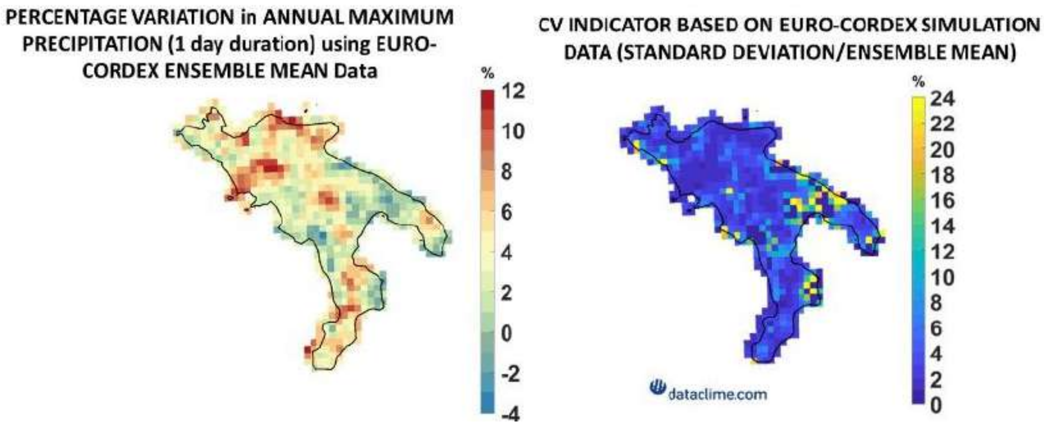


Figure 2-5 Spatial patterns of the past change in annual maximum precipitation in the CORDEX climate model ensemble (difference between the two periods 1971-1995 and 1996-2020); left: ensemble mean; right: variation between single climate models

[27] Avino A., Manfreda S., Cimorell L., Pianese D. 2021: Trend of annual maximum rainfall in Campania region (Southern Italy). Hydrological Processes 35/12, https://doi.org/10.1002/hyp.14447

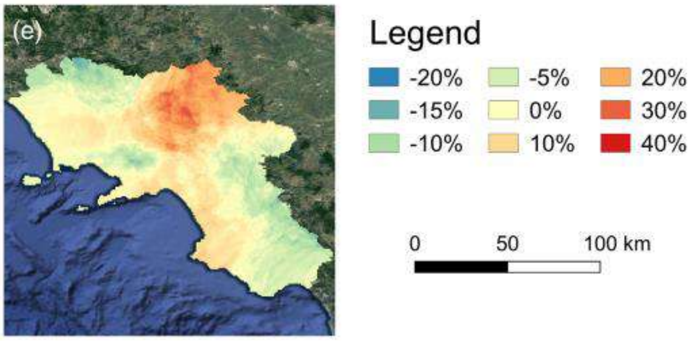


Figure 2-6 Spatial patterns of the past change in annual maximum precipitation in observation records (24 hours duration, difference between the two periods 1970-1990 and 1991-2018; source: Avino et al. 2021)

Based on the ensemble median results provided in Table 2-12**, future extreme precipitation can be expected to increase within a range of +5% and +25%.** It is therefore recommended to apply, as a general and trans-sectoral climate change adaptation activity, an increase within this range for design storm precipitation values in hydraulic design applications.

The climate model projections that inform this current recommendation are based on simulations at the daily time scale. Trends in observational records (Avino et al. 2021) show tendencies that increases on sub-daily time scales of few hours might be higher than on the daily scale. With the ongoing development of climate models that have a higher resolution in space and time (e.g. Raffa et al. 2023), this issue will be further investigated and should be considered for future recommendations.

Based on the expected increase in extreme precipitation, it can clearly be expected that **future flood discharge will also increase**. The extent of this increase will depend on the intensity and duration of a rainfall event and on catchment characteristics at the time of the rainfall event. In a first application of the increases in IDF curve values elaborated here, increased design rainfall input will be applied in the **rainfall-runoff simulations of flood discharge in Casamicciola Terme** by Prof. Pianese's team. In addition to generating information on future design discharges for planning purposes along the simulated streams, these simulations **will also provide a general estimate of future increases in flood discharge**, due to increasing precipitation intensities, for the island of Ischia. Figure 2-7 exemplarily shows an IDF curve with a 20-year return period for the reference period and the future IDF curves assuming the increases under the three different emission scenarios, using the ensemble mean increases provided in Table 2-12. Note, however, that the projections of single climate models within the EURO-CORDEX ensemble vary considerably, as shown in Figure 2-8 for the future IDF curve with a 20-year return period and the RCP4.5 emission scenario.

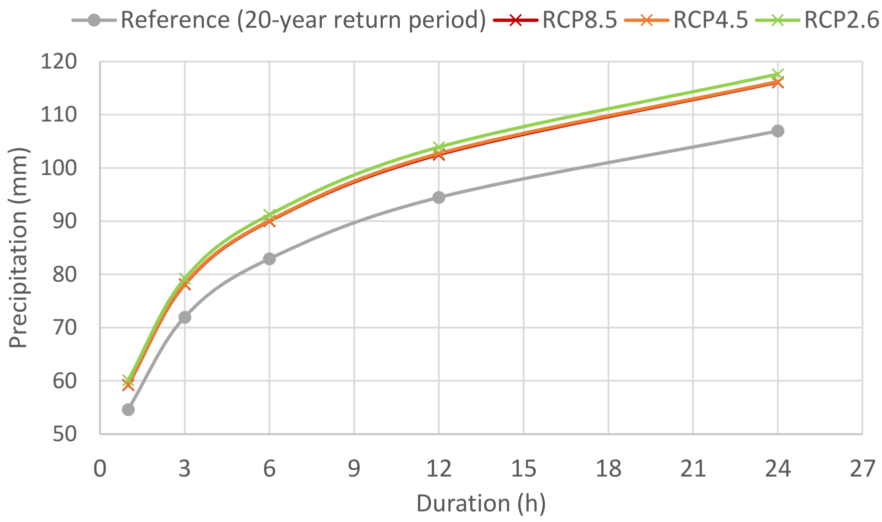


Figure 2-7 IDF curves for the island of Ischia for a 20-year return period, under the baseline reference climate and under three climate scenarios for 2036-2065

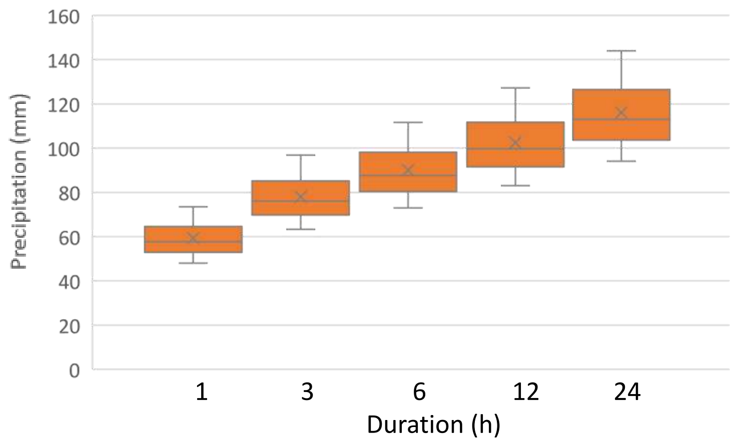


Figure 2-8 Range of future IDF curve values for the 20-year return period, under RCP4.5, by the different models in the EURO-CORDEX ensemble (ensemble mean values are marked with an x)

2.5 Wildfires

As described in Chapter 1.5, wildfires apparently occurred more often in the last years than previously (with no recorded wildfire incidents before 2021), which already might be a sign of the impact of warmer temperatures. Typically, future projections of wildfire danger are based on the calculation of the Fire Weather Index (FWI[28]) which uses data on air temperature, relative humidity, wind speed and precipitation. *Table 2-13* presents the projections of change in FWI (in %) calculated with the EURO-CORDEX data for the three emission scenarios and the four seasons.

Clearly, wildfire danger is projected to increase in the future, with increases of 9 to 14 % in the FWI. Relative changes are distributed relatively evenly over the year, with slightly higher increases in the spring and summer. The absolute danger of wildfire is of course highest in the summer months (but reference values for the baseline period were not calculated due to missing parameters in the observational data set).

[28] FWI does not consider fuel sources nor land use management of fire risk.

Table 2-13. Projected climate data for Fire Weather Index (FWI, % change). The standard deviation is presented in brackets (only for annual values). Source: Dataclime

	Annual	DJF	MAM	JJA	SON
2050 RCP2.6 (variation)	+9 (5)	+8	+9	+9	+9
2050 RCP4.5 (variation)	+14 (4)	+11	+14	+14	+12
2050 RCP8.5 (variation)	+16 (3)	+15	+18	+16	+14

2.6 Sea level rise and storm surges

2.6.1 Sea level rise

The latest AR6 report (published on August 09, 2021) from the Intergovernmental Panel on Climate Change (IPCC) which follows the special report entitled "Climate change, the oceans and the cryosphere" published in September 2019, presents the latest results of the different models for the year 2100. In AR6, based on five different hypotheses concerning the quantity of greenhouse gases that will be emitted in the years to come (period 2000-2100), each scenario gives a variant considered as probable for the climate that will result from the emission level chosen as the working hypothesis. The four scenarios are named after the range of radiative forcing thus obtained for the year 2100: the SSP1-1.9 scenario corresponds to a forcing of +1.9 W/m2, the SSP1-2.6 scenario to +2.6 W/m2, and the same for the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios.

Estimates of global sea level rise on a global scale compared to the 1995-2014 level and to the 2100 deadline (Figure 2-9) vary as follows according to the scenarios:

- +0.28-0.55 m for scenario SSP1-1.9;
- +0.32-0.62 m for scenario SSP1-2.6;
- +0.44-0.76 m for scenario SSP2-4.5;
- +0.63-1.01 m for scenario SSP5-8.5.

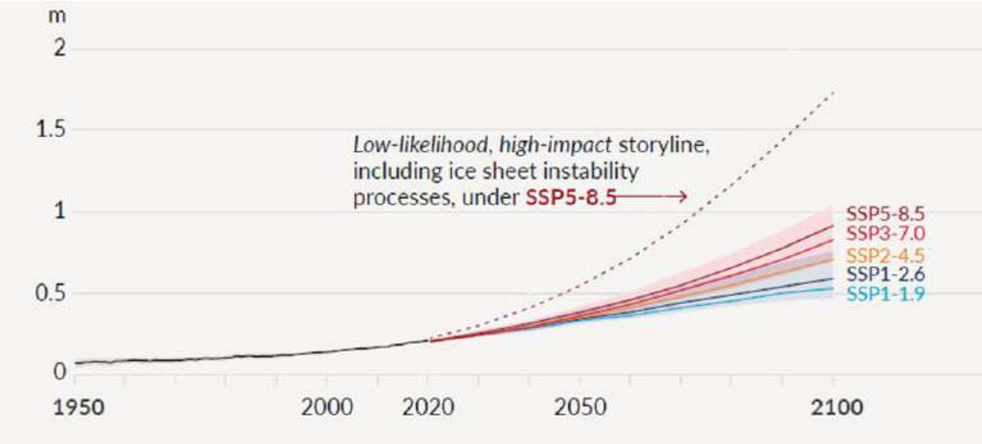


Figure 2-9. Projections of sea level rise for 2100 according to the different scenarios, IPCC 2021

It should be noted that there is an additional scenario called "ice cap break-up" whose probability is low but which is still considered plausible by the experts but whose consequences are difficult to quantify because of the existing uncertainties on the response processes. from ice caps to global warming. This scenario would lead to an increase in the general sea level of nearly 2m by 2100.

The report also provides information on regional variations in sea level rise across the globe as shown in Figure 2-10.

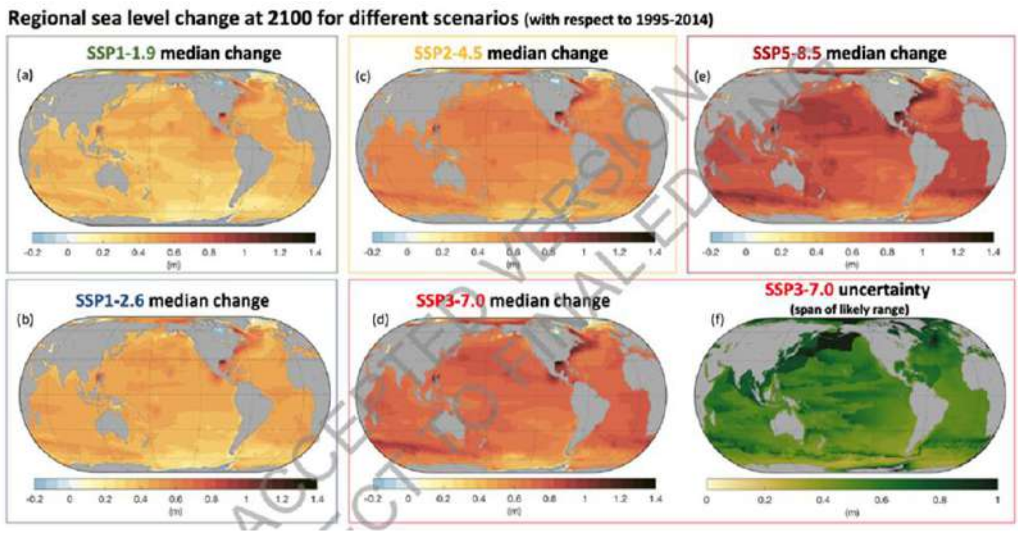


Figure 2-10. Regional variation in sea level rise across the globe for different scenarios

The regionalized **IPCC** sea level rise projections were extracted for the island of Ischia and are presented for the two most pessimistic scenarios (SSP5-8.5 and SSP5-8.5 Low Confidence) in Figure 2-11, with the values of 0.25 m and 0.26 m, respectively.

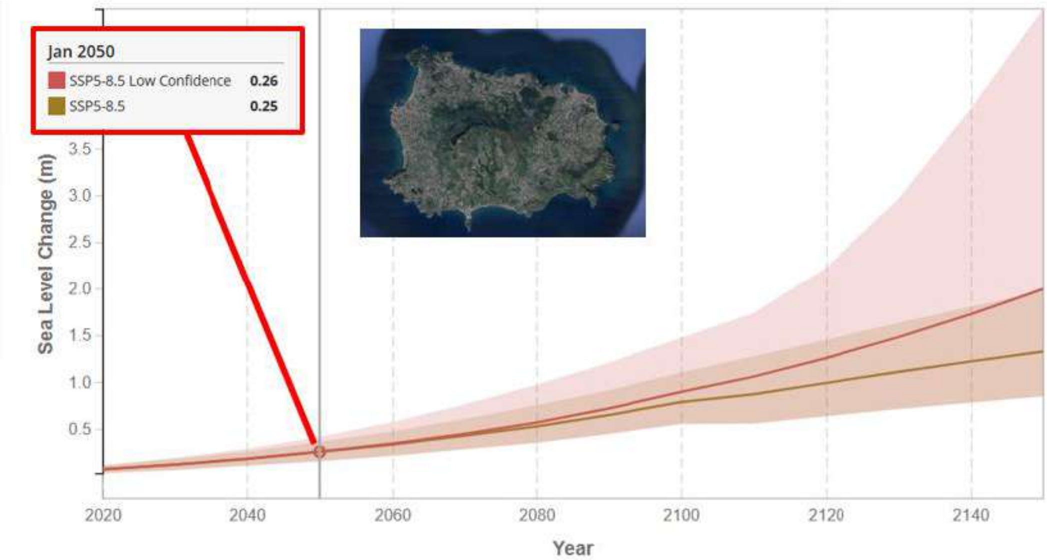


Figure 2-11. Extraction of sea level rise data for the island of Ischia for 2050 according to the SSP5-8.5 and SSP5-8.5 Low Confidence scenarios

Further to this, the IPCC states that uncertainty in climate change-driven future sea level, for 2050, is around 0.15 m for the global mean sea level (with IPCC projections for SSP1-2.6 between 0.17–0.32 m (likely range) and for SSP5-8.5 between 0.23–0.40 m (likely range). For the extracted sea level rise values for Ischia for SSP5-8.5, of 0.25-0.26 m, this would imply a range of around 0.17 – 0.34 m.

Using sea surface height anomalies from the **MEDSEA** model configuration, the sea surface height surrounding Ischia is projected to increase by 0.19 m, under RCP8.5 by 2050. This is projected to occur uniformly around this island, for areas where data is available (Figure 2-12. CMCC'S MEDSEA value of 0.19 m calculated under RCP8.5 lies within the IPCC's uncertainty range.

In addition, the "Modelling present and future climate in the Mediterranean Sea: a focus on sea-level change" paper by Sannino et al, published in 2022 suggests that sea levels within the Mediterranean Sea, surrounding Ischia, are projected to rise between 0.2-0.25 m for the period 2046-2065, compared to the reference period of 1985-2005. Using a combination of data from this source, as well as IPCC's sea level rise findings, further highlights that sea level rise might be greater than the 0.19 m value that anomalies from the MEDSEA model configuration is stating.

Therefore, for further risk analyses the higher value of 0.26 m was adopted (for the consideration of a conservative assessment, but without adopting more extreme assumptions on the upper limit of the uncertainty range of IPCC projections).

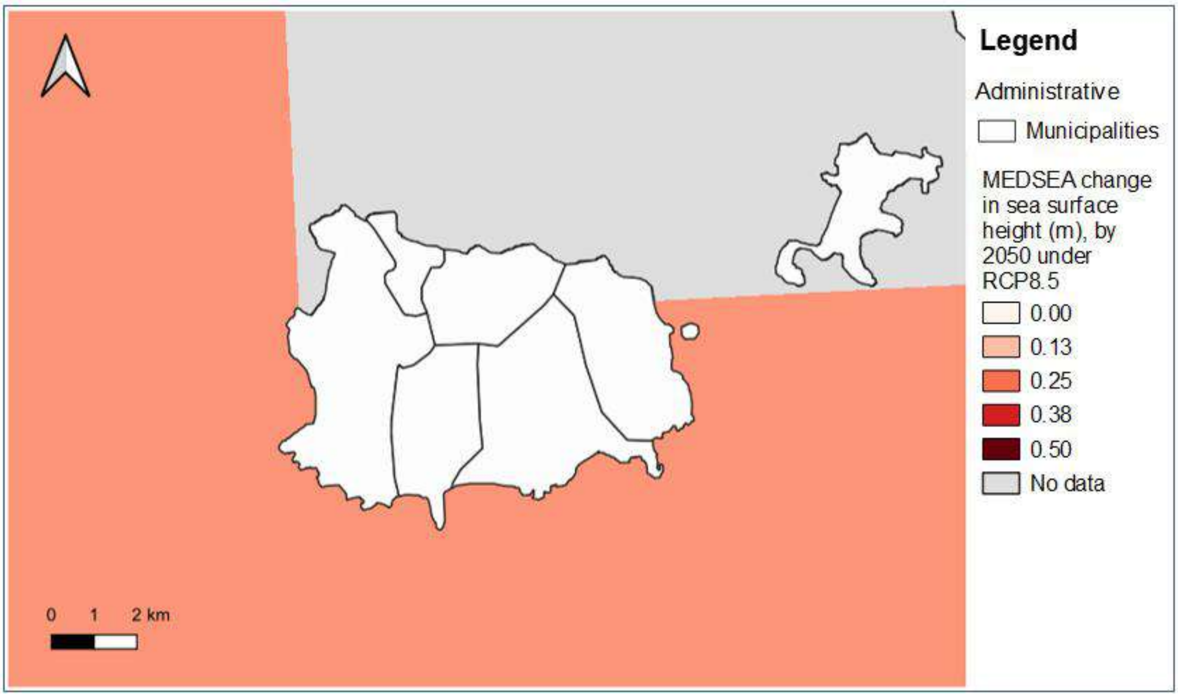


Figure 2-12: Change in sea surface height around Ischia by 2050, under RCP8.5. Source: DataClime

2.6.2 Increased storm intensity

Ischia is located right in front of the city of Napoli on the Italian western coastline. The island is open to every wave direction; however, its eastern coastline facing the continent is less exposed to the waves than the rest of the island.

The fetch between the Strait of Gibraltar and the Isle of Ischia is very large (> 1800 km) and can therefore allow the formation of very high waves during storms coming from the west.

An example of the wave conditions on the 22nd of November on the western Mediterranean Sea (issued from a wave modelling forecast), a couple of days prior to the landslide, show waves up to 5,5m coming from the south-west on Ischia coastline at 7am. In the evening at 9pm the swell turned completely west, and the waves reached more than 7m according to Figure 2-14.

The day of the landslide, on the 26th of November 2022, the forecasts show an unusual meteorological system that looked like an intense cyclonic depression, its centre located above Ischia and with wind (and therefore generated waves) turning counterclockwise around the island. In the Mediterranean Sea, this type of meteorological pattern is called a “Medicane”.

The **Medicane** is the combination of the two words: **Mediterranean** and **hurricane**. It is a Mediterranean subtropical cyclone, also called T.M.S. (Tropical-like Mediterranean Storm) by scientists.

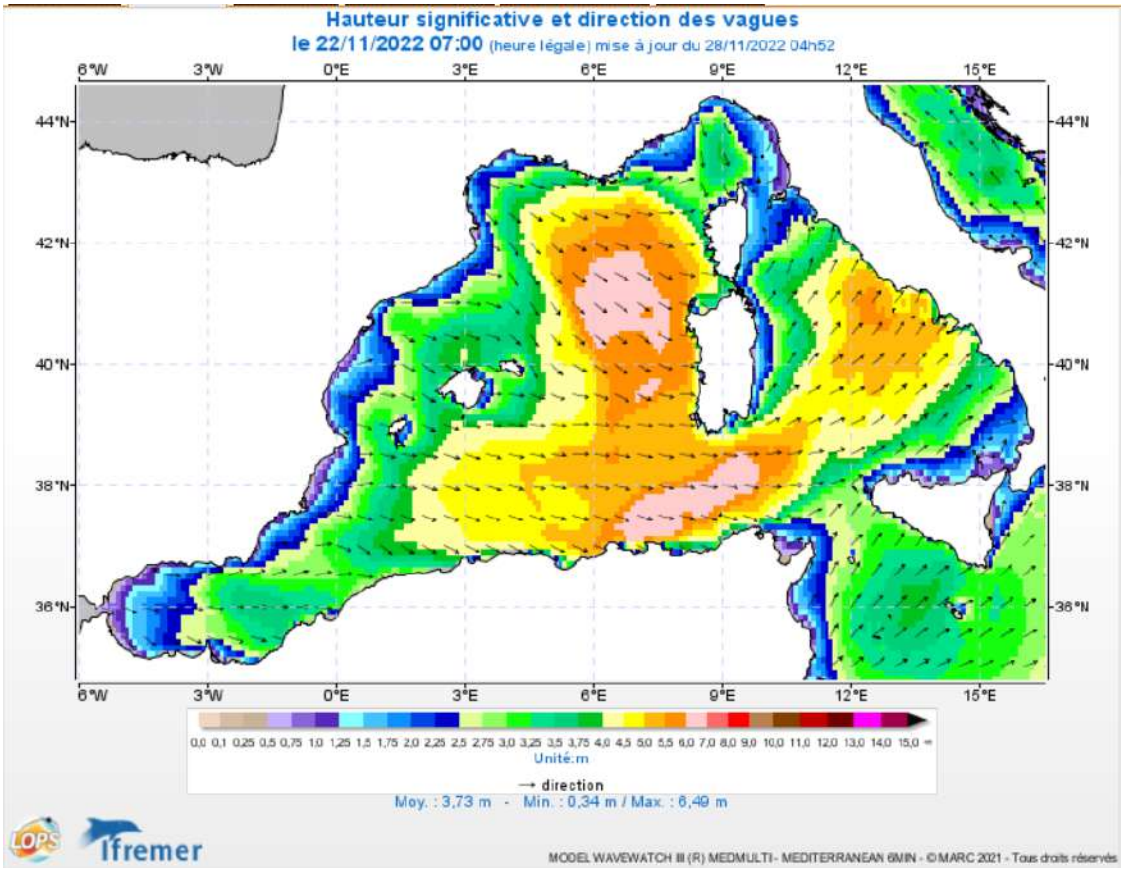


Figure 2-13. Wave modelling forecast for the 22nd of November 2022 at 7am. (source: . https://marc.ifremer.fr/resultats/vagues)

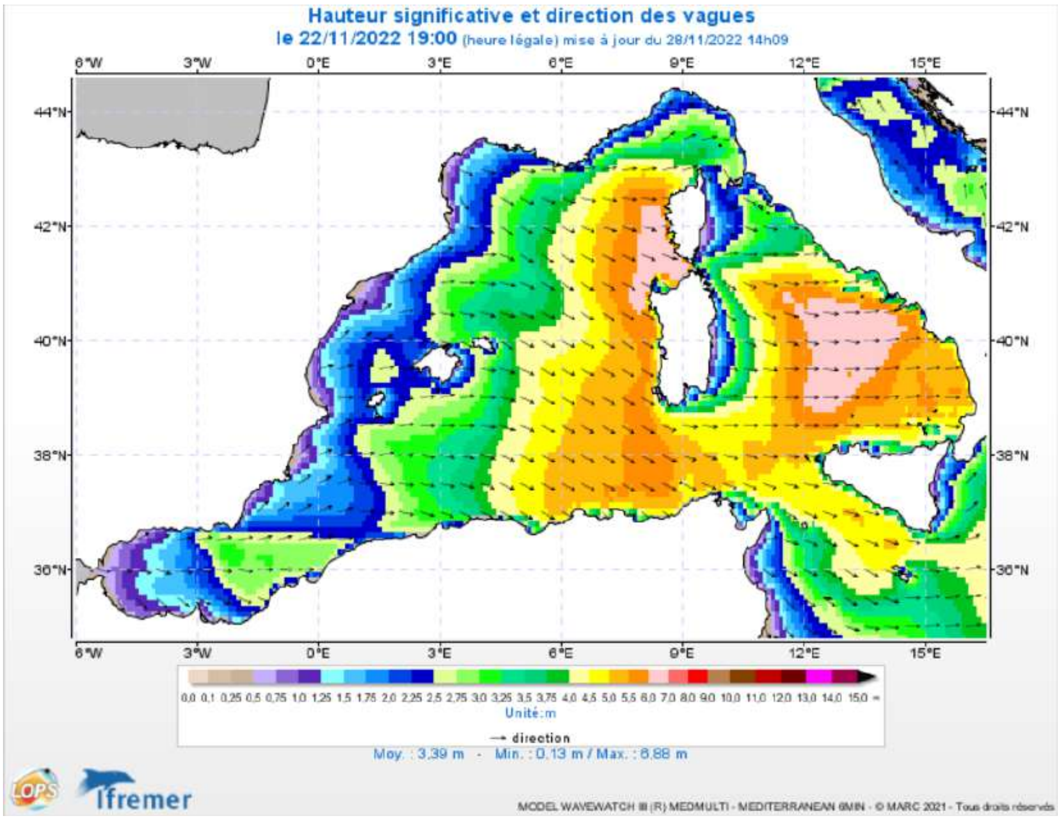


Figure 2-14. Wave modelling forecast for the 22nd of November 2022 at 9pm (source: https://marc.ifremer.fr/resultats/vagues)

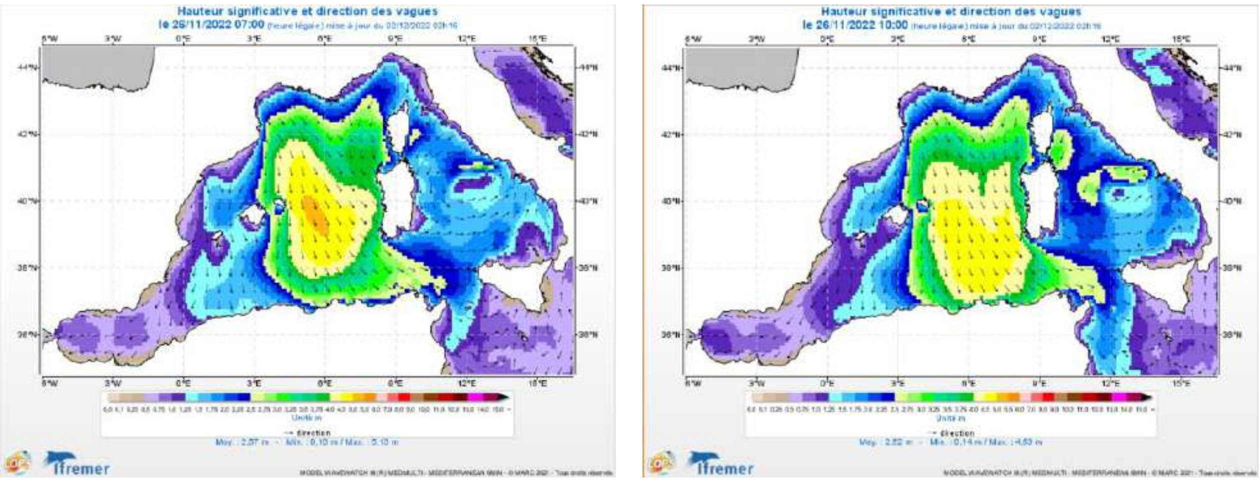


Figure 2-15. Wave modelling forecast for the 26th of November 2022 at 7am and 10pm, day of the land slide, showing the formation of a "Medicane". (source: https://marc.ifremer.fr/resultats/vagues)

According to the last scientific publications (here-after mentioned), global warming will induce changes in the wind and wave climate in the Mediterranean Sea.

For example, in: *Projected future wave climate in the NW Mediterranean Sea by M. Casas-Prat, J. P. Sierra published in 2013* projected future regional wave climate scenarios at a high temporal-spatial scale were obtained for the NW Mediterranean Sea, using five combinations of regional-global circulation models. Changes in wave variables were analyzed and related to the variations of the forcing wind projections, while also evaluating the evolution of the presence of the different types of sea states.

To assess the significance of the changes produced, a method was proposed, which accounts for the autocorrelation of data and correctly reproduces the extremes. For the mean climate, relative changes of Hs (significant wave height) up to ±10% were obtained, whereas they were around ±20% for the extreme climate. In mean terms, variations of Hs are similar to those associated with wind speed but are enhanced/attenuated, respectively, when fetch conditions are favorable/unfavorable.

Medicane is an already known consequence of climate change and will therefore be more and more frequent in the following years leading both in higher intensity of the wave but also in different directions[29] [30] [31].

2.6.3 Storm-surge trends

Europe

Calafat, F.M., Wahl, T., Tadesse, M.G. et al. in "Trends in Europe storm surge extremes match the rate of sea-level rise. Nature 603, 841–845 (2022)." have shown that coastal communities across the world are already feeling the impacts of climate change through variations in extreme sea levels. These variations reflect the combined effect of sea-level rise and changes in storm surge activity. Understanding the relative importance of these two factors in altering the likelihood of extreme events is crucial to the success of coastal adaptation activities.

Existing analyses of tide gauge records agree that sea-level rise has been a considerable driver of trends in sea-level extremes since at least 1960. However, the contribution from changes in storminess remains unclear, owing to the difficulty of inferring this contribution from sparse data and the consequent inconclusive results that have accumulated in the literature. In the abovementioned publication, they analyse tide gauge observations using spatial Bayesian methods to show that, contrary to current thought, trends in surge extremes and sea-level rise both made comparable contributions to the overall change in extreme sea levels in Europe since 1960.

They determined that the trend pattern of surge extremes reflects the contributions from a dominant north–south dipole associated with internal climate variability and a single-sign positive pattern related to anthropogenic forcing. Their results demonstrate that both external and internal influences can considerably affect the likelihood of surge extremes over periods as long as 60 years, suggesting that the current coastal planning practice of assuming stationary surge extremes might be inadequate.

Mediterranean Sea

The study "The impact of climate change on the storm surges of the Mediterranean Sea: Coastal sea level responses to deep depression atmospheric systems, Ocean Modelling published in 2023 by Christos V. Makris, Konstantia Tolika, Vasilis N. Baltikas, Kondylia Velikou, Yannis N. Krestenitis, aims to systematically assess the impacts of projected climate change on episodic events of sea level elevation in coastal areas of the Mediterranean, induced by severe weather conditions identified as deep depressions. They try to add new insight in the long-term, climatic timescale, identification of affected parts of the Mediterranean coastal zone correlated to low atmospheric pressure systems, indicative of the Mediterranean basin during the 21st century.

To achieve this goal, an integrated quantitative assessment is proposed by combining projections from available projections, based on Representative Concentration Pathways; RCP 4.5 and 8.5, with advanced numerical modelling and statistical post-processing for the definition of cyclonic weather impacts on characteristic coastal zone hotspots. To this end, climate projections and outputs from three Regional Climate Models (RCMs) of the Med-CORDEX initiative at the Mediterranean basin scale are used and extensively evaluated against re-analysis data.

These atmospheric datasets feed a robust storm surge model (MeCSS) for the simulation of barotropic hydrodynamics (sea level elevation and currents) thoroughly validated against in situ sea level observations by tide-gauges. The results corroborate a projected storminess attenuation for the end of the 21st century,

[29] https://www.ipcc.ch/report/ar6/wg2/chapter/ccp4/#Cavicchia--2014
[30] https://www.ipcc.ch/report/ar6/wg2/chapter/ccp4/#Nissen--2014
[31] https://www.ipcc.ch/report/ar6/wg2/chapter/ccp4/#Romera--2017

yet local differentiations in storm surge maxima around the Mediterranean coastal zone are pinpointed. Moreover, a slight reduction of average storm-induced Mean Sea Level (MSL; component attributed solely to the meteorological residual of sea level elevation) is also apparent towards the end of the 21st century. Extreme storm surge magnitudes range between 0.35 and 0.50 m in the Mediterranean with higher values along parts of its northern coasts (Venice lagoon, Gulf of Lions, northern Adriatic and Aegean Seas, etc.) and the Gulf of Gabes in its southern part. Overall, the spatial distributions of surge maxima are estimated to remain similar to those of the past throughout the entire Mediterranean coastal zone.

Differentiations between the two scenarios (RCP4.5 and 8.5) used are obvious, not so much related to the spatiotemporal distribution of storm surge maxima, which shows a very stable pattern, but more in terms of their magnitudes. Indicatively, a decrease of surge maxima from -30% to -2% can be observed towards the end of the 21st century, especially for RCP8.5-driven MeCSS simulations. This is a spatially averaged estimation, yet for some specific coastal sites in Croatia, Spain, Italy, and France, such as Rovinj, Bakar, Toulon, Trieste, Ajaccio, Genova, Marseilles, Naples, Venice, Cagliari, Ancona, Ibixa, and Barcelona, the storm surge maxima might increase from 1% to 22% under different RCM/RCP combinations towards the end of the 21st century. Their analysis leads to the quantification of deep depression systems' effect on the coastal sea level elevation due to storm surges towards 2100. The strongest correlations of deep depression events to high sea levels are observed in several parts along the northern Mediterranean coasts (Gulfs of Valencia and Lions, Ligurian and northern Adriatic Seas). They are followed by mid-latitude areas around Corsica, Sardinia, the mid-zonal Italian Peninsula and the Adriatic, and the northern Aegean Sea. The influence of deep depressions on storm surges is lower for Sicily, South Italy, Peloponnese, Crete, the southern Aegean archipelago, and Alboran Sea.

The only exceptions in the generally unaffected southern Mediterranean littorals are the Gulfs of Gabes and Alexandretta. These apply to the 20th century; however, they seem to repeat for 21st century estimations, with even more pronounced differentiations between the southern and the northern parts. A projected northward shift of the main deep depression centres over the Mediterranean towards the end of the 21st century, is likely the reason for the latter. The climate change signal (difference of Future–Reference Period) of the deep cyclones' effect on the episodic increases of coastal sea level seems to have a very clear pattern of slight attenuation in certain regions, i.e., Sardinia, Corsica, the Ligurian and Adriatic Seas, and the entire Italian peninsula for all RCM-fed implementations towards the end of the 21st century. Conditionally, this is the case for the Gulf of Valencia, the north-western African coasts, the Alboran, Ionian, Aegean, and Libyan Sea coasts, under specific combinations of RCM/RCP forcings.

On the other hand, a possible increase of the Mediterranean deep depressions' influence on the coastal storm surges might be the case for the Gulf of Lions, the Ionian, Aegean and Levantine Sea basins, covering the north-central and north-eastern coasts of Africa. In general, a positive influence of deep depressions to storm surge maxima would probably refer to areas of mid-to-high storm surge maxima (e.g., Aegean, Ionian, Gulf of Lions or Valencia or Gabes, etc.), but not the highest throughout the basin (e.g., Venice lagoon, Ligurian, Adriatic, etc.). In the latter coastal regions, however, intense local wind forcing mechanisms (i.e., Scirocco) are bound to play an essential role in the formation of high storm surges. The produced results can be used in focused studies for integrated hydrologic/hydrodynamic modelling under projected climate change conditions in the 21st century.

2.7 Summary of climate projections and classification of climate hazard change for the vulnerability assessment

The presented climate projections can be summarized as follows:

Temperature

- The average mean temperature is projected to increase between 1° C (RCP2.6) and 1.8°C (RCP8.5) by 2050.

- The number of summer days (T > 29.2°C) is projected to increase across all emissions scenarios, between 7 days (RCP2.6) and 14 days (RCP8.5).
- The number of tropical nights (minimum temperature > 20°C) is projected to increase across all emissions scenarios, between 21 days (RCP2.6) and 36 days (RCP8.5).
- The number of days contributing to "warm spells", when the maximum temperature (TX) remains above its climatological 90th percentile, is projected to increase across all emissions scenarios, between 37 days (RCP2.6) and 89 days (RCP8.5).
- Cooling degree days are projected to increase across all emissions scenarios annually, with up to 206 cooling degree days under RCP8.5. On the contrary, heating degree days are projected to decrease across all emissions scenarios.
- Overall, the temperature-related projections show a clear trend towards increased average and extreme temperatures in the future, indicating more severe heat waves and increased risk of droughts and wildfires. The projections show some uncertainty related with the extent of the future changes, but these are mostly related to the emission scenarios (with stronger changes expected for higher emissions).

Precipitation

- The average daily precipitation in wet days is projected to slightly increase by 4 mm under RCP2.6 and projected to slightly decrease under both RCP4.5 (-2 mm) and RCP8.5 (-1 mm).
- The number of very heavy precipitation days (P≥20mm) per year is projected to increase under RCP2.6 and RCP8.5 by 1 day, under RCP4.5 there is projected to be no change.
- The annual maximum 1-day precipitation is projected to increase across all emissions scenarios, between 4 mm (RCP2.6) and 8 mm (RCP8.5).
- The number of consecutive dry days is projected to increase under both RCP4.5 (+3 days) and RCP8.5 (+2 days), with no change projected under RCP2.6.
- Overall, the precipitation-related projections show a substantial uncertainty, not only between different emission scenarios, but also between different climate models. This is not only related to uncertainty in the representation of precipitation processes in climate models, but also to the inherently high natural variability. For extreme precipitation, the climate models generally agree on a future increase, with uncertainty related mainly with the extent of this increase.

Wind

- No relevant changes in extreme wind speed are projected (with a small decrease indicated under RCP8.5).

Hydro-geo hazards

- **Landslides:** Based on climate change projections of precipitation and conditional probabilities of rainfall and landslide occurrence, the occurrence probability of landslides is projected to change between -15 % and +20 % under a future climate for 2040-2060, depending on the climate scenarios and model projections. A more pronounced increase can be expected for very extreme events with a disastrous potential like the event in 2022, with worst case scenarios showing an increase from one occurrence in 22 years in the past to four or five occurrences in 22 years in the future.
- **Floods:** Extreme precipitation with return periods between 5 and 100 years is projected to increase between 5% and 25%, depending on the return period and the emission scenario. The small scale, precipitation-driven floods on Ischia are expected to show a similar increase in flood discharge. Numerical simulations of flood discharge based on increased storm precipitation will be carried out using the results of this study and will provide estimates of the range of flood discharge increase due to climate change.

Wildfire

- With the Fire Weather Index clearly increasing (with higher increases in higher-emission scenarios) the danger of wildfire is projected to increase under a future climate.

Sea level rise

- Regional ocean models indicate an increase of 0.19m and under RCP8.5 by 2050. Global climate model projections under RCP8.5 range between 0.17 m and 0.34 m increase, with ensemble mean values around 0.25/0.26 m. The latter were adopted for further impact modelling.
- A literature review does not show a clear trend for future changes in storm surges in the Mediterranean Sea. Therefore, no change was assumed in impact analyses.

A summary of the strongest seasonal changes by 2050, as projected by the CORDEX climate model ensemble mean under RCP2.6, RCP4.5 and RCP8.5 is provided in Table 2-14.

Table 2-14: The season each variable is projected to experience its greatest change (increase/decrease) from its current baseline value by 2050 under each emission scenarios. This table covers the variables for which the seasonal differences are relevant and known.

Variable	2050 RCP2.6	2050 RCP4.5	2050 RCP8.5
Mean Temperature	JJA/SON (increase)	JJA (increase)	SON (increase)
Summer days	JJA (increase)	JJA (increase)	JJA (increase)
Warm spell duration	SON (increase)	JJA (increase)	SON (increase)
Cooling Degree Days	JJA (increase)	JJA (increase)	JJA (increase)
Heating Degree Days	DJF (decrease)	DJF (decrease)	DJF (decrease)
Tropical Nights	JJA (increase)	JJA (increase)	JJA (increase)
Avg. Precipitation in Wet Days	DJF/JJA (increase)	JJA (decrease)	MAM/JJA (decrease)
Very Heavy Precipitation Days	DJF (increase)	No change	No change
Maximum 1-Day Precipitation	DJF (increase)	JJA (decrease)	DJF (increase)
Consecutive Dry Days	MAM/SON (increase)	JJA (increase)	JJA (increase)
Extreme Wind Speed	DJF (decrease)	DJF/JJA (decrease)	DJF (decrease)
Fire Weather Index	MAM/JJA (increase)	MAM/JJA (increase)	MAM/JJA (increase)

Based on these expected changes in different climate variables and related climate hazards, the severity of the change of the main climate hazards was evaluated and classified as shown below in Table 2-15. The **classification of climate hazard change** is based on expert judgement and considers the extent of the projected future change, the uncertainty related with the projections and the natural variability for each of the climate hazards.

Table 2-15 draws from a classification of exposure in the terms of the EU "Technical guidance on the climate proofing of infrastructure in the period 2021-2027", summarizing the general changes over the entire island. Despite its small area, there are spatial variations, and not all sectors include infrastructure assets or operations in all parts of the island. The actual exposure is therefore assessed in the sectoral vulnerability assessments in Chapter 3 and might partly vary from the overall classification presented here (e.g. there is only a small number of agricultural lands located close to the coast, so that the exposure to coastal flooding is low for this sector, despite change in sea level and related coastal flooding being classified as high for the overall island).

Table 2-15 Classification of hazard change for the main climate hazards on the island of Ischia (1: small change, 2: medium change, 3: large change)

Climate hazard	Hazard change (from 1 small to 3 large change)	
Heat	High	3

Drought	Medium	2
Wildfire	Medium	2
Storm precipitation	Medium	2
River Flooding	Medium	2
Landslides	Medium	2
Wind	Low	1
Coastal Flooding	High	3

3 Vulnerability assessment, potential climate impacts and possible adaptation activities

The following sections will provide an assessment of potential climate impacts on the main economic sectors and activities on the island of Ischia, based on the climate change projections for relevant climate hazards provided in Chapter 2 above. In combination with the specific climate sensitivities of the assets and operations of each sector, the climate vulnerability of each sector is assessed. Considering the main climate vulnerabilities, possible adaptation activities are identified and, where possible, the cost of the recommended adaptation activities is estimated.

Due to the limited timeframe of this study, the knowledge of the current situation and future climate change conditions is limited (e.g. only high-level estimation of flood and landslide risk). Also, the inventory of sector-specific assets and historical weather-related impacts is incomplete, despite the attempts to include as much information by local stakeholders as possible, through field missions completed within the short timeframe. Therefore, the presented study provides a first climate vulnerability assessment, equivalent to a Phase 1 (screening) as defined in the EU "Technical Guidance on the climate proofing of infrastructure in the period 2021-2027".

The sectoral climate vulnerability classification is calculated, for the sectors for which such a classification was considered an achievable and useful analysis, from the sectoral exposure and the sectoral sensitivity based on the classification scheme shown in Table 3-1.

Table 3-1 Classification of climate vulnerability based on exposure and sensitivity classifications

Sensitivity **Exposure +**	**1**	**2**	**3**
1	1 - Low	1 - Low	2 - Medium
2	1 - Low	2 - Medium	3 - High
3	2 - Medium	3 - High	3 - High

However, it was attempted to analyse impacts with high relevance, and the related options for adaptation activities, in the most relevant sectors in more detail. For some sectors with more detailed analysis, like the Ports and coastal infrastructure sector with estimations of required quay heights, the basic vulnerability matrix was not considered a useful analysis and is not provided.

More detailed analyses were also necessary to allow an estimation of the cost of adaptation activities for the cost-benefit analysis performed for Part 2 of this report. However, for all activities recommended in this study, further, more detailed studies are required before implementation and to allow for flexible adjustments in the future.

The following sections of Chapter 3 provide sectoral assessments for the key sectors defined between EIB and the Struttura Comissariale (roads, buildings including the island hospital, ports and coastal infrastructure, water supply and wastewater, energy supply, tourism, agriculture and forestry and nature-based solutions). After the sectoral analyses, cross-sectoral recommendations for the most effective adaptation activities related to landslides and floods are summarized, which are generally perceived as the most dangerous climate hazards on Ischia. A further cross-sectoral section provides general design recommendations for a climate-resilient reconstruction. The final section of this Chapter 3 provides a summary of its key findings.

3.1 Roads

3.1.1 Roads in Ischia

The road network in Ischia consists of four categories. They include: a major road that runs in a rough circle around island (road SP270) having total length of 30.5km, linking the main towns and districts of Ischia Island; a secondary road network of 163.7km; and a tertiary road network of 148.6km. Additionally, there is a network of paths, 217km in total. The road network also stretches to each of the smaller towns and important destinations such as beaches and tourist attractions. There are also many roads in the mountain areas providing routes that allow for road users to cut directly across the island.

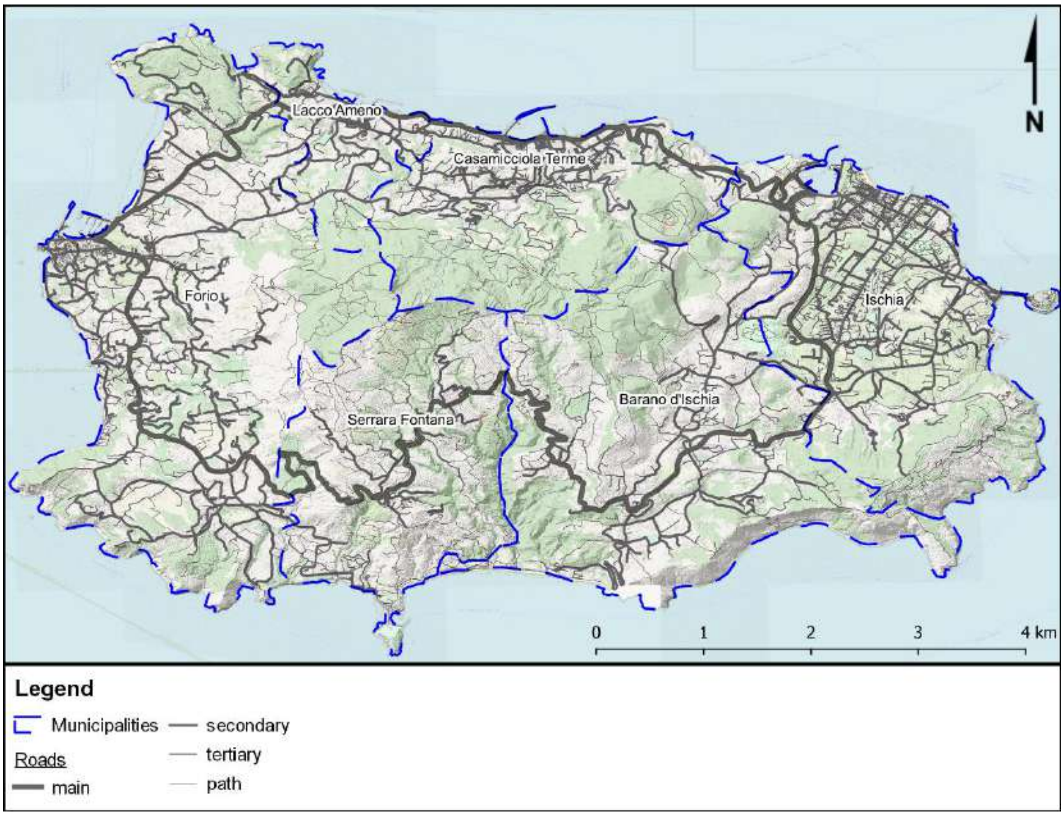


Figure 3-1 Road network of Ischia.

3.1.2 Climate sensitivity and potential climate impacts on road infrastructure in Ischia

The changing climate over the short to medium and long-term will bring with it an increase in various hazards to the road transport infrastructure. In summary, the main climate changes projected are:

- Increased maxima of the daily maximum temperature
- Decreased and/or increased rainfall
- Increased frequency of extreme weather events
- Longer drier/drought periods
- Sea-level rise

Each of these climate hazards and associated impacts have distinct effects on the road transport infrastructure as described in the following chapters below.

In addition to improper design, many of the problems related to a lack of climate resilience of the road infrastructure stem from a lack of or poor-quality maintenance. Water remaining on road surface, road failures, overtopping, wildfires, ineffective drains, etc. are all brought about by insufficient maintenance. This is an international problem, as no country in the world is known to have a maintenance budget adequate for all the necessary tasks. However, areas of highest strategic importance that are most impacted should be prioritized and maintenance provided as regularly as possible, but certainly before the onset of the wet season. Maintenance should be preventative, and works should be done as soon as the first visible signs of defects appear on road surface.

Certain pavement defect types might indicate different problems on road structures and its subsoil. Wide longitudinal cracks might reveal locations where land mass has moved under the road and torn pavement. Alligator cracks show locations with poor drainage or possibly blocked culverts and side drains.

Preventative maintenance against initial pavement defects reduces the risk of a road failing and becoming inaccessible.

Table 3-2 Example of pavement defects in Ischia

	
Alligator cracking due to inadequate bearing capacity and possibly poor drainage	Severe cracking leads to accelerated deterioration

3.1.3 General landslides (landslides, debris and rockfalls)

Risk of GMFs might increase when events of extreme rainfall become more frequent in the future. In the following maps (Figure 3-2 and Figure 3-3), roads under mass movement risks based on GIS assessment are presented. This analysis is a very general screening of possible risk sections and does not yet illustrate the actual risk in the field, since some adaptation activities might be already in place. After identification of road sections under risk, more detailed risk mapping and scoring and prioritization can be done, as a combination of desk study and field surveys, separately for landslides and rockfalls (not part of this study).

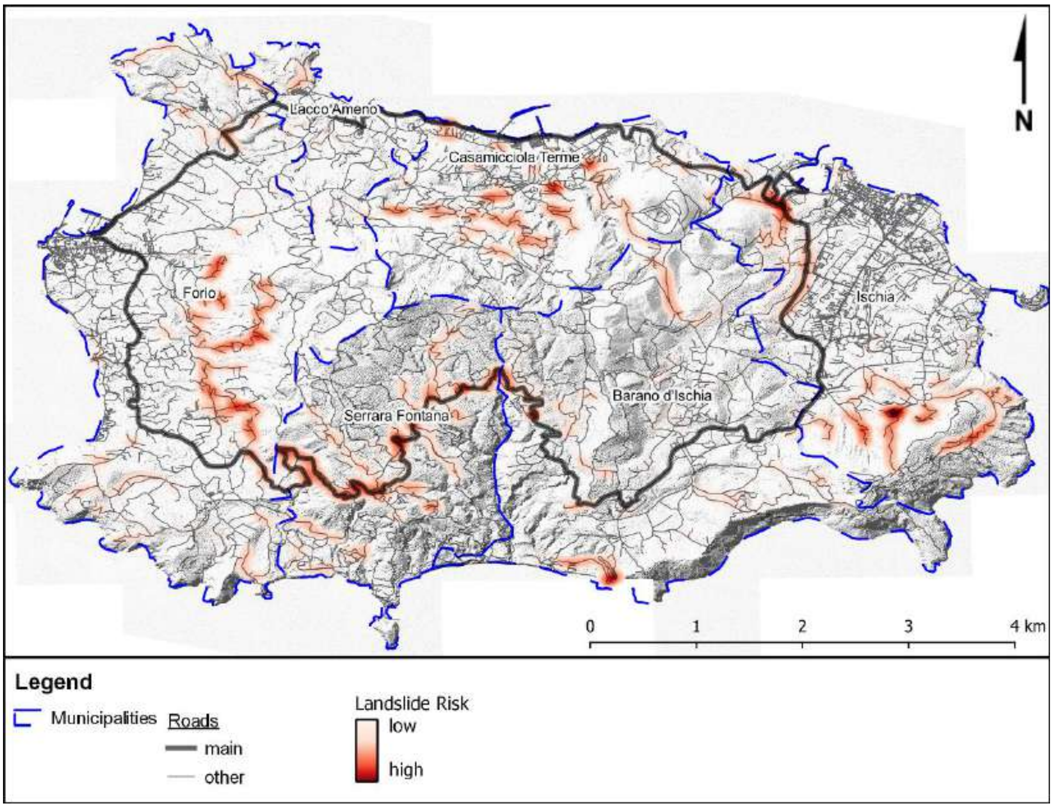


Figure 3-2 GIS-study of the landslide risk probability for the roads

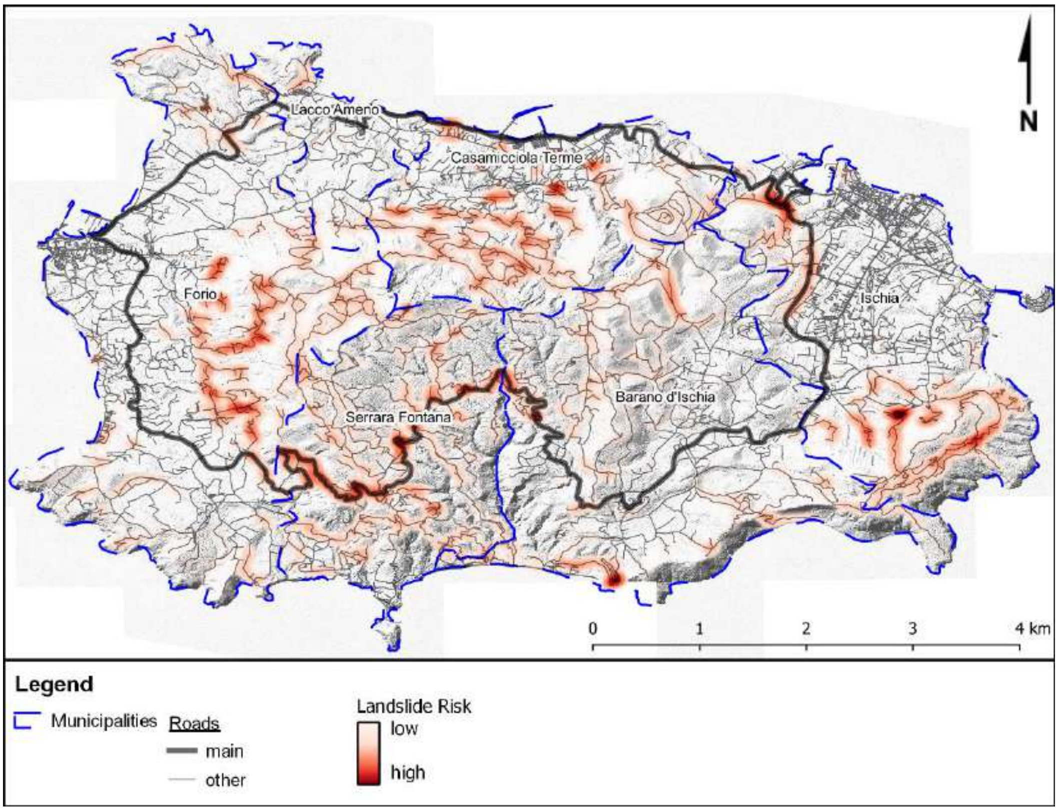


Figure 3-3 GIS-study of the landslide risk probability for the roads and paths

Table 3-3 shows the volume (km) of road under risk of mass movements.

Table 3-3 Road network under exposure of landslides (including rockfalls) based on GIS-data

Road category	**Total length (km)**	**Under high exposure (%)**	**Under moderate exposure (%)**	**Under low exposure (%)**	**No exposure (%)**
Major	30.5	15%	8%	11%	66%
Secondary	163.7	8%	10%	8%	73%
Tertiary	148.6	8%	12%	9%	71%
Path	217	23%	20%	15%	42%
Total	**559.8**	**14%**	**14%**	**11%**	**60%**

3.1.4 Flooding

Flooding is an uncontrollable event related to topography and precipitation and occurs in both valleys (streams and rivers) and flat areas (flood plains and estuaries). Thus bridges, culverts, embankments and roads themselves can be subjected to periodic inundation often leading to damage or even destruction of the road or the bridges and culverts.

In the following maps (Figure 3-4 and Figure 3-5), roads under flood risks based on GIS analysis are presented. This analysis is a general screening of possible risk sections and does not indicate the actual risk in the field, since some adaptation activities might already be in place. After identification of road sections under risk, more detailed risk mapping and scoring should be done, as a combination of desk study and field surveys. Table 3-4 shows the volume (km) of roads in flood prone areas.

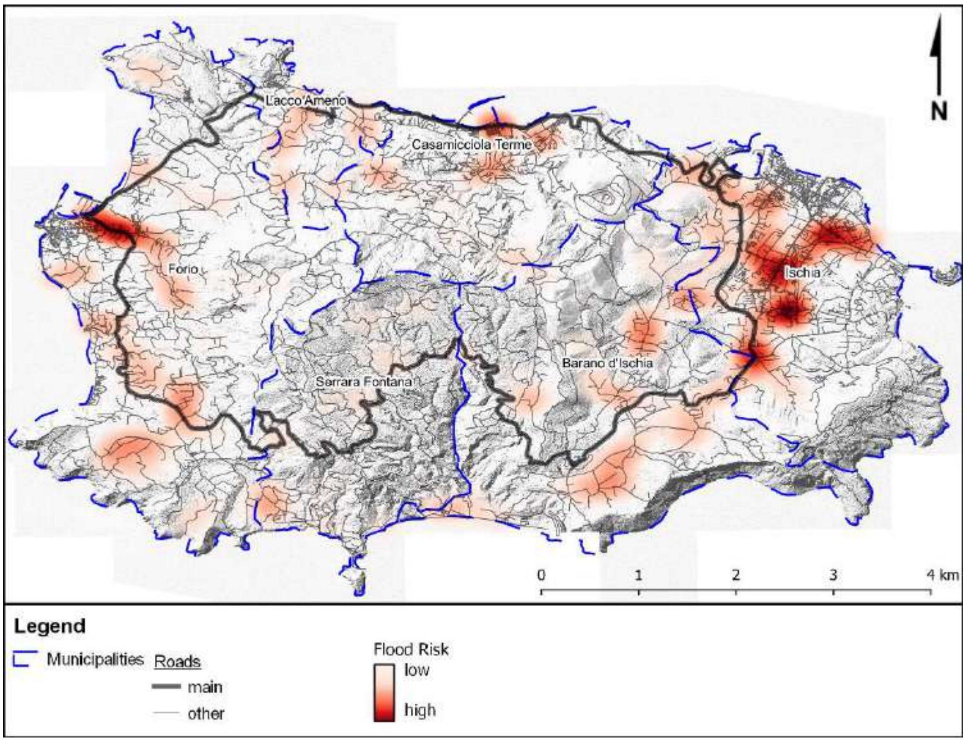


Figure 3-4. GIS analysis (heat map) of the flood risk for the roads.

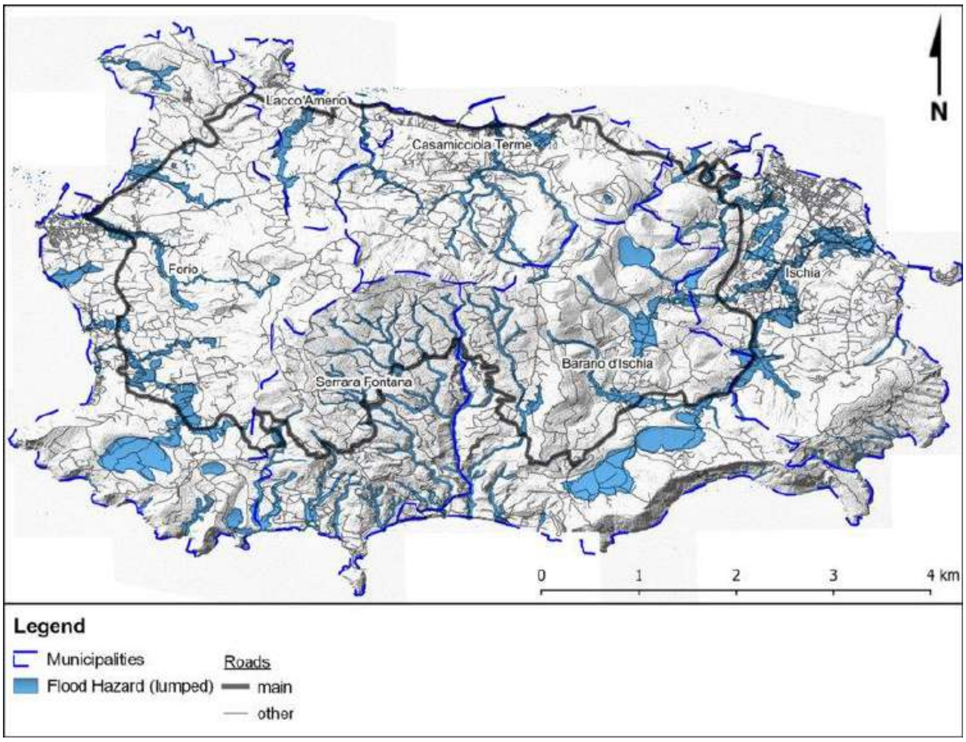


Figure 3-5 Flood map and road network of Ischia Island

Table 3-4 Road network in flood prone areas.

Road category	**Total length (km)**	**Under risk total (%)**
Major	30.5	16%
Secondary	163.7	16%
Tertiary	148.6	14%
Path	217	10%
Total	**559.3**	**13%**

3.1.5 Sea-level rise

The sea level surrounding Ischia is projected to increase by 0.26 m, under RCP8.5 by 2050. Rising sea level may increase the impact of wave action on coastal roads or the coastal structures under them. It is very hard to re-align some of the roads in Ischia further to the inland as available land is very limited. It is possible to construct embankments to isolate the roads from the effect of sea-level rise. Whereas the impact is likely to be marginal (i.e. most of the roads are currently at 4 or 5 m above sea level), in some locations, protection measures on side slopes and embankments against wave action will need to be installed. Sea-level rise is probably affecting only 1 or 2 road sections on the island (roads to Spiaggia Sant'Angelo and Castallo Aragonese), so the impact is not that significant but can prevent entrance to the sites during Aqua Alta events. A more detailed digital elevation map paired with a coastal model can provide exact information on the possible need for adaptation on the mentioned sites.

3.1.6 Wildfire

Ischia has vegetation in the wet season, that dries off in the dry season. The timing of this (and possibly even the types of vegetation) are expected to change with climate change[32]. Burning of vegetation has a deleterious effect on the stability of soils and increases the possibility for landslides and debris flows[33]. Burning also has an impact on bituminous materials (particularly runaway wildfires) as well as wooden components of the road infrastructure, mostly road furniture (guard railings). It will be important that the impacts of wildfires are minimised.

Roads going through forested areas are directly in risk of wildfires. During wildfire events, roads are impassable due to smoke and fire.

Figure 3-6 Road section going through forest

In Figure 3-7, a land cover map shows the roads under potential wildfire risks. The map shows historical wildfire events from the EFFIS-dataset as well as CORINE land cover, showing the landcover categories of the island, including areas prone to wildfires, i.e. different types of forest.

[32] https://www.sciencedirect.com/science/article/abs/pii/S0034666715000433
[33] https://www.sciencedirect.com/science/article/abs/pii/S0012825205001467

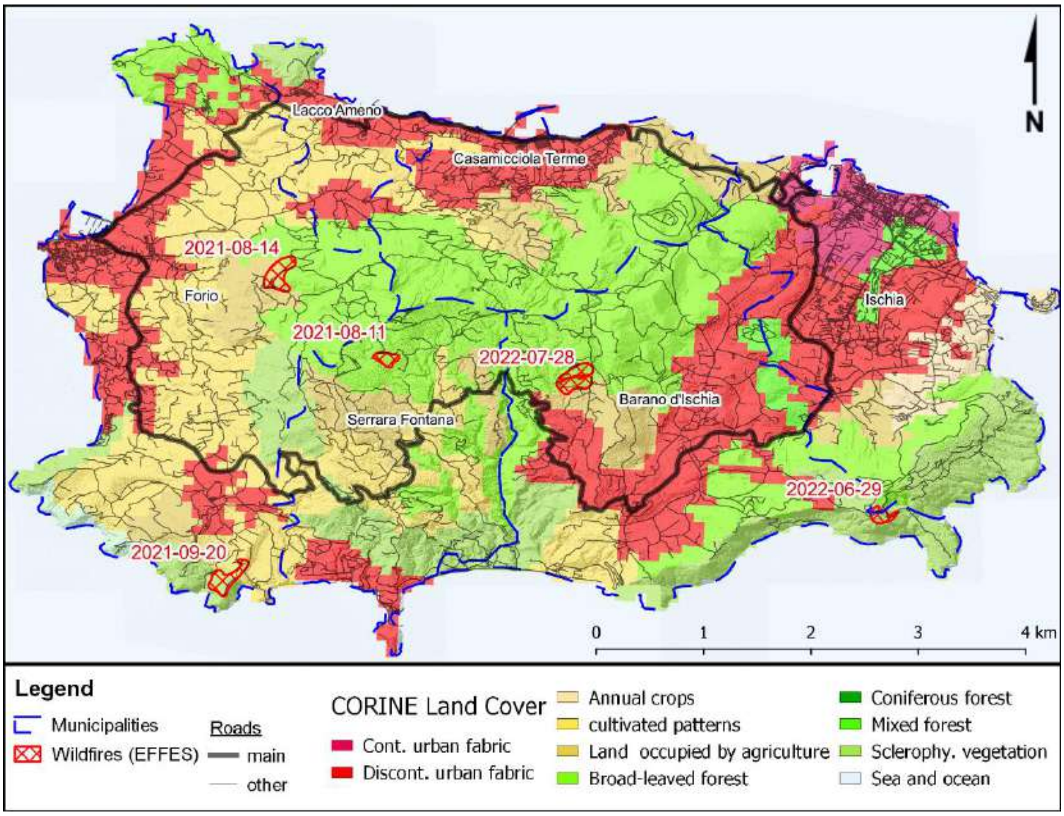


Figure 3-7 Land Cover map considering historic wildfires from EFFIS-dataset as well as CORINE land cover showing the landcover categories of the island (including area prone to wildfires) [34]

3.1.7 Increased temperature

Prolonged higher temperatures will have a direct impact on facilities such as concrete bridges and asphalt pavements and lead to evolutionary changes in vegetation growth and type. They will also affect erosion and siltation of drainage structures and increase windiness (amount and speed).

One of the projections identified in most countries is the increase in the number of consecutive very hot days (> 35°C). This will have an effect on asphalt roads that will remain in a soft condition (more prone to rutting), thick concrete structures that will not cool at night except in shadow areas and are likely to develop strong temperature gradients, and the drying out of soils around the road environment.

Increased temperatures, in combination with the increased windiness described below, will lead to a significant increase in uncontrollable wildfires, as witnessed in Italy in the past few years. This too will increase the potential for erosion and slope surface instability as the soil-binding effects of plant roots will in many cases be lost after extreme burning.

3.1.8 Changes in precipitation patterns

In many cases, the reduction in rainfall is likely to prove beneficial to the road infrastructure, for instance by decreasing soil moisture and thus increasing the in-situ shear strength of soils. However, reduced precipitation will also create a number of problems. Excessive drying of certain soils will lead to shrinkage and cracking of the soils. These cracks can be transferred to the overlying pavement structures, which will allow a rapid ingress of water into the soil when the first rain falls if they are not sealed.

[34] https://effis.jrc.ec.europa.eu/about-effis/technical-background/european-fire-database

Increased rainfall might exceed the capacity of the drainage system, causing flooding. Poor or inadequate drainage will also weaken the road structures leading to lower bearing capacity and serious pavement defects. Increased rainfall might affect the stability of the slopes and lead to landslides.

3.1.9 Increased frequency of extreme events

Most countries, including Italy, already have periodic extreme events and hence the use of storm return periods in the design of bridges and drainage works. Such extreme events are expected to increase in frequency and intensity as described in Chapter 2.2.

Such future events are likely to result in periodic flooding, increased mass movements (most of which are induced by water), increased road failures where roadside drainage is inadequate, possible bridge failures (mostly related to blockages caused by debris (usually trees)) in flooded rivers, among other impacts.

Locations where roads and structures have been in place for many decades and survived numerous extreme storms in the past, are failing under present extreme events. This is partly due to the deterioration of the facilities with age but is more commonly associated with the greater intensity of the water runoff.

3.1.10 Longer drier/drought periods

The increase in the number of extreme events together with a possible projected decrease in rainfall will lead to longer periods when no rainfall occurs. This will lead to dying-off of vegetation, increased susceptibility to erosion.

Issues such as water shortages will also impact construction processes, where obtaining sufficient water for compaction, curing of stabilized layers, etc. (already a problem in many countries) will become more difficult. In addition, the use of groundwater from declining levels and with diminishing quality will affect future construction.

3.1.11 Other issues

Various other issues such as fog, smog, high or low humidity and increased ultra-violet radiation, could all have direct or indirect effects on the performance and operation of the transport infrastructure, but these are generally minimal and are likely to be counteracted as they are observed.

3.1.12 Summary of potential climate change impacts

A summary of the potential climate change impacts related to the various climate change hazards is provided below in Table 3-5.

Table 3-5 Climate hazards and impacts on the road infrastructure

Climate hazards	Impacts on the Road and Bridge Infrastructure
Precipitation changes: Extreme rainfall events / Increase/decrease of seasonal and annual rainfall	• Landslide risks increase • Risk for increased rockfalls • Flooding of roadways and wash-aways • Loss of strength of layer materials, especially in the upper support layers of the road • Damage to thin bitumen bound surfaces • Damage to pavement edges • Softening the surfacing material of unpaved roads • Loss of shape of unpaved roads • Erosion and weakening of unpaved shoulders • Erosion of drainage (ditches) • Increase of hydrodynamic pressure of roads • Road erosion, landslides and mudslides that close or damage roads and cause siltation of drainage structures

	• Overloading and blockages of drainage systems, causing erosion and flooding • Impact on soil moisture levels, affecting the structural integrity of roads, bridges and tunnels. • Adverse impact of standing water on the road base • Risk of floods from runoff, landslides, slope failures and damage to roads if changes occur in the precipitation pattern • Traffic hindrance and safety • Excessive moisture in materials – construction delays • Reduced working periods and increased construction delays • Water damage to partially completed works • Need for more coffer dams or flood-control measures during drainage and bridge construction • Additional maintenance costs • More frequent bush clearing and vegetation control • Additional repairs required to drains • Need to retain good shape of unpaved road surfaces – more frequent maintenance • Increased and improved unpaved shoulder maintenance • Increased pothole patching and crack sealing of paved roads • Existing potholes will deepen rapidly • Changes in rate of vegetation growth
Decreased rainfall	• Drying out and shrinkage of subgrades • More loss of fines from unsealed roads • Less water for construction and maintenance • Change of vegetation types and runoff characteristics
Sea level rise	• Inundation of roads in coastal areas • Erosion of the road base • Extra demands on the infrastructure when used as emergency/evacuation roads • Increased salinity of water affecting infrastructure components • Under-cutting of sea cliffs adjacent to roads
Temperature changes: Higher maximum temperature and higher number of consecutive hot days (heat waves)	• Concerns regarding pavement integrity, e.g. bitumen softening, traffic-related deformation rutting, embrittlement (cracking due to early oxidation), migration of liquid asphalt. • Impact on landscaping • Differential thermal gradients in large bridge members • Excessive drying out of unsealed road surfaces – more gravel loss, corrugations and dust • Greater losses of construction water by evaporation • More rapid aggregate deterioration and cementation reactions
Drought (Consecutive dry days)	• Susceptibility to wildfires that threaten the transportation infrastructure directly • Susceptibility to mudslides/debris flows in areas deforested by wildfires when rains do come

	• Consolidation/shrinkage of the substructure with (unequal) settlement as a consequence • More generation of smog • Unavailability of water for compaction work • Drought increases mortality of sensitive plants along road alignments • More frequent and intense wildfires
Increased wind speed	• Threat to stability of bridge decks • Damage to signs, lighting fixtures, roadside furniture and supports • Higher wind speed causes the greater dynamic force of water generated by waves on road embankments • Windblown trees blocking the roadway • More movement of sand in dry areas (onto the road and drains)
Foggy Days	• Traffic hindrance and safety

3.1.13 Vulnerability matrix

As a summary, a vulnerability matrix in presented in Table 3-6, summarizing the exposure to climate hazards under a changing climate, the sector sensitivity and the resulting climate vulnerability. Clearly, the main relevant climate hazards for the road sector are floods and landslides.

Table 3-6 Vulnerability matrix for roads

Climate hazard	**Exposure** (from 1 small to 3 large change)	
Heat	High	3
Drought	Medium	2
Wildfires	Medium	2
Storm precipitation	Medium	2
River flooding	Medium	2
Landslides	Medium	2
Wind	Low	1
Coastal flooding	High	3

	Sensitivity				
Climate hazard	**Main Road**	**Other Roads**	**Paths**	**Bridges**	**Sector average**
Heat	1	1	1	1	1
Drought	1	1	1	1	1
Wildfire	1	1	1	1	1
Storm precipitation	1	1	1	1	1
River flooding	3	3	2	1	2
Landslides	3	3	2	2	3
Wind	1	1	1	1	1
Coastal flooding	1	1	1	1	1

	Vulnerability				
Climate hazard	**Main Road**	**Other Roads**	**Paths**	**Bridges**	**Sector average**
Heat	2	2	2	2	2
Drought	1	1	1	1	1

Wildfire	1	1	1	1	1
Storm precipitation	1	1	1	1	1
River flooding	3	3	2	1	2
Landslides	3	3	2	2	3
Wind	1	1	1	1	1
Coastal flooding	2	2	2	2	2

3.1.14 Potential adaptation activities

The adaptation of transport infrastructure facilities to make them climate resilient generally requires conventional engineering considerations or nature-based solutions and judgment that is applied routinely by experienced road engineers.

The biggest input into providing appropriate and cost-effective adaptation activities is to determine the vulnerable areas and then identify and understand the causes of the problems in these areas. No adaptation technique can be effectively and/or economically implemented if the fundamental resilience problem is not properly identified and the cause is not fully understood.

Risk assessments improve planning of adaptation to climate change and inform the implementation and monitoring of climate change adaptation activities. Adaptation is usually more effective when initiated at an early stage of project development, and when undertaken as a planned process rather than in response to experienced impacts. Better knowledge of climate change risks will make it easier and less costly to respond.

The adaptation technique for any specific problem and location will be unique to that location but must be based on a thorough understanding of the problem and its causes. The behavior of the specific asset when subjected to various problems must also be identified and clearly understood and the consequences of any adaptation interventions (including the "do nothing" scenario) identified.

In most cases, there will be more than one solution and the most appropriate one, based on technical viability, minimizing the consequences, the capacity of local contractors to implement it, costs and aesthetics should be selected. Ischia has high standards from the aesthetics point of view to any construction works owing to being a very popular tourist destination.

The process of identification of vulnerable areas would normally be carried out during a risk assessment, which can be done in a number of ways.

Once vulnerable areas are identified, each one needs to be assessed and the problems and causes identified before any detailed adaptation activities can be designed. In some cases, this may require the input of specialists in selected fields, e.g., geotechnical, hydrological, structural engineering, revegetation, etc.

It cannot be overemphasized that the final adaptation design solutions for each vulnerable area will require detailed investigations and inspections, and will be unique to the site and conditions, but a preliminary estimate of the implications (time and cost) can usually be obtained prior to this, based on typical unit costs of various operations and asset prevailing at the time of the assessment.

It is also important to look back at the previous attempts to tackle hazards. How has the previously built structures lasted over time against the hazard, which solutions has failed, and which have been successful?

There is no doubt that Ischia will be affected by climate change in future and adaptations to increase the resilience of the transport infrastructure to these changes will have to be introduced in order to manage some of the particularly severe consequences.

It should be also noted, that in Ischia, it is strictly regulated what kind of structures are suitable for the unique landscape and scenery of Ischia, especially due to the tourism industry.

In the following Table 3-7, is a summary of typical climate hazards and engineering adaptation options. More Ischia specific adaptation activities are presented in Chapter 3.1.16.

One way to collect data to plan maintenance works, is to use Artificial intelligence (AI) model for automatic pavement defect detection is fast and reliable way to sport critical locations along the road network.

Figure 3-8 AI analysis of pavement defects

Table 3-7 Climate hazards and related possible adaptation activities.

Climate Hazard	Related Possible Adaptation activities
Precipitation changes: Extreme rainfall events / Increase of seasonal and annual rainfall causing flooding	• Stabilization of the base layer • Paving of unpaved surface (double bituminous surface dressing for the low volume roads) • Raising road elevation (at least 0.5m over the maximum flood level) • Increase capacity of compaction for lower moisture percentage • Building of erosion protection • Building of steel nets against rockfalls • Building of gabions • Building of permeable roads • Building of debris deflectors • Building of rip-rap protection • Building of underdrains in build-up areas • Building of scour checks • Building of cut-off drains • Planting of grass sodding • Improving side drainage (ditches) • Adjusting (flattening and shaping) embankment slopes • Building of retaining walls in sections prone to land slides • Increasing size and number of drainage structures • Raising embankment height to avoid over-flooding • Realigning natural water courses (not always successful) • Updating design for drainage systems • Slope stability studies in an attempt to minimize mass movements and mudflows as a result of increased precipitation

	• Measures to enhance slope stability and prevent mass movements and rock fall
Sea level rise	• Building of protective walls • Raising road elevation (at least 0.5m over the maximum flood level) • Building of erosion protection • Stabilization of the base layer • Relocation of the road
Higher maximum temperature and higher number of consecutive hot days (heat waves)	• Heat resistant paving materials (use of stiff bitumen) • Improved pavement material specifications • Consideration of polymer-modified bitumen • Advanced construction technologies
Wildfires	• Vegetation control
Drought (Consecutive dry days)	• Dust can be avoided permanently through paving of the road surface (double bituminous surface dressing for the low volume roads)
Fog	• Installation of reflective poles on the road edge

3.1.15 Findings from the field mission

Consultants carried out a field trip in October 2023 to establish the current situation on the roads. The aim was to clarify, together with the stakeholders, what kind of engineering adaptations have been done, have they been functional and durable, what are the problems and possible solutions. In the following figures, some of the findings are introduced.

	
Steel nets against landslides having biotextile (coconut or hemp) under it allowing vegetation.	High concrete retaining wall with anchors against landslides.
	

Steel nets against landslides. Structure is at its end of capacity and needs to be rebuilt, or possibly replaced by a wall.	The most typical structure in Ischia against mass movements are stone walls. Either with binder material or not.
	
Serious failure of a concrete wall on enbankment against erosion.	Steel nets built to protect against the rock falls
	
Reduced capacity (width) of the main road due to landslide	Mud flood in 2022 due to inadequate drainage, blocked the roads and damaged other structures.

As explained before, from the long list of engineering adaptation options above, it is best to use only those suitable for the island of Ischia, in terms of functionality, their anticipated environmental and social impact, durability, aesthetics and resources and capacity to design and build them.

3.1.16 Recommended adaptation activities

It was not possible to carry out a detailed risk assessment, with a scoring system, due to resource constraints. However, some of adaptation objectives identified by the client are presented in the following tables. The list is based on stakeholder experience and knowledge of historical events, and the reasons for them. This can be also considered as a starting point for the final, network level, project identification and prioritization work.

Table 3-8 Project scheme 1: Road SP270 against landslides

Location: Via Dottore Tommaso Morgera (SP270, 40.75069102092889, 13.898638733077789)	Photo

			
Adaptation	Steel nets need to be replaced, possible partially with retaining walls. Length 150m, height 15m. Hydraulic structures (drainage system) will be needed, if wall is chosen.	Criticality	Very high – main road with high traffic, access to hospital and heliport. No alternative route.
Historical events	Landslides and rockfalls in 2020's	Cost Estimate	Steel net / wall 1.0M€

Table 3-9 Road project scheme 2: Road SP270 against landslides

Location: Via Litoranea (SP270, 40.75167852987871, 13.896214016129749)		Photo	
			
Adaptation	Steel nets need to be replaced, possible partially with retaining walls. Length 250m, height 10-15m. Hydraulic structures (drainage system) will be needed, if wall is chosen.	Criticality	High – main road with high traffic, access to hospital and heliport. Alternative route exists.
Historical events	Unknown	Cost Estimate	Steel net / wall 1.5M€

Table 3-10 Project scheme 3: Road "Via cava" against flooding

Location: Via Cava (40.75062520283365, 13.894145471712399)	Photo

			
Adaptation	Drainage upgrading, mixed sewer into separated sewers. Increased capacity for the storm water. Length at least 200m.	Criticality	High – secondary access to hospital and school. Alternative route exists.
Historical events	Flooding 2022	Cost Estimate	1.0 M€

Table 3-11 Project scheme 4: Road "via Corbaro" against landslides

Location: Via Corbaro/No name (40.72663771679728, 13.877876859886504)		Photo	
			
Adaptation	Slope stability. Using Biotextile and steel nets in various locations.	Criticality	Moderate – Low volume road, however no alternative routes and access to the properties.
Historical events	Landslides, rockfalls	Cost Estimate	0.5 M€

In addition to the road project schemes identified during the field mission and discussions with the local stakeholders, a more comprehensive list of road related project candidates was provided by the local municipalities. This list contains various project schemes to adapt against landslides and floodings with a total budget estimate of 23M€. It was not possible for the assignment team to assess all these locations and their criticality, and it is therefore recommended to further study the provided schemes.

3.2 Buildings

3.2.1 Building stock of Ischia

There are around 67 000 – 68 000 habitants (different sources propose varying numbers) on the island year around. In summer, the number quadruplicates as the tourist season starts.

The increase in population has increased the number of buildings. According to several sources[35] many buildings have been built in derogation of the local construction regulations and without building permits. These kinds of buildings are often built with poor materials and /or on fragile soils and, therefore, are particularly vulnerable to geophysical hazards. Considering this, the vulnerable buildings may also pose a risk of building material debris in possible flood events. The spreading debris can damage other buildings in vicinity of the flood.

*Data from the Legambiente environmental group shows that some 28,000 requests to participate in amnesties for houses built illegally were submitted since 1985 on the densely populated island, representing about half of all Ischia's buildings. (*Reuters /CTV news). There has been talks that excessive construction has also weakened the land.

As a result of unauthorized construction, there is probably a large variation in construction methods and construction quality (poor construction quality), which causes challenges for defining and implementing climate change adaptation activities.

Most of the building stock on the island consists of stone buildings typical of the Mediterranean region. Ischia Island has a high percentage of masonry buildings, in 5 of the 6 municipalities masonry buildings represent more than 50% of structures. The municipality of Ischia has the highest percentage of reinforced concrete buildings of the municipalities.

Baraccato is a building style unique to the island (a portion of the old building stock). It consists of the masonry wall reinforced with a wooden frame. The adaptation activities and investments should also be considered with the culture heritage preservation of protected buildings in mind.

The age of the building stock varies significantly between different areas but can be considered relatively new. Only a few percent of building stock are over 100 years old. For example, in the municipalities of Casamicciola Terme and Lacco Ameno, 35 to 47 % of the buildings are built between the First and Second World War (1919- 1945). The municipality of Barano D' Ischia has 51 % and Serrara Fontana 61 % of their building stock built after 1982.

The critical infrastructure on the island consists of a hospital, ports, a fire brigade and a helicopter port. The location of this critical infrastructure can be seen on figure 3-9.

[35] https://www.euronews.com/green/2022/11/28/deadly-ischia-landslide-was-caused-by-climate-change-and-illegal-construction-experts-say

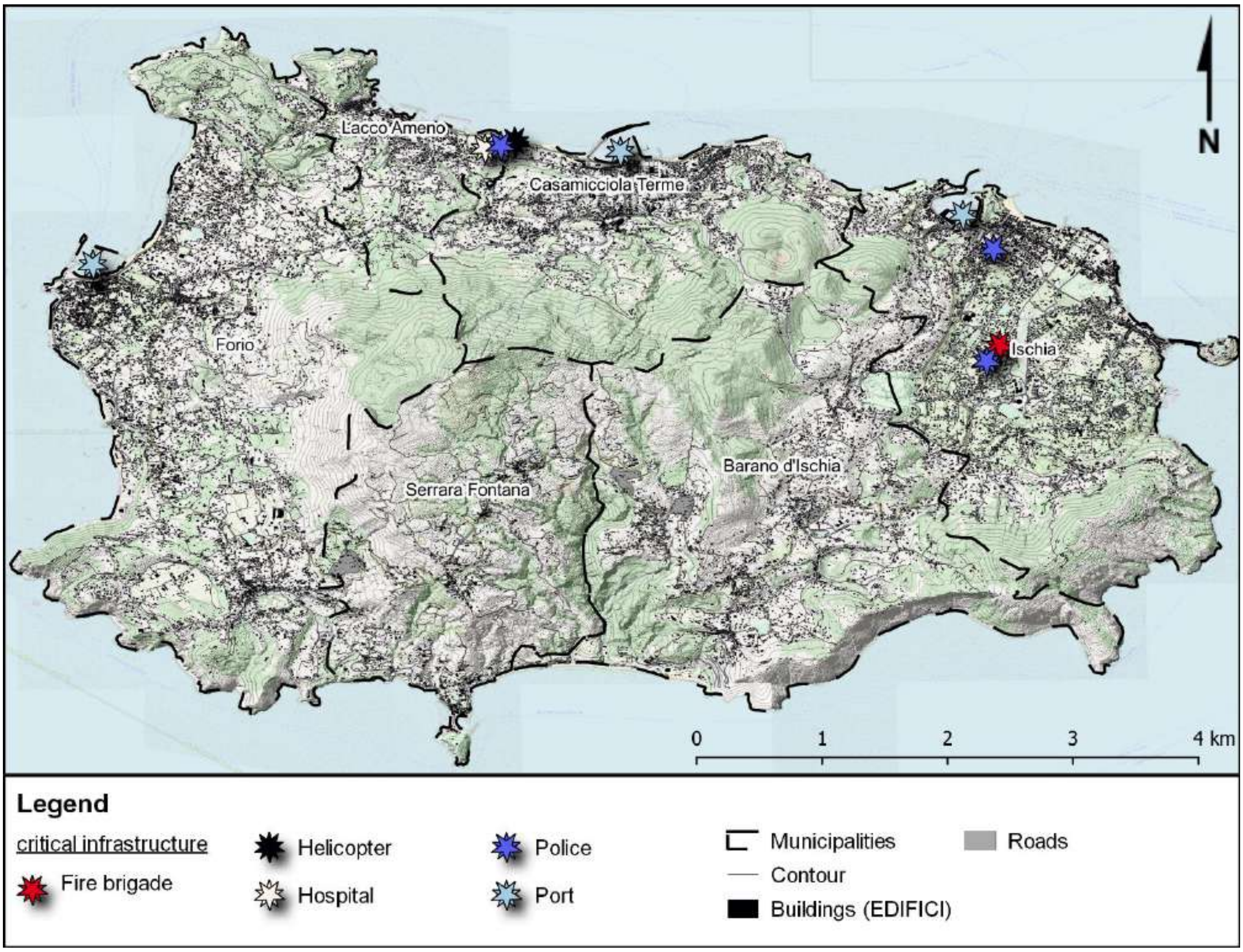


Figure 3-9: The map of Ischia. The building stock of the island is shown as black dots on the map. Critical infrastructure also shown on the map as symbols.

3.2.2 Increased temperatures

The increased temperatures have several consequences on buildings and occupants. Heat waves and increased temperatures in general will lead to higher indoor temperatures that can impact human health and labour performance. Also, façade materials can be damaged from thermal expansion leading to premature deterioration of materials. In Ischia, the number of summer days, cooling degree days and warm spells are all projected to increase significantly as the mean temperature rises in all RCP scenarios.

The number of tropical nights is projected to increase significantly. This will lead to a situation where cooling by natural ventilation is ineffective as the temperature does not decrease under 20°C during the three summer months. Prolonged higher temperatures might require the installation of additional cooling systems. Passive adaptation activities such as sunshades can be utilized to provide glare protection and shade in order to reduce indoor heating load, but it is very likely, that active cooling and ventilation systems (air conditioning) are also needed to provide immediate cooling in periods of extreme heat and tropical nights to maintain tolerable indoor conditions.

When planning new buildings, it is recommended to consider the prevention of indoor heat load; and energy efficiency of structures to minimize the energy consumption needed for cooling, for example by thermal insulation of buildings and passive cooling methods. Active cooling systems should also be considered in the design of hygrothermal performance of envelope structures (new buildings and retrofitting procedures). Cooling may induce condensation of humidity in structures that may lead to moisture related damages.

3.2.3 Changes in precipitation patterns

The number of consecutive days when daily precipitation is less than 1mm per year is projected to increase under both RCP4.5 and RCP8.5, while under RCP2.6 it is projected to not change from the baseline. The average annual daily precipitation sum in wet days is projected to increase under RCP2.6 to experience a decrease under both RCP4.5 and RCP8.5. Overall, the mean precipitation will decrease slightly, but the projected changes are not assessed to have significant effects to the building sector.

In many cases, the reduction in rainfall is likely to prove beneficial to the buildings and their foundations as the moisture stress to envelope structures decreases. However, reduced precipitation will also create several problems. Excessive drying will induce shrinkage and cracking of soil that can lead to vertical soil movements and subsidence that damages foundations.

On the other hand, increasing precipitation together with wind-driven rain will lead to faster deterioration of materials and moisture related damages to the building envelope. The stress of increased precipitation and wind-driven rain to envelope structures in new or renovated building should be considered when designing the hygrothermal performance of structures (water tightness of the building envelope and structures ability to dry if wet). Especially in the older buildings material vulnerable to moisture damage may have been used in the envelope structures.

3.2.4 Increased frequency of extreme events

In Ischia, both very heavy precipitation days and maximum 1-day precipitation are projected to increase at least to some extent in all the assessed scenarios.

Sudden heavy precipitation might exceed the capacity of the drainage systems (both common and houses own underground drains) causing local flooding and affect the stability of the slopes leading to landslides, which can be detrimental to buildings. Flooding can also damage the basement and bottom level structures causing collapses and moisture related damage. Heavy rains can also cause damage to envelope structures when roof drainage cannot handle the excessive rainfall leading to leakages.

The adaptation activities recommended are mostly dependent on larger scale procedures to prevent areal flooding and landslides (for example, embankments and larger drainage structures that effect whole areas). For separate buildings the main activities to consider are strengthening of foundation and load-bearing structures in high-risk areas and protection of structures against moisture damage from flooding (moisture resilient materials, site specific drainage systems/barrier or floodproofing to prevent water from entering buildings).

It is recommended that new adaptation activities, for example building specific drainage systems (drainage of the roof structures and site drainage), should be designed according to IDF curve (RCP2.6) maximum 1-day precipitation model taking also into account the flood prone areas. The site-specific recommendations should be specified separately to each building or site.

3.2.5 Longer drier/drought periods

The increase in the number of extreme events together with a possible projected decrease in mean precipitation will lead to longer periods when no rainfall occurs. This will lead to dying-off of vegetation and, increased susceptibility to erosion.

Drought periods have effects on the soil and can induce wildfires and flooding or landslides if the soil or vegetation's ability to retain water is reduced. The adaptation activities to prevent these are described later in the buildings sector part of the report.

Building wise the risk of drought is related to the possible soil shrinkages, vertical soil movements and drought-induced subsidence affecting the condition of foundations and other load-bearing structures in the lower parts of buildings. The prevention of damage would include deep or semi-deep foundations on new buildings and investigations and structural strengthening of current building stock. As about 50% of the building stock in Ischia is built without proper building permits the building foundations are likely to have significant variation in quality and building methods. Therefore, it is recommended to consider regulatory actions from the authorities to investigate and repair foundations if needed prioritizing the risk areas concerning flooding and landslides.

3.2.6 Increased windiness

The risks for buildings related to windiness are considered low in Ischia as there are no particularly tall buildings. Recommendations for adaptation activities would include the assessment of taller buildings or structures against wind loads and possible strengthening of structures.

3.2.7 Sea level rise

The sea level surrounding Ischia is projected to increase by 0.26 m, under RCP8.5 by 2050. There are some buildings in Ischia Island that are built next to the water line. Rising sea level may increase the impact of wave action on those buildings. Recommendations for coastal adaptation activities for Ischia are presented in section 3.4.

Building wise it may be relevant in some cases to assess the repairability or usability of some buildings. In the risk areas it is recommended to consider regulatory actions from the authorities to investigate and repair/strengthen foundations if needed prioritizing the risk areas on the seaside regarding the RCP8.5 model. Basement floors are also subjected to rising water levels. Water proofing of basements and moisture resistant materials are to be considered in the buildings affected by ground water rise.

3.2.8 Groundwater quality and depth changes

Groundwater has an impact on the strength of construction materials both building foundations and basements and in surrounding earthworks (cuts and fills). A lowering of groundwater levels is expected, which will result in an overall improvement in geotechnical conditions. However, as the sea level rises the groundwater levels in coastal areas will rise, reducing the strength of foundation materials and causing moisture related damages to ground floor or basement structures.

Together with sea-level rise, however, the salinity of the groundwater in coastal areas will increase bringing with it a new set of problems in terms of corrosion of concrete reinforcement and certain aggregates. Also, the hot springs and large elevation differences in the island affect the groundwater level.

The possible effects and repair needed must be assessed for separately for each building. The adaptation activities and assessment needs are described in the sections 3.3.5 and 3.3.7.

3.2.9 Landslides (landslides, debris and rockfalls)

Risk of soil movements increases as events of extreme rainfall and drought become more frequent. Below in the Table 3-12 is a calculation of the volume of buildings that are exposed to landslides. This analysis is a very general screening of possible risk sections and does not yet tell the actual risk in the field, since some adaptation options might be already in place. After identification of individual buildings/areas of buildings under risk, more detailed risk mapping and scoring and prioritization can be done, as a combination of desk study and field surveys, separately for landslides and rockfalls.

The recommendations for adaptation activities for buildings coincide with the recommendations of the road sector. Protective structures, for example retaining concrete walls and steel nets have been installed in certain locations, but the conditions of the current structures are not entirely known, and coverage is recommended to be assessed in relation to the risk maps, prioritizing the dense urban areas. The landslide risks are present in all the municipalities of Ischia. Taking into account the historical data on landslides, the municipality of Casamicciola Terme should be prioritized in the activities.

Table 3-12 Percentage of Buildings under exposure of landslides (including rockfalls) based on GIS-data

landslide exposure

Under high exposure	Under medium exposure	Under low exposure	no exposure
7%	12%	12%	69%

A model of areas that have a risk for landslides is presented in the *Figure 3-10*. Locations of buildings are also shown. Buildings that were damaged in the last earthquake and landslide can be seen on *Figure 3-11*.

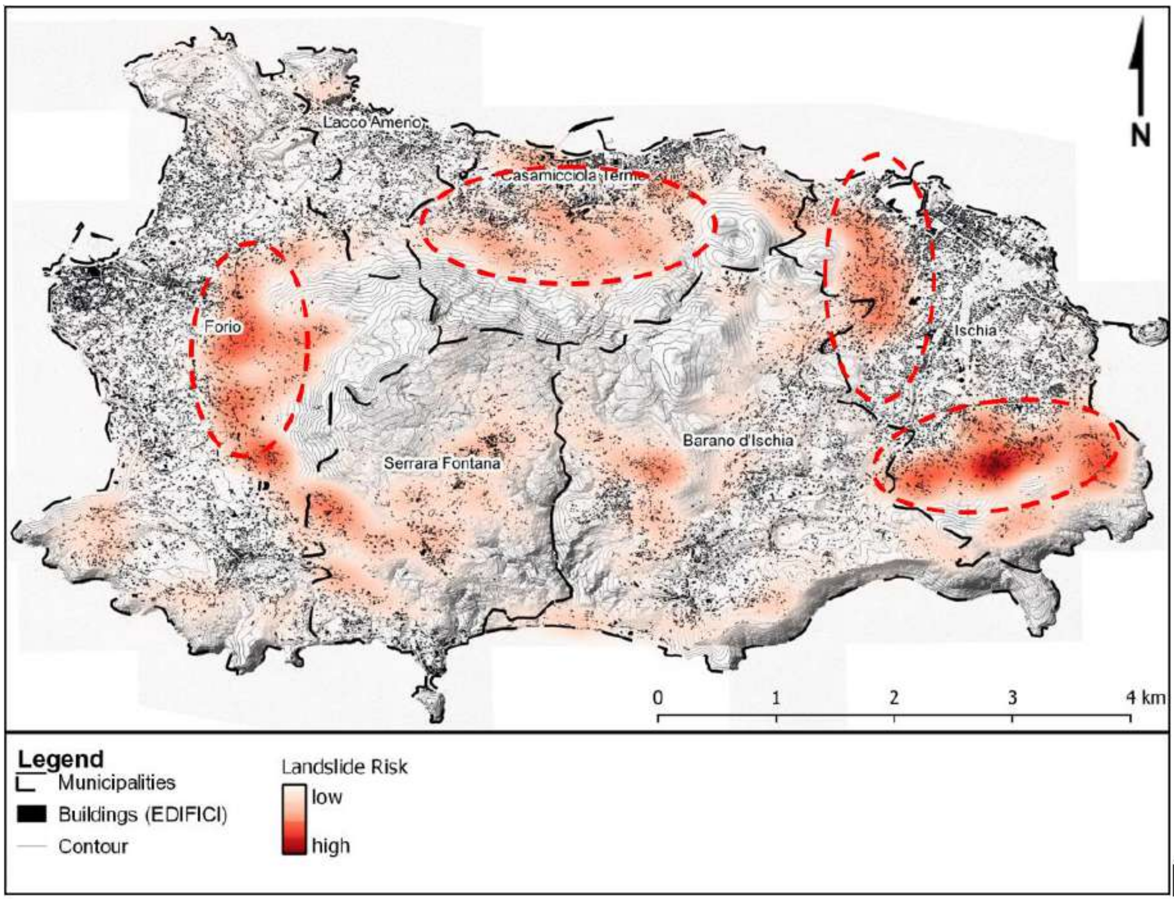


Figure 3-10: Four areas of higher risk that should be priorisized are depicted in this map. The historical data and the density of buildings have been taken into account in the risk assessment.

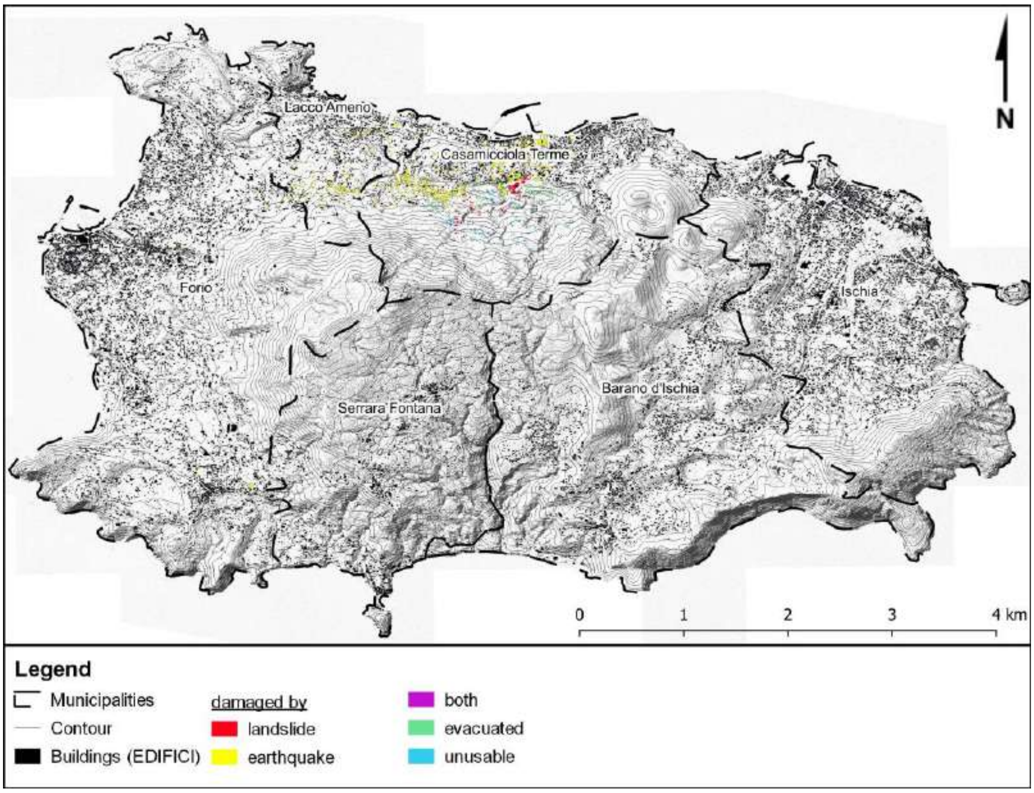


Figure 3-11: Buildings that were damaged by the last earthquake and landslide.

3.2.10 Flooding

11 % of the buildings in Ischia are under flood exposure (3276 out of 30320). In the following map (Figure 3.14), buildings under flood risks based on GIS analysis are presented. The flood risks are present especially in the urban areas of Ischia and Barano d'Ischia municipalities.

The recommendations for adaptation activities coincide with the recommendations of the road sector. Protective structures, for example embankments have been installed in certain locations, but the conditions of the current structures are not entirely known, and coverage is recommended to be assessed in relation to the risk maps prioritizing the dense urban areas. This has to be assessed in a more specific risk analysis, but according to a preliminary assessment only the municipality of Serrara Fontana seems to be a lower risk area from the perspective of the building sector.

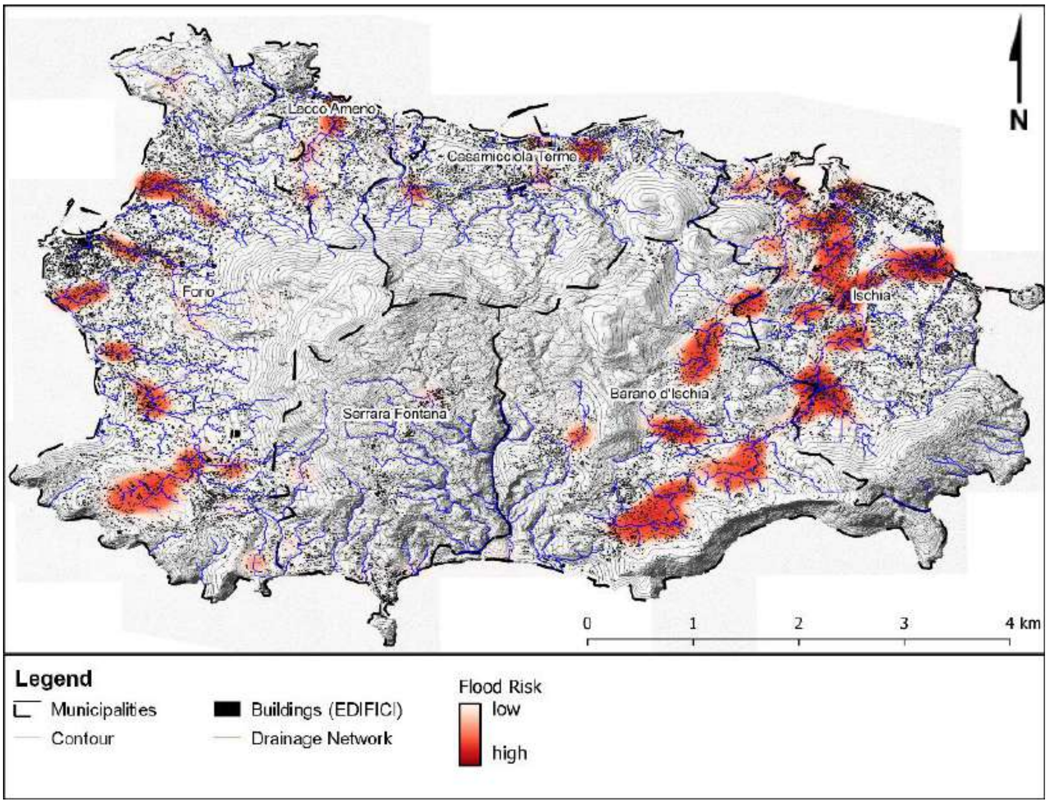


Figure 3-12: GIS-study of the flood risk and the locations of buildings.

3.2.11 Wildfire

It will be important that wildfires are minimised. There is a risk that forest fires will spread next to populated areas even causing building fires, but on the other hand, densely populated areas do not have much forest or other flammable vegetation. Some populated built areas could be impassable due to smoke and fire during a wildfire event.

Increased temperatures, in combination with the increased windiness described below, can lead to a significant increase in uncontrollable wildfires, as witnessed in Italy in the past few years. This too will increase the potential for erosion and slope surface instability as the soil-binding effects of plant roots will in many cases be lost after extreme burning.

Vegetation control might be an effective way to protect zones in the urban areas in particularly hazardous zones. This has to be assessed in a more specific risk analysis, but according to a preliminary assessment the municipalities of Ischia, Barano d'Ischia and Forio are recommended to be considered.

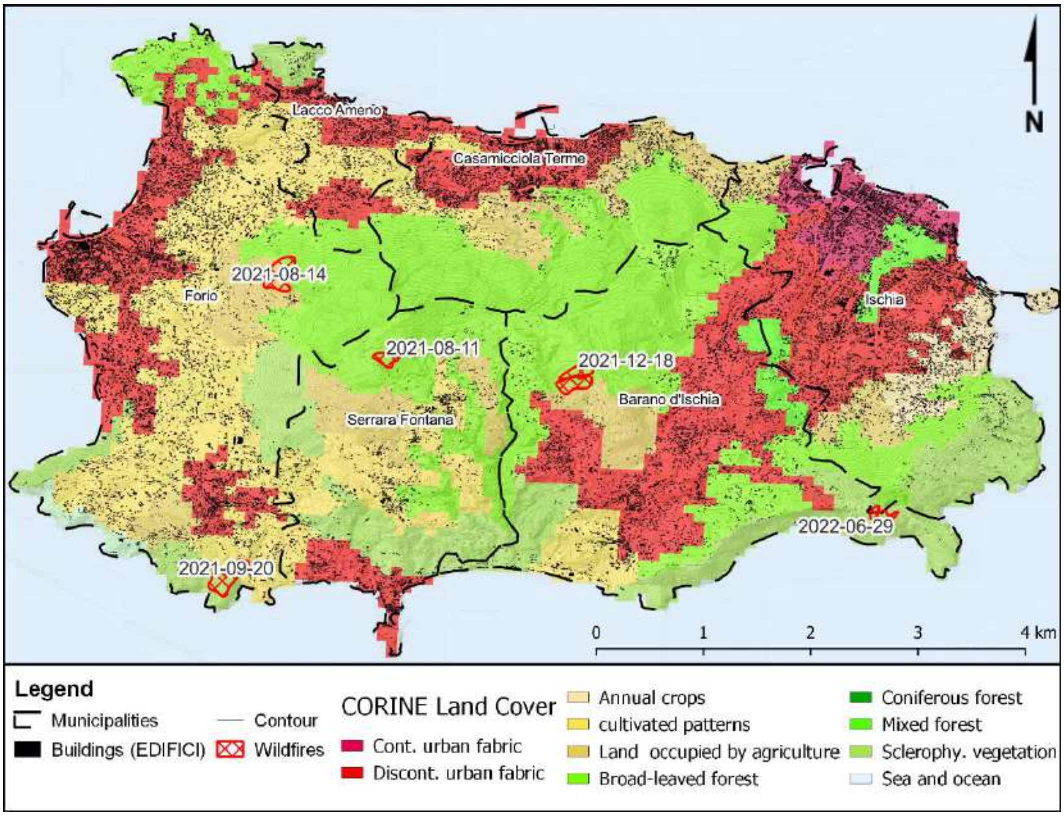


Figure 3-13: GIS-study of the recent locations wildfires in Ischia.

3.2.12 Critical infrastructure – the island hospital

There is a hospital on the island, built in the 1960s. The hospital building is made of concrete structures. An expansion project is currently underway.

According to the information received, water has flooded the hospital during the previous landslide/earthquake (the hospital is in an area where there have been landslides). In addition, the building has recently had problems with rising groundwater levels at the basement floor, damaging the structures. Next to the building there is an old retaining wall that may be damaged and there is a risk of it collapsing.

Damage has also been observed in the structures protecting the building. There have been landslides near the hospital that could have damaged the hospital building as well. For this reason, it is recommended to examine the condition of the protective structures around the hospital building and to define the repair needs based on the findings.

According to the information received from the expansion work and investigation reports, the geotechnical conditions have been precisely investigated. However, there is no information on the climate change related stresses impacting the hospital building (old or new part). Main hazards affecting the building are increased heat and heavy precipitation. Wind-driven rain is also projected to increase. Areas to consider are, for example, taking the building's cooling needs into account during the design phase and designing the building's outer shell structures to better withstand short-lasting heavy rains. Also, the hygrothermal performance of the building envelope is recommended to be assessed regarding the implementation of cooling systems and the possible repair needs of the present envelope structure.

A new concrete pile retaining wall will be built at the site, between the extension part and the upper slope and will protect both the extension part and the original hospital from the pressure of the earth masses from above. In addition, it will likely reduce the moisture stress to the building (lowering of the groundwater level and channelling of runoffs along the retaining wall on both sides of the building).

To protect the hospital building, it may also be necessary to construct new protective structures on the slope above the building and repairs/extensions of existing protective structures (tying the soil with protective nets, protective ramparts to guide water masses/possible landslides, reservoir/tunnel structures related to delaying rainwater etc.).

It is recommended that new cooling systems at least in critical infrastructure should be designed according to the RCP 8.5 temperature model.

3.2.13 Other Issues relevant for buildings sector

Various other issues such as fog, smog, high or low humidity, increased ultra-violet radiation, etc., could all have direct or indirect effects on the performance and operation of the building stock, but these are generally minimal and are likely to be counteracted as they are observed.

3.2.14 Summary of potential climate change impacts

A summary of the potential hazards related to the various climate change hazards is provided below (Table 3-13).

Table 3-13 Climate variables and related hazards and impacts on the buildings.

Climate Variable	Hazards and Impacts on the Building infrastructure
Precipitation changes: Extreme rainfall events / Increase/decrease of seasonal and annual rainfall	• Landslide risks will increase • Risk for increased rockfalls • Flooding causing damage to buildings • Loss of strength and/or stability of the subsoil below the foundations of buildings • Increase of hydrodynamic pressure to foundations • Erosion of drainage (ditches) • Overloading and blockages of drainage systems, causing erosion and flooding • Soil erosion, landslides and mudslides cause siltation of drainage structures (including building drainage) • Impact on soil moisture levels, affecting the structural integrity of buildings • Long term excessive moisture or sudden heavy rainfall causes damage to envelope structures (loss of bearing capacity, mould growth etc.) • Need for more coffer dams or flood-control measures during construction • Additional maintenance costs • More frequent bush clearing and vegetation control • Additional repairs required to drains • Changes in rate of vegetation growth
Decreased rainfall	• Drying out and shrinkage of subgrades and their possible effects on building foundations (building subsidence, damage to structures) • Less water for construction and maintenance • Change of vegetation types and runoff characteristics
Sea level rise	• Inundation of basements and foundations in coastal areas • Increased salinity of water affecting infrastructure components (for example reinforced concrete, the rapid rusting of reinforcement) • Under-cutting of sea cliffs adjacent to buildings
Temperature changes: Higher maximum temperature and higher number of consecutive hot days (heat waves)	• Impact on landscaping • Overheating of buildings and increasing need for cooling • Active cooling will affect the hygrothermal performance of envelope structures inducing mold growth • Greater losses of construction water by evaporation • More rapid aggregate deterioration and cementation reactions

Drought (Consecutive dry days)	• More frequent and intense wildfires • Susceptibility to wildfires that threaten the built infrastructure directly (in densely populated areas there is less flammable vegetation) • Susceptibility to precipitation-induced mudslides/debris flows in areas deforested by wildfires • More generation of smog
Increased wind speed	• Threat to stability of buildings • Higher wind speed causes the greater dynamic force of water generated by waves on buildings located on waterfronts • More movement of sand in dry areas (onto the road and drains)

As a summary, a vulnerability matrix in presented in Table 3-14.

Table 3-14 Vulnerability matrix

Climate hazard	Hazard change	Exposure	Sensitivity	Vulnerability
Heat	3	3	2	3
Drought	2	3	2	3
Wildfires	2	2	3	3
Storm precipitation	2	2	3	3
River Flooding	2	2	2	2
Landslides	2	2	3	3
Wind	1	1	2	1
Coastal Flooding	3	3	2	3

3.2.15 Potential adaptation activities

The adaptation activities to make building infrastructure climate resilient require in general conventional engineering considerations and judgment that is applied routinely by experienced civil engineers. Unauthorized construction in Ischia is quite common, and, in the future, construction guidance and supervision should be increased so that buildings are designed and built in accordance with the regulations, so that they can better withstand increasing weather stresses.

There are no specific general adaptation activities or recommendations that could directly be applied to all buildings on the island. Rather the recommendation for adaptation activities should be assessed separately for each building, also considering the remaining lifespan of each building and the planned lifespan of renovated structures. This is relevant, for example, for the design parameters for precipitation (site and building specific drainage systems) and temperatures (active cooling systems), recommended to building owners or by regulatory actions from the authorities. In general, the main hazard that should be considered are, heat stress (indoor and envelope structures), heavy precipitation, the effects of drought induced movement of soil or groundwater stress for building foundations and the effects of possible flooding.

The adaptation activities of building sector against flooding, wildfires and landslides are generally the same as the recommendations for the road and energy sector to protect larger areas against the hazards. The differences come from the risk assessment of hazardous areas. Dense urban/populated areas should be prioritized in the execution of said activities.

Regarding the adaptation activities of building sector against major risks involving larger areas (such as flooding, wildfires, and landslides), the risk assessment should include the assessment of effectiveness of the activities and potential uncertainties. If all risk factors cannot be removed in such a way that there is no danger to residents or sudden structural failures, relocation as a possible adaptation activity should also be considered. As the land area available for new construction projects is limited on the island, this could also mean relocation of certain functions to the mainland.

It should be also noted, that in Ischia, it is strictly regulated what kind of structures are allowed to be built in the unique landscape and scenery of Ischia. Adaptation options should be also esthetically approved.

In the following Table 3-15, is a summary of typical climate change events and engineering adaptation options from buildings point of view.

Table 3-15. Climate impacts and related possible adaptation activities

Climate Hazard	Related Possible Adaptation Activities
Increased Temperatures	• Wider use of passive heat protection (sunshades etc.) • Active cooling systems to provide immediate cooling in periods of extreme heat • Thermal insulation of new buildings and retrofitting of the current building stock (assessing the hygrothermal performance of structures is needed)
Precipitation changes: Extreme rainfall events / Increase of seasonal and annual rainfall causing flooding and landslides	• Stabilization of the base layer • Increase capacity of compaction for lower moisture percentage • Building of erosion protection • Building of steel nets against rockfalls • Building of gabions • Building of debris deflectors • Building of rip-rap protection • Building of underdrains in build-up areas • Building of scour checks • Building of cut-off drains • Planting of grass sodding • Building of retaining walls in sections prone to land slides • Increasing size and number of drainage structures • Raising embankment height to avoid over-flooding • Realigning natural water courses (not always successful) • Updating design for drainage systems • Slope stability studies in an attempt to minimize mass movements and mudflows as a result of increased precipitation • Measures to enhance slope stability and prevent mass movements and rock fall • Designing new buildings and retrofitting of current buildings stock against heavy rainfall and wind-driven rain. • Designing new buildings and assessing/retrofitting of current buildings stock against flooding damage (the moisture stress to structures and stability of foundations and load-bearing structures) • Directing new construction projects further away from the hazard areas of flooding and land slides
Drought (Consecutive dry days)	• Recycling of grey water • Water-efficient fixtures and fittings • Rainwater harvesting • Onsite water source such as onsite water storage or wells • Deep or semi-deep foundations on new buildings • Structural strengthening of the current building stock (horizontal and vertical reinforcements)
Wildfires	• Vegetation control - protection zones in the urban areas in hazardous zones

Sea level rise	• Building of protective walls • Building of erosion protection • Stabilization of the base layer • Directing new construction projects further away from the water line • Renovating existing basement structures against moisture damage (water proofing and moisture resistant materials) • Assessing and renovation of structures for sea water induced corrosion
Increased wind speed	• Stability assessment and strengthening of tall buildings especially in open areas

3.2.16 Recommended adaptation activities

It was not possible to carry out a full detailed risk assessment for the whole island during this assignment due to resource constraints. However, the adaptation opportunities identified are presented in the following tables. It should be also noted that the adaptation activities recommended in other sectors of this study also protect the buildings of Ischia.

The recommended adaptation activities for the hospital building are:

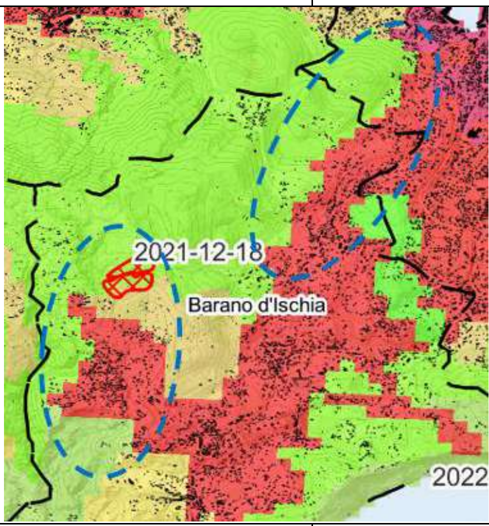
Table 3-16 Project scheme 6: Ospedale Anna Rizzoli - Adaptation against identified hazard.

Location: Ischia Hospital		Photo (Google Earth)	
			
1. Adaptation	Renovation of the envelope structures – façade, roof (old part) based on an assessment of the repair needs	Criticality	Medium – Given the age of the building, in the end of its lifespan
2. Adaptation	Active cooling systems and passive shading to ensure tolerable indoor conditions based on the RCP 8.5	Criticality	High – To ensure tolerable indoor conditions
3. Adaptation	Repairs of the basement structures (moisture)	Criticality	Medium – affects the usability of basement
4. Adaptation	Site specific drainage should be assessed according to the IDF curve for 1-day maximum rainfall	Criticality	Medium – should be assessed soon
5. Adaptation	Protective structures around the hospital	Criticality	High – major risk of landslides in the area
Historical events	Area is prone to landslides	Cost Estimate	1. 1 500 000 – 2 000 000 € 2. 500 000 – 700 000 € 3. 700 000 – 1 000 000 € 4. 200 000 – 300 000 € 5. 2 500 000 € (site specific)

In addition:

- The condition of the protective structures around the hospital should be investigated in order to determine precise repair needs.
- The IDF curve (RCP2.6) (presented at the figure 2.7) should be used to assess the moisture stress from 1-day maximum rainfall.
- Investigations and repairs of the basement structures of the old part of the building to determine the repair/alteration needs (moisture resilient materials should be used and external or internal waterproofing of the basement wall and floor structures)

Table 3-17 Project scheme 7: Ischia - Adaptation against wildfires

Location: Ischia and Barano d'Ischia			
			
1. Adaptation	Vegetation control to create a buffer zone next to populated areas	Criticality	High – To prevent wildfires spreading to populated areas
2. Adaptation	Enhanced fire department supervision of risk areas during wildfire season	Criticality	High – To prevent wildfires spreading from spreading out of control
Historical events	Several wildfires have been observed in Ischia in recent years.	Cost Estimate	1. 500 000 – 1 000 000 € 2. 100 000 – 200 000 €

3.3 Ports and coastal infrastructure

Marine submersion and coastal erosion are two of the major risks facing coastlines, not only on the island of Ischia, but on most of the world's coasts, and which will worsen with the consequences of climate change. The island of Ischia is already largely subject to both phenomena as proven by the hazard maps produced by the Italian administration (respectively in *Figure 3-14* for the submersion and in Figure 3-19 for erosion).

3.3.1 Marine submersion

It is interesting to compare marine submersion for different scenarios:

- Actual submersion observed on low-lying areas along the island (mainly during Aqua Alta and storms events);
- Projected submersion on low-lying areas along the island with sea level rise due to climate change only;
- Risk of submersion due to sea level rise combined with storm surge and wave set-up.

Actual submersion on low-lying areas

The map of the actual submersion risk on low lying areas has been produced by the Authority of the North West Bacino della Campania "carta della pericolosità da inondazione della costa bassa" and is provided in Figure 3-14.

The maps describe the areas most sensitive to the risk of coastal flooding along the entire coastal stretch of the island of Ischia, zooming on the areas of interest.

The danger zones highlighted mainly concern the island's beaches.

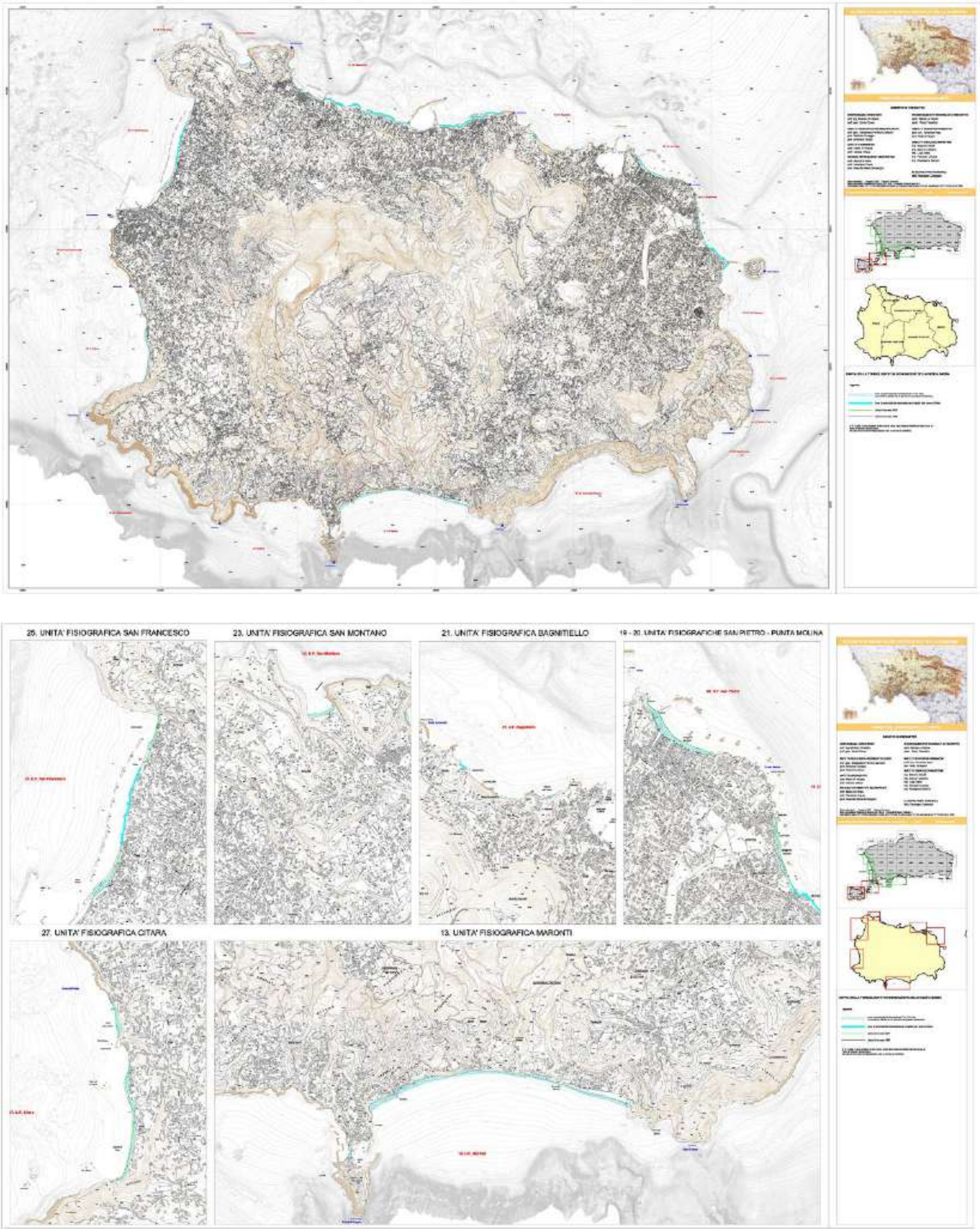


Figure 3-14: Map of actual risk of submersion of low-lying areas

Risk of submersion due to sea level rise on low-lying areas

Climate change will cause an irremediable rise in sea levels, the first consequence of which will be the flooding of low-lying areas that will find themselves under the future water level, especially for an island surrounded by the sea. This process can be studied statically in mapping the areas of the island located under the future sea level considering the sea level rise due to climate change using the climate central tool (https://coastal.climatecentral.org/).

Climate Central's Sea level rise and coastal flood maps are based on peer-reviewed science in leading journals. As these maps incorporate big datasets, which always include some error, these maps should be regarded as screening tools to identify places that may require deeper investigation of risk.

Maps are based on global-scale datasets for elevation and tides in addition to sea level rise projections.

Areas lower than the selected water level and with an unobstructed path to the ocean are shaded. By default, areas below the water level but that appear to be protected by ridges are not shaded.

This approach makes it easy to map any scenario quickly and reflects threats from permanent future sea-level rise well. However, the accuracy of these maps drops when assessing risks from extreme flood events (as this a statistic and not dynamic approach). The created maps are not based on physical storm and flood simulations and do not take into account factors such as erosion, future changes in the frequency or intensity of storms, inland flooding, or contributions from rainfall or rivers (that are detailed further in this report).

Map areas are identified as vulnerable based on land elevation relative to the selected shoreline water level. These areas are further refined using connectivity criteria. This efficient approach produces accurate maps for areas threatened by permanent sea level rise alone. It is also suitable for minor floods that may rise and fall slowly. As flood severity increases or flood-peak duration decreases, factors like wind direction and the inland attenuation of flood height from water-flow friction with the land surface become more important. In these cases, bathtub approaches become less accurate and increasingly overestimate the total flood extent. Physical modelling of many thousands of possible storm and tide combinations is an alternative approach for developing more reliable flood risk surfaces but comes with a great computational cost.

This map generally does not shade isolated areas whose elevation falls below the selected water level, but which ridges, or other features protect from inundation. Small discontinuities may be seen along the edge between water and land due to limitations in the methods used to generate these surfaces in a dynamic, real-time interactive. Potential coastal defences such as levees are accounted for when data is available. However, levee and coastal defence data is incomplete.

The map uses elevation data from Climate Central's CoastalDEM®, which was peer-reviewed and published in *Kulp and Strauss 2018* and further improved in *Kulp and Strauss 2021*. CoastalDEM was made by using artificial intelligence to improve elevation data developed by NASA. The horizontal resolution of CoastalDEM elevation data is one arcsecond, or about 30 meters (100 feet).

Submersion due to sea level rise on low-lying areas is a static phenomenon that can be anticipated as it is constant and progressive in time.

Figure 3-15: Map of Ischia Island with identified below sea-level areas considering a sea-level rise of 0,26 m.

Climate Central was chosen, as it was not possible to use the topographic data used to elaborate the map of the actual submersion risk on low lying areas produced by the Authority of the North West Bacino della Campania.

It was also not possible to use the Detailed Elevation Map (DEM) used for the maps integrating the sea level because the DEM data are not accurate between the shoreline and +1m in elevation.

Risk of submersion due to sea level rise combined with storm surge and wave set-up

Another point to be analysed is the combined effect of the projected sea level with storm surge and wave set-up. As one can see in Figure 3-16, both parameters were considered and added together in order to assess the possible flooded areas during a storm event.

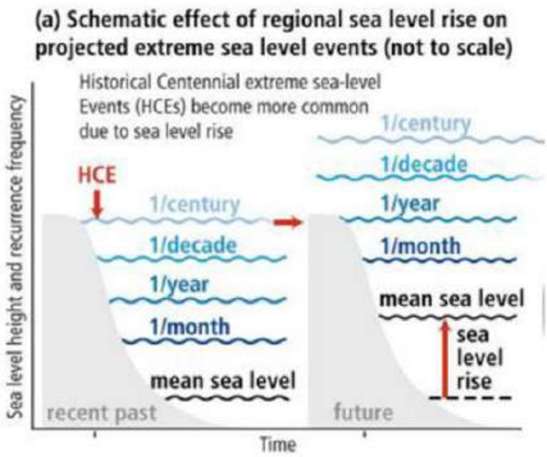


Figure 3-16: Addition of sea level rise and *return period storm surge actions*

The Detailed Elevation Map (DEM) was used as topographic data to produce the submersion map for two scenarios:

- Projected sea level rise + 100 year return period storm surge = +1.26m
- Projected sea level rise + 100 year return period storm surge + wave run-up = +2.26 m

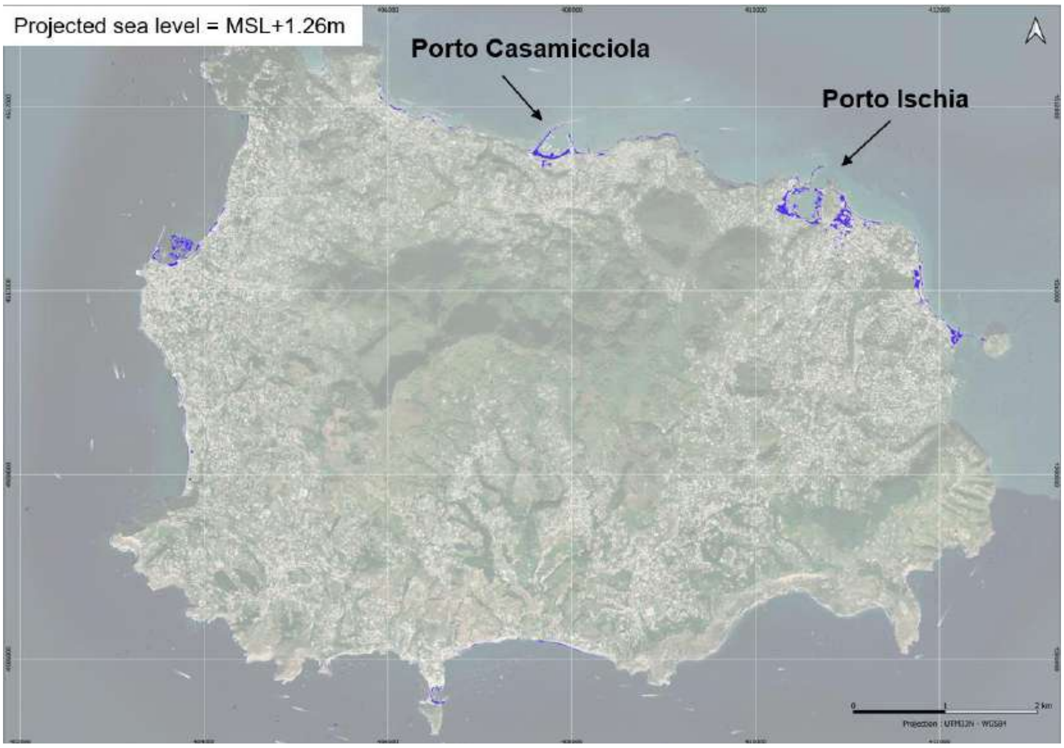


Figure 3-17: Map of submersion of low-lying area for a projected sea level of MSL+1.26m

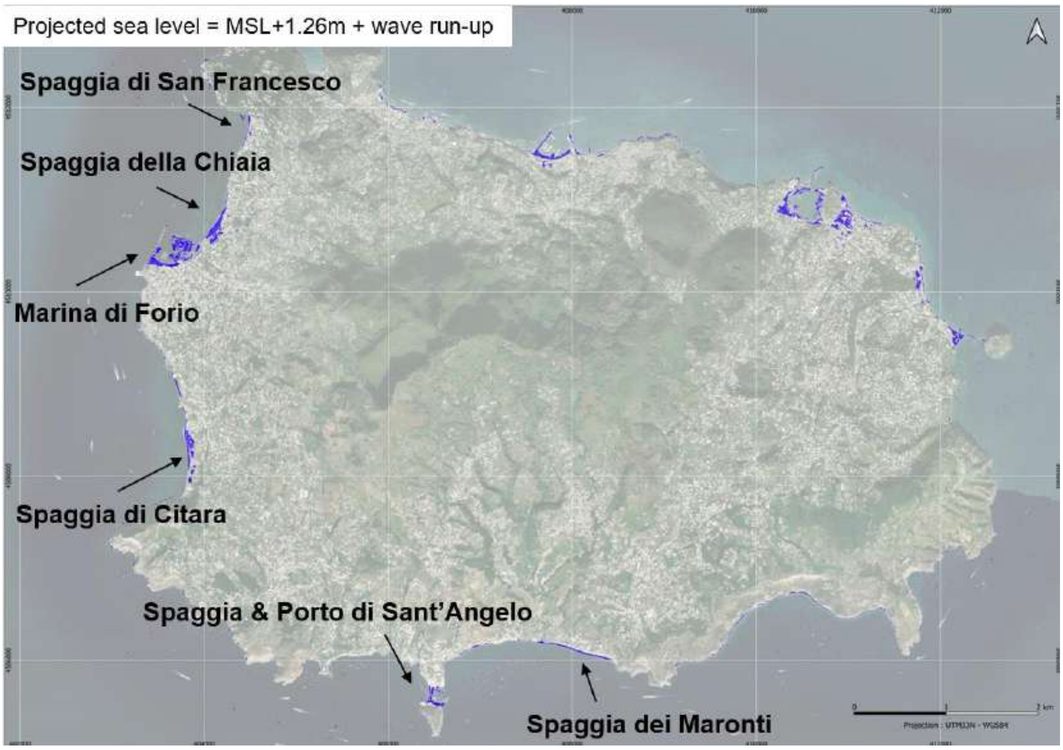


Figure 3-18: Map of submersion of low-lying area for a projected sea level of MSL+1.26m + *wave run-up = 2.26m.*

Both maps highlight low-lying areas where marine submersion intrusion and flooding issues will occur. Among the impacted sites, one can cite for example Ischia Porto and Casamicciola Terme Porto (more subjected to aqua alta events), but also la Spaggia di San Francesco, la Spagia della Chiaia, Marina di Forio, la Spaggia di Citara, la Spaggia and il porto di San'Angelo and la Spaggia dei Maronti (more exposed to waves impacts during storm events).

A site visit was undertaken in October 2023, to confirm the numerical data with a site inspection.

This showed that while the quays of Porto Ischia are extremely low, those of the ports of Casamicciola Terme and Forio are relatively high. Considering the socio-economic impacts of the submersion on a port, it appears inevitable and urgent to treat the levels of the quays of Ischia Porto.

3.3.2 Coastal erosion

The coasts of the island of Ischia undergo intense erosion both on the hard portions (cliffs) and on the soft portions (beaches). The erosion of a very steep volcanic island by the combined effect of rain and the assault of the sea is a natural phenomenon that forges the morphology of landscapes over time. Erosion can be amplified by the effects of climate change, and in particular the rise in sea level and the intensification of extreme phenomena (storms and intense rains).

In the Mediterranean Sea, fluctuation of the shoreline can vary according to different time scales, depending on the local hydro-sedimentary context, the climatic conditions, and the variations in sea level as well as the anthropogenic influence through the impact of artificially installed coastal structures.

The position of a coastline fluctuates over days, seasons and years. If the average of the positions tends towards the open sea, we speak of accretion, if the average of the positions tends towards the retreat, we speak of erosion. However, seasonal fluctuations can lead to erosion or accretion without being linked to general trends.

This is why it is very difficult to rely on a photo taken at a specific time to deduct the position of the coastline for the corresponding year.

In the Mediterranean Sea, if the tides are low, fluctuations in the position of the coastline vary greatly, particularly between summer when the waters are low because of the anticyclone, and winter when the waters are higher under the effect of low pressures. A winter storm can also cause significant coastline retreat while summer conditions tend to bring sand back to the beaches.

There may be erosion caused by the presence of anthropic coastal infrastructure (built too close from the shore) as when the waves reach these structures and reflect on them, they carry the sediments far too offshore to a depth too great for them to return during calm conditions, in particular also because of the steep slopes of the island.

According to Figure 3-19, the rocky cliffs in strong erosion are mainly concentrated in the South of the island where the slopes are the steepest and where the developments are less numerous, whereas according to *Figure 3-14* flood hazard are mainly found towards the beaches and harbours.

Regarding coastal erosion, both images show the shoreline positions in 2004 compared to 1998. If only two dates cannot lead to any conclusions of the behaviour of the shorelines (no indication on tides, sea level period the images were taken to draw the shoreline, climate conditions, last storm events previous the date, references taken...), nevertheless it seems that spaggia di Maronti in the South and spaggia di Montano are both in accretion.

A site visit was undertaken in October 2023, to confirm the numerical data with a site inspection.

The expertise showed that the west coast along Forio is subject to an intense erosion that directly threatens the seaside road and homes at the back. Some work to protect and maintain the cliff was carried out but did not hold and has collapsed. In Barano and San'Angelo we also can observe strong erosion of the cliffs. Illustrations are shown in Figure 3-20.

It seems more than urgent and necessary to treat the Forio coastline to prevent the road from being swallowed by the sea and the infrastructures and buildings being put in danger.

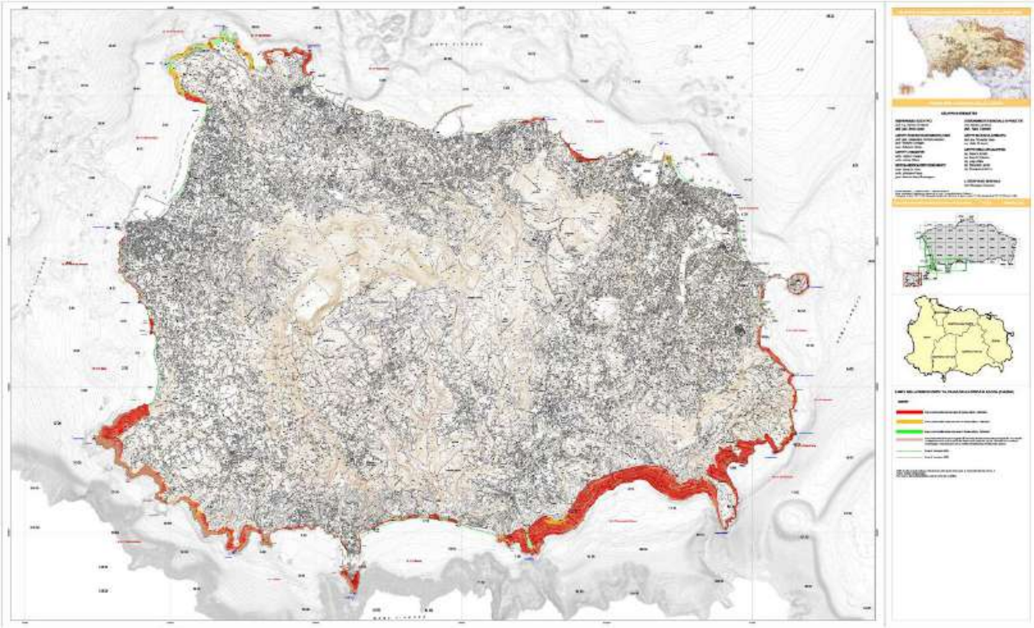


Figure 3-19: Map of coastal erosion in Ischia

Figure 3-20: Pictures of coastal erosion issues around the island of Ischia

Risk of damages on coastal infrastructures

Due to the steep slopes both on land and at sea, the volcanic island of Ischia has a coastal relief and characteristics typical of seasides not benefiting from a continental shelf, where cliffs falling into the sea or small narrow beaches are found.

In the long term, natural erosion due to the swell climate, especially waves during storms, is compensated by terrigenous inputs, particularly during volcanic episodes.

Since the installation of human beings on the island and its artificialization, combined with a lack of lava eruption, the coastal erosion of the island has not been compensated by accretion. This has led to man-made efforts to stabilize or curb the phenomenon.

Many man-made structures have been erected all around the island, as illustrated on the figure below.

We can observe artificial dykes, groynes, emergent and submerged breakwaters usually made of rocks. Detailed of each structure are shown in appendix.

Figure 3-21: *Inventory of all the coastal artificial defences around the island of Ischia*

These types of structures were mainly put in place around the world in the 1970s to prevent impacts linked to waves but have since proven their ineffectiveness in the long term. They often induce more inconveniences than advantages – for example, if they protect a part of the coast, they often generate erosion on another.

With rising sea levels and the likely intensification of storms in the Mediterranean, these structures will either be inefficient and will need to be redesigned or they will have to be repaired or dimensioned again with greater rocks to be able to correctly fulfil their role.

However, concerning the artificial structures put in place for coastal erosion, new nature-based solutions, may be found, and some of the present structures will have to be removed.

Indeed, the so-called "hard" structures are increasingly banned from coastal development projects and particularly with regard to the fight against erosion linked to the effects of climate change.

If they have long seemed reassuring, their benefit-disadvantage ratio is largely negative. In addition to their prohibitive price, they cause erosion, water quality problems, require maintenance, have a large carbon footprint, and are no longer suitable for current challenges.

If the protection of certain sites seems essential with hard structures, adaptation and protection with solutions based on nature must be the priority, especially for the beaches around the island, the promenades and the roads.

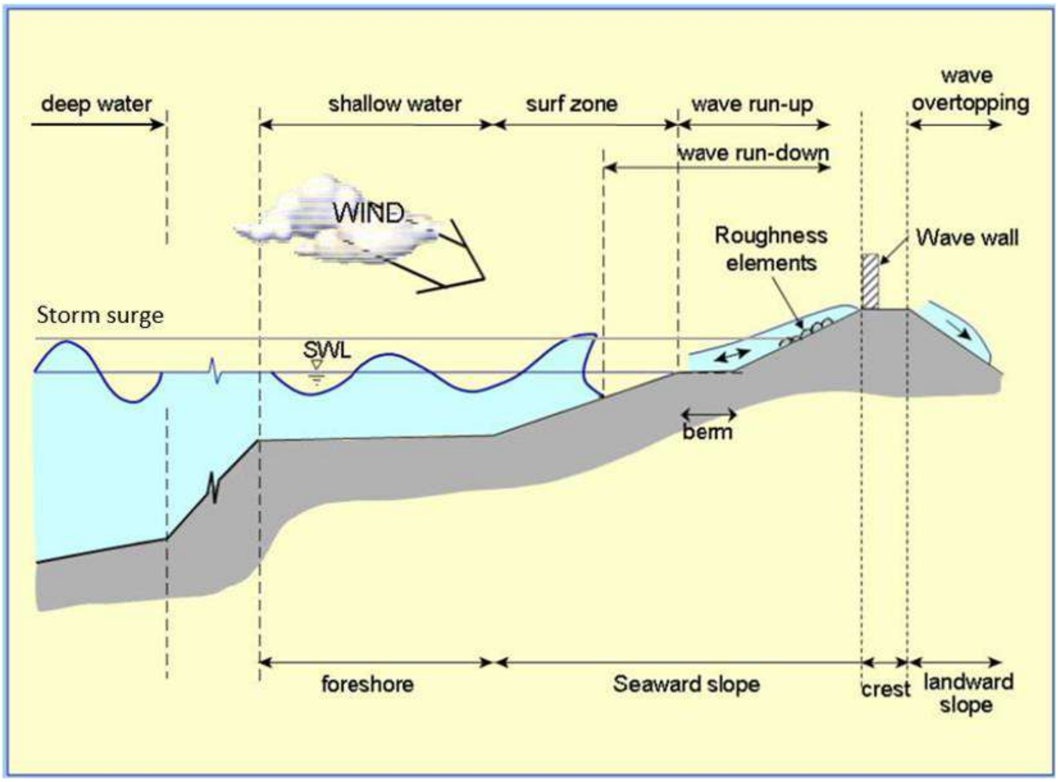


Figure 3-22: *Effects of wind waves on coastal structures*

Harbour breakwaters forming sheltered areas for boats mooring will probably have to be raised, repaired if damages following the assaults of the sea over time are detected and new studies will have to consider updated waves hypothesis for the design of the block armours.

Indeed, sea level rise combined with intensification of extreme events will lead to wave overtopping of harbour structures (breakwaters) but may also lead to increased agitation effects inside the harbours and submersion events of the quays.

It is now common to observe many ports in the Mediterranean Sea getting flooded during important storm events due to the combined effects of the storm surge and wave agitation.

All harbours shall be redesigned and adapt their protecting breakwaters and quays levels to the projected sea level and return periods wave characteristics.

Figure 3-23: *Overtopping of harbour protection wall during a Mediterranean storm.*

3.3.3 General Recommendations for coastal climate change adaptation

Based on the geomorphological context, the current location of the stakes and their vulnerability towards coastal hazards, it is necessary to study several development scenarios for zone to meet the needs in terms of defence against the sea and according to the problems to solve.

On a coastline, the general strategy types regarding climate change are summarized by the following approaches as illustrated in Figure 3-24: "hold the line", "move seaward", managed realignment", limited intervention", "adaptation", or "do nothing".

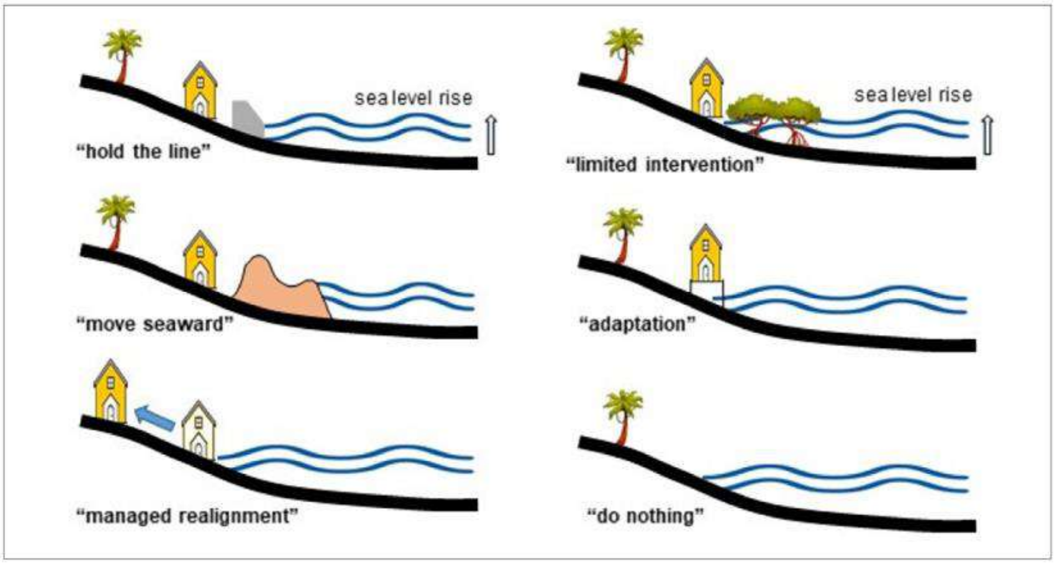


Figure 3-24. Coastal erosion adaptation strategies (source: "Coastal Structures as Beach Erosion Control and Sea Level Rise Adaptation in Malaysia: A Review")

It seems important to strive to comply with the recommendations of international strategies regarding coastal erosion, and in particular those resulting from the latest IPCC reports, namely the search for so-called "soft" solutions that do not call on techniques that implement heavy concrete or rockfill elements and if possible, nature-based solutions (NBS).

The scenarios recommended in the context of "disartificialization" or the implementation of nature-based solutions must be exploited. It is necessary to propose combinations of solutions (for example a toe stop associated with a beach replenishment and fences at the top of the beach or breakwaters associated with a beach replenishment, the creation of dune and their stabilization, etc.).

Soft solutions for protecting the coastline and maintaining the coastline are recommended. These solutions can be combined to optimize their coastal protection effect.

In general, the soft and nature-based solutions for the protection of the beaches consist mainly in favouring beach nourishment by the addition of materials (often coarser than current ones) combined with the removal of any anthropic structure (hard ones), the restructuring of dunes stabilized with fences and support systems from the beach.

On urban sites, the reconstruction will have to go through adaptation activities with installation of submersible structures as much as possible, or infrastructures allowing the flow of water underneath (built on piles for example for the roads or building directly implemented on the buffer zone).

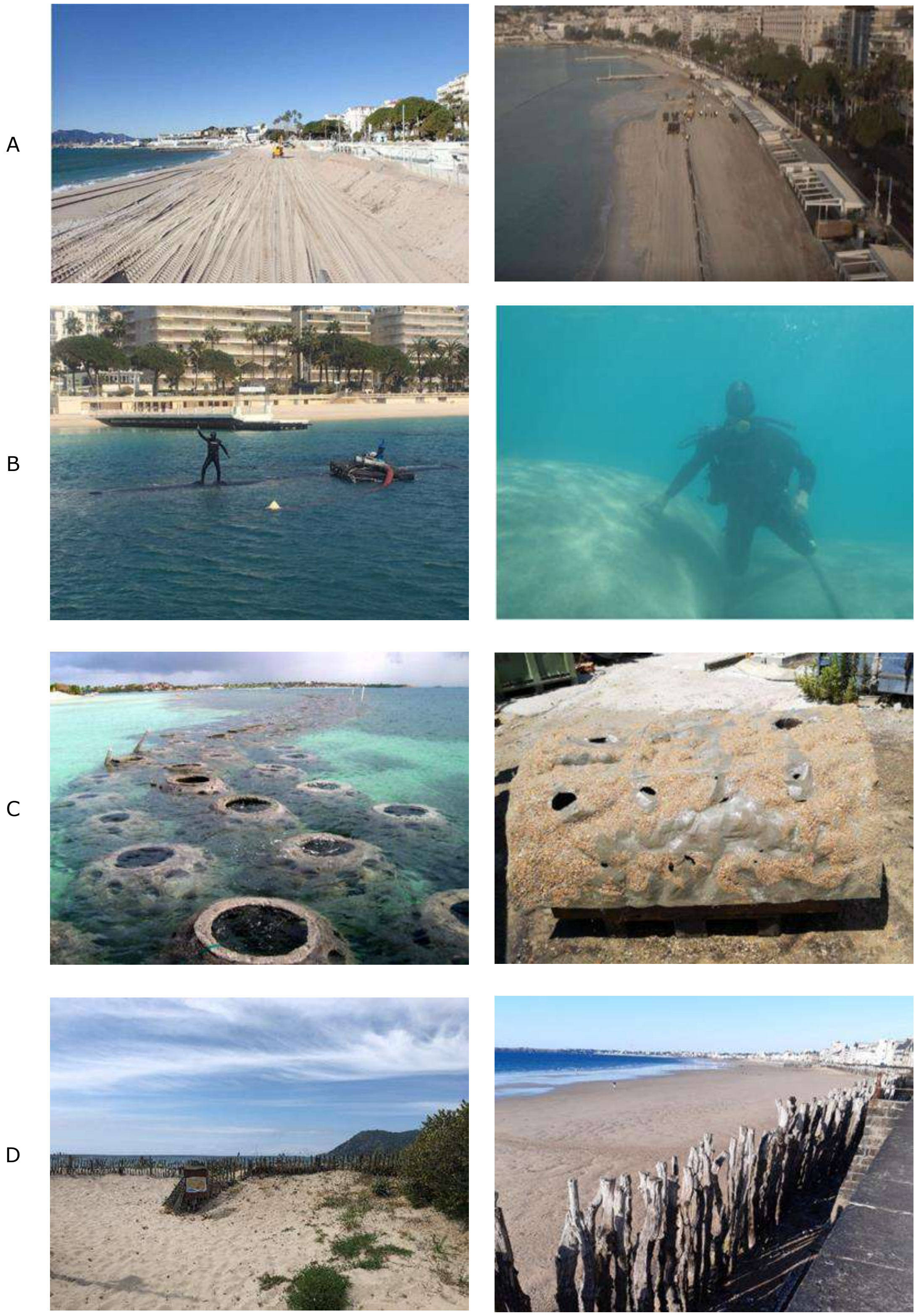


Figure 3-25: *Examples of soft solutions and nature-based solutions – A. beach nourishment -B. Geotubes, C. Reefballs, and D. recreation of dunes*

For harbour structures such as breakwaters and quays, they will have to be redesigned completely (or at least raised in light of projected sea level rise).

For the cliffs in danger of erosion, it will be possible to reinforce some parts of the cliffs where the stakes are high and no other options than protecting the site are possible. . In other areas, it will be necessary to avoid intervention and, let the erosion proceed and evacuate or forbid the access to the most threatened areas. Each site should be treated and studied independently.

3.3.1 Recommended adaptation activities

For Ischia, the general climate change adaptation activities can be summarised as followed:

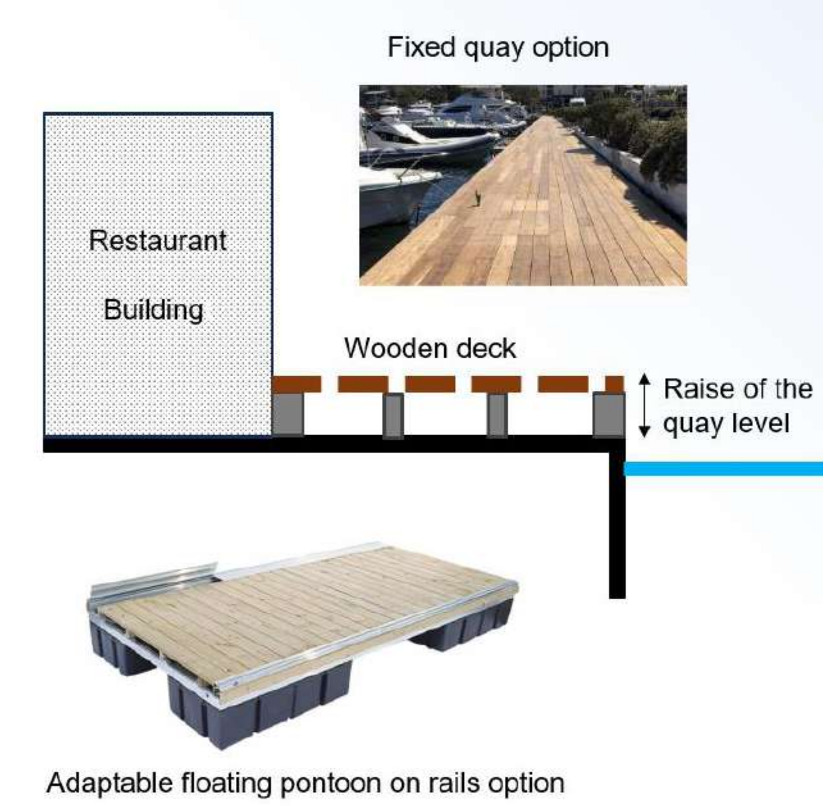
- Redesign of port infrastructure (quays) and raising of breakwaters considering new design parameters;
- Stabilization of the cliffs where absolutely necessary and let the erosion go on anywhere else (do nothing);
- Desartificilization of the coastal areas (breakwaters, groins, dykes) and demolition of the hard infrastructures built too close to the shore;
- Renaturalization as much as possible of the coasts and retreat where possible
- Adaptation of the infrastructures where retreat is not possible;
- Soft and nature-based solutions for beach protection such as dunes rehabilitation and creation, beach nourishment;
- Breakwater heights should be assessed, and the projected sea level rise taken into account in the possible redesign;
- To improve the accuracy of the coastal risk assessment, a better digital elevation model (DEM) is required. The current digital elevation model that was received by the assignment team, is inaccurate with height levels of less than 1 meters which are the essential height levels for the coastal assessments. An estimated cost for a high accuracy DEM for the island of Ischia is 50 k€;
- A local coastal model is also required to gain precise information about the expected water levels in different part of Ischia Island. An estimated cost for such model is about 50 k€ per area of interest.

According to the vulnerability studies, considering potential physical impacts of climate change on coastal areas combined with socio economic aspects, it appears that at least three urgent actions must be taken:

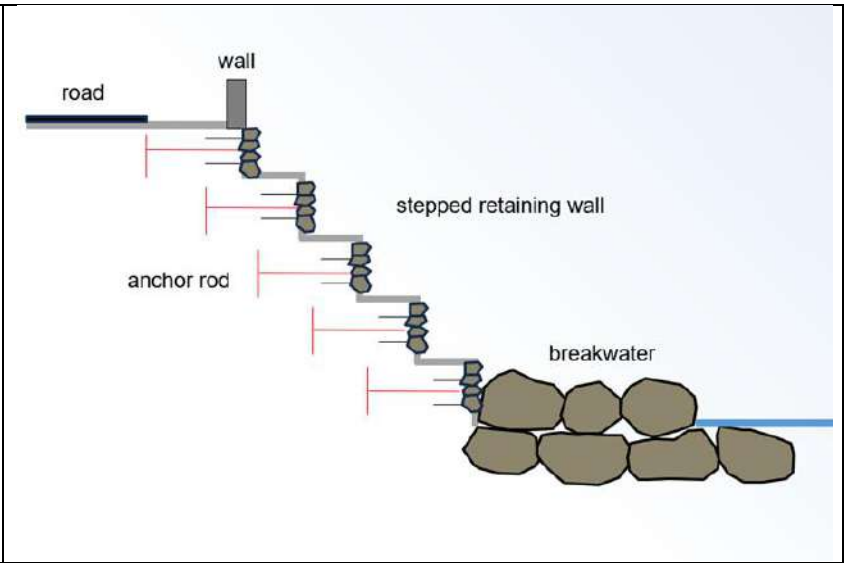
- ➢ Redesign and construction of Ischia Porto low quays
- ➢ Cliff erosion stabilization for road protection in Forio
- ➢ Erosion stabilization for the island heliport

Location: Ischia Porto (40.74428471694494, 13.942420259263367)	Photo

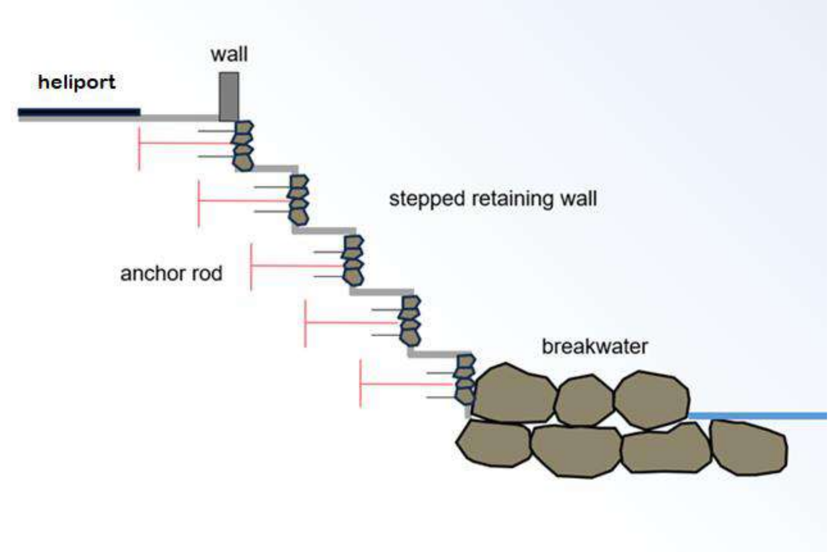
		 	
Adaptation	Raise of the quay level with a protective concrete wall along the edge of the actual quays on the restaurants section, with wooden deck on top. 2 options: - Fixed wooden deck on fixed concrete piles - Adaptable floating deck (pontoon) on rails varying with the sea level	Criticality	Main harbor of the island for passengers and
Historical events	Aqua Alta	Cost Estimate	2 M€ (fixed quays) – 3 M€ (adaptable floating pontoon on rails)
Notes	It should be noted that the costal model was also showing inundation in other parts of the Ischia port but due to the inaccuracy of the digital elevation model near the sea level, this could not be fully confirmed. A better digital elevation model at the sea level is required for confirming the need for adaptation.		

Adaptation layout	

Location: Forio (40.73112915085678, 13.855594217182011)		Photo	
			
Adaptation	Stabilization of the cliff against erosion with retaining wall coupled with the installation of natural rock breakwater at the toe of the wall	Criticality	Seaside road threatened to be swallowed and buildings and houses in danger
Historical events	Collapse of the previous works	Cost Estimate	10 – 15 M€

Adaptation layout	

<table>
<tr><td colspan="2">Location: Casamicciola Terme (40.75097601529328, 13.898745056761506)</td><td colspan="2">Photo</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Adaptation</td><td>Stabilization of the heliport against coastal erosion with retaining wall coupled with the installation of natural rocks breakwater at the toe of the wall</td><td>Criticality</td><td>Seaside heliport threatened to be swallowed.</td></tr>
<tr><td>Historical events</td><td>Structural movements of the heliport and cracking of the superficial structures.</td><td>Cost Estimate</td><td>5 M€ (The cost can be significantly lower if it can be done in conjunction with for example the Forio roadside protection works as the most costly part of the work is getting all the required equipment in place.</td></tr>
</table>

Adaptation layout	

3.4 Water supply and wastewater

3.4.1 Socioeconomic importance of water supply on Ischia

Water supply plays a significant socioeconomic role on the island of Ischia. A reliable and sustainable water supply is fundamental to supporting the island's tourism industry, agricultural production, environmental preservation, and public health. Currently, Ischia is a popular tourist destination known for its beautiful landscapes and natural thermal springs with many hotels that majorly contribute directly or indirectly to the economy of the island. In addition to the general population, tourists also need access to clean water for drinking and other recreational activities.

The agricultural industry, which currently covers 9% of the island land area, requires adequate water supply for irrigation. While neither the agricultural sector nor industrial water usage is currently very high, these numbers are projected to increase according to EVI (Energia Verde Idrica S.p.A.), the company that is responsible for the entire piped water supply on the island. Lastly, a sustainable water supply is vital for maintaining local ecosystems and preserving natural habitats which are crucial for environmental protection, as well as a tourist attraction.

3.4.2 Methodology for assessing the climate change impacts on water resources and water supply

The applied methodology includes the following steps:

1. Assessment of potential climate change impact on water resources

First, climate change impacts on water resources on Ischia Island were assessed by analysing overall rainfall, rainfall pattern, water quality (including water quality in the catchment of the piped water supply) and identifying the local water resources on the island.

2. Assessment of potential climate change impact on water demand

Next, assessment of climate change impacts on water demand was conducted by looking at the overall water demand and how that changes relative to temperature increase, evapotranspiration, and water demand per sector.

- Assessment of potential climate change impact on infrastructure

Finally, the climate change impacts on infrastructure were assessed through qualitative responses on past events and hotspots. In addition, water infrastructure in risk areas were identified by overlaying maps on water supply, irrigation pipelines, pumping stations, treatment plants, treated sewage, outflows with landslide and coastal flooding maps (GIS).

- Development of climate change adaptation activities

After climate change impacts on water resources, water demand and infrastructure were assessed, and climate change adaptation activities were developed. Based on the qualitative information that was collected through interviews, the diversification of water resources and the management of these water resources (groundwater recharge, storage, reuse, etc) were identified as viable climate change adaptation activities that need development. Based on the water infrastructure identified as at risk through GIS analysis, additional climate change adaptation activities should include the development of pipeline deviations, pumping stations and treatment plants.

The assessment is based on a literature review of potential climate impacts and climate change projections assessed by the consortium. The most important stakeholder has been identified as EVI S.p.A., who is responsible for water supply and wastewater collection and treatment. Stakeholder consultation with EVI has been conducted for assessing water supply issues related to local water resources used in Ischia.

Water resources feeding into the piped water supply, the general condition of the water supply and wastewater treatment, past observed impacts on the water supply network were also discussed during the consultation. In addition, the socioeconomic impacts of the vulnerable water supply situation in Ischia were assessed.

3.4.3 Water resources

Ischia has various local water resources, which were also used for the water supply in the past. An overview of the river network is provided in Figure 3-26. Further, the island has several cold and hot springs. The main springs are Buceto and Nitrodi.

In the past, water was supplied via tractors transporting water from Buceto natural spring gallery with sedimentation tanks until 1960. This water is still available and can be collected at the spring points, but it is not chlorinated and thus cannot be supplied officially. Since 1985, water is entirely supplied to the island from Naples through 3 pipes. There are also many private wells. Buceto is located at an elevation of 400m AMSL and has a potential to provide 60m³/day, Nitrodi spring is located at 250m AMSL and can provide 30m³/day. Iervaniello spring (near Buceto) is a non-perennial, weather-dependent source providing 20m³/day in the rainy part of the year from September to May.

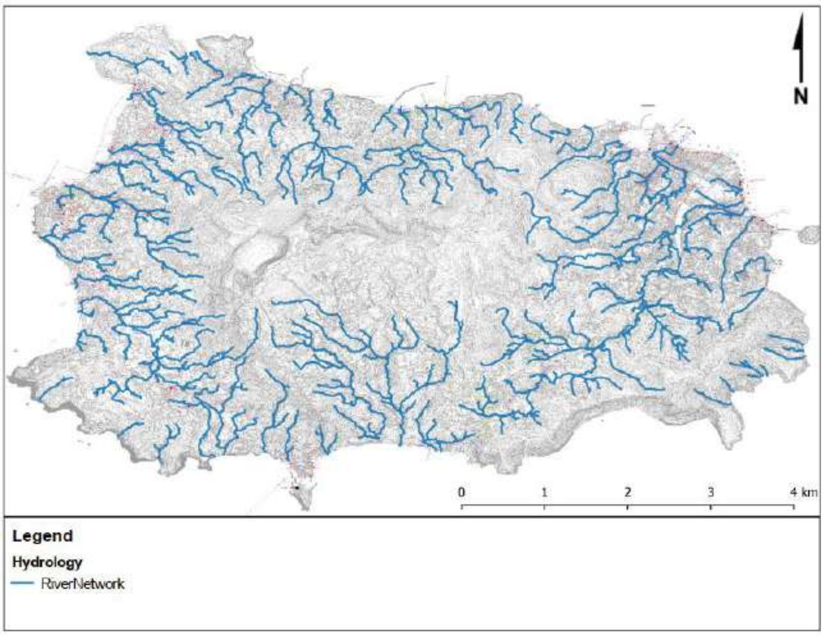


Figure 3-26 River network of Ischia

The three underwater pipelines to Ischia supply water from mainland Italy. The water provided by these pipelines is sourced from groundwater wells which are said not to be impacted by extreme weather events but could possibly be impacted by changing climatic conditions affecting the aquifer recharge. A shortage of water supply was reported in 2012 for which the detailed conditions leading to the shortage would need to be examined. Desalination is seen too be too expensive as RO costs are estimated to be 10€ per m³.

3.4.4 Water supply and water use in Ischia

The entire water supply in Ischia from July to October is 40,000 m³/day. In the winter, the water supply is 28,000 m³/day. Thermal groundwater is pumped from various wells along the coastal strip of Ischia to supply thermal spas around the island. While economically beneficial to the island, groundwater pumping can have potentially detrimental effects on water quality and aquifer recharge and must be managed sustainably[36].

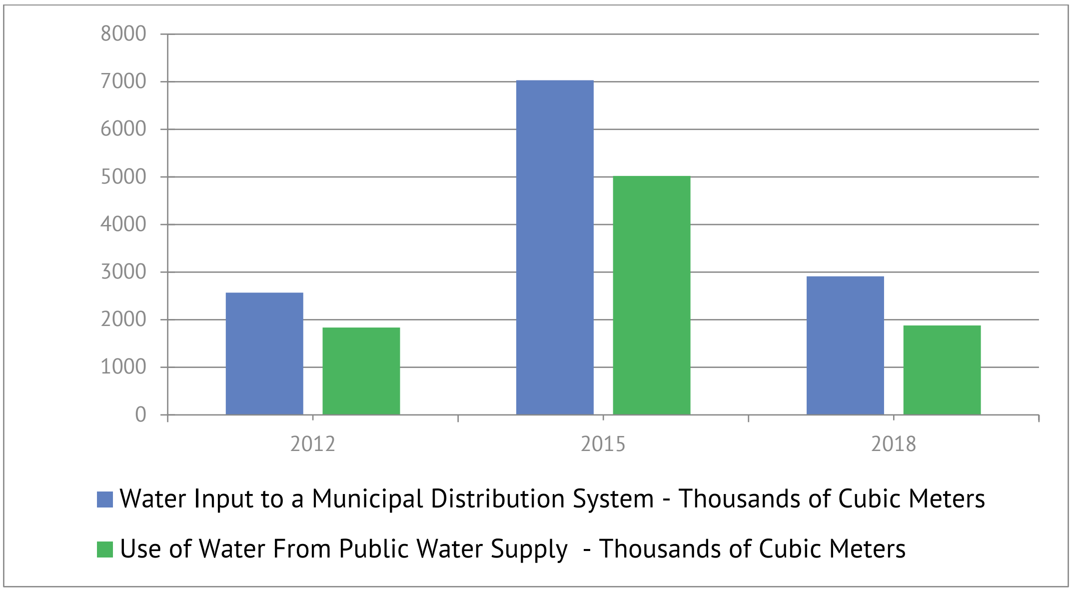


Figure 3-27 Water input and use in Ischia in the past (Source: Knoema Dataservice[37])

3.4.5 Current status of wastewater infrastructure

Ischia is divided into six municipalities, each having its own wastewater system. However, these wastewater treatment plants have been deemed outdated and non-functional. According to a report by Technital[38], the existing sewerage system in the municipality of Casamicciola Terme, which serves 30% of the population, consists of a network of plastic pipes that collect both sewage and surface rainwater runoff. During heavy rain events, these pipes often burst and cause flooding in cellars and basement areas because the network of pipes is under scaled and cannot handle the load during these conditions.

In an energy audit by Intelligent Energy Europe, it was reported that the island lacked a basic sewage treatment system in 2011 and that most of the sewage was sent directly to the sea. While there is an ongoing project for a treatment plant and reutilisation for irrigation of pine plantations and protection of the sea from pollution, currently there is no reutilisation of treated water.

36 https://www.researchgate.net/publication/344979938_Relationship_Between_Aquifer_Pumping_Response_and_Quality_of_Water_Extracted_from_Wells_in_an_Active_Hydrothermal_System_The_Case_of_the_Island_of_Ischia_Southern_Italy. Piscopo et al. 2020, Water 12(9):2576, DOI: 10.3390/w12092576

37 https://knoema.com/IS_DCCV_CONSACQUA/public-water-supply-use-italy?territory=1035740-ischia

38 Restructuring of the sewerage network of the municipality of Casamicciola on the island of Ischia (Italy) - Technital Spa

3.4.6 Climate change impact on water resources, water supply, irrigation and wastewater treatment

The climate change impact on the water resources on the island were not assessed in more detail as the main source of water for the piped water supply is sourced from the mainland. As per perception by the interviewed stakeholder EVI, the landslides and floods did not have an impact on the main water resources of the island. Assessments on the mainland related to the vulnerability of the water sources due to climate change impacts was not conducted but it can be generally assumed that some risks might be prevalent, such as:

- Changing rainfall pattern leading to less groundwater recharge and thus water resource availability;
- Increased temperature leading to higher water demand, more evapotranspiration and increased demand for irrigation reducing the availability of surface water for groundwater recharge and putting an additional pressure on the abstraction of groundwater sources;
- Abstraction of groundwater (overexploitation due to increased demand) leading to salinization of near coastal wells.

Regarding the water supply infrastructure, many supply pipelines and sewerage networks are in landslide and flood prone areas. In the last landslide event in November 2022, a part of Casamicciola Terme with 1000 residents was disconnected from water supply for 4 months. Repair works for the infrastructural damages to water supply lines were 250,000 €. More costs (6Mio €) occurred for the repair and desilting of the sewerage system where sand and mud from landslides entered the mixed sewer system and clogged it. This led to inundation and contamination of buildings with untreated sewage leading to expensive repair measures. The pre-treatment of wastewater was also affected and led to more discharge of untreated wastewater into the sea. This seemed to be the major damage related to climate change impacts to the public water supply company, requiring investments into climate proofed infrastructure. Thus this is being analysed in more detail in the following subchapters.

i. Water supply and sewerage infrastructure in areas prone to landslides

Many parts of the mixed sewer systems (Tratto di mista) and the covered mixed drains (Alveo tombato misto-scatolare) are located in regions or close to regions which are prone to landslides (see Figure 3-28) and are thus affected by surface runoff of mud which can potentially clog the mixed sewers and cause the damages related to flooding with wastewater mentioned by the stakeholders.

The municipalities which are mainly affected are shown in Figure 3-28 and listed below:

1. Barano d’Ischia (most affected, see zoomed in Figure 3-29),
2. Casamicciola Terme,
3. Lacco Ameno,
4. Serrara Fontana

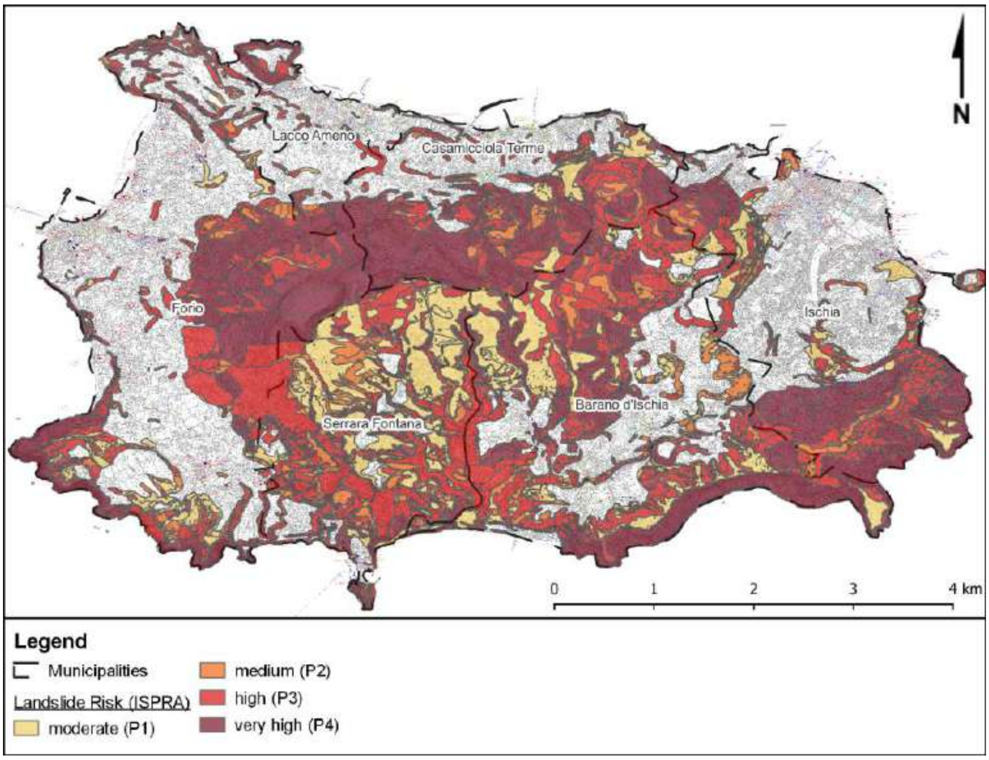


Figure 3-28 Overlay of wastewater network with landslide risk.

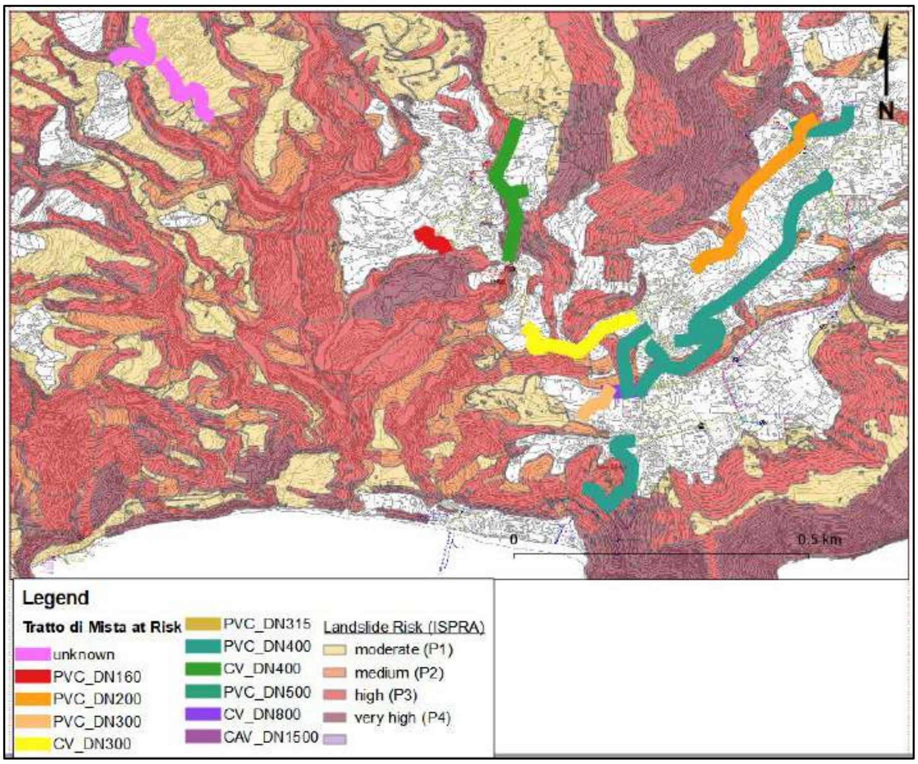


Figure 3-29 GIS Mixed wastewater pipelines at Risk: Zoom in at Barano d'Ischia (most affected)

Overall, approximately 9,685 m of mixed sewer pipeline are at risk, with 5,603 m at high risk and 4,082 m at medium risk. Pipeline lengths that are within the landslide risk (ISPRA) boundaries were considered high risk for these measurements and the lengths that were directly adjacent or connected to part of a pipeline that was within the landslide risk boundary were considered medium risk.

As a disclaimer, these are "high-level" measurements of the pipelines that are only intended to provide rough estimates for the purpose of this study and need to be studied in greater detail for a more precise analysis. As seen in the legend, diameter thickness ranges from 160-1,500 mm and made of either PVC or Vibrated Cement (CV). In some cases, the diameter was not included and thus there is a category called "unknown". The full length of the pipeline, from source to drain, was measured in the high and medium risk areas.

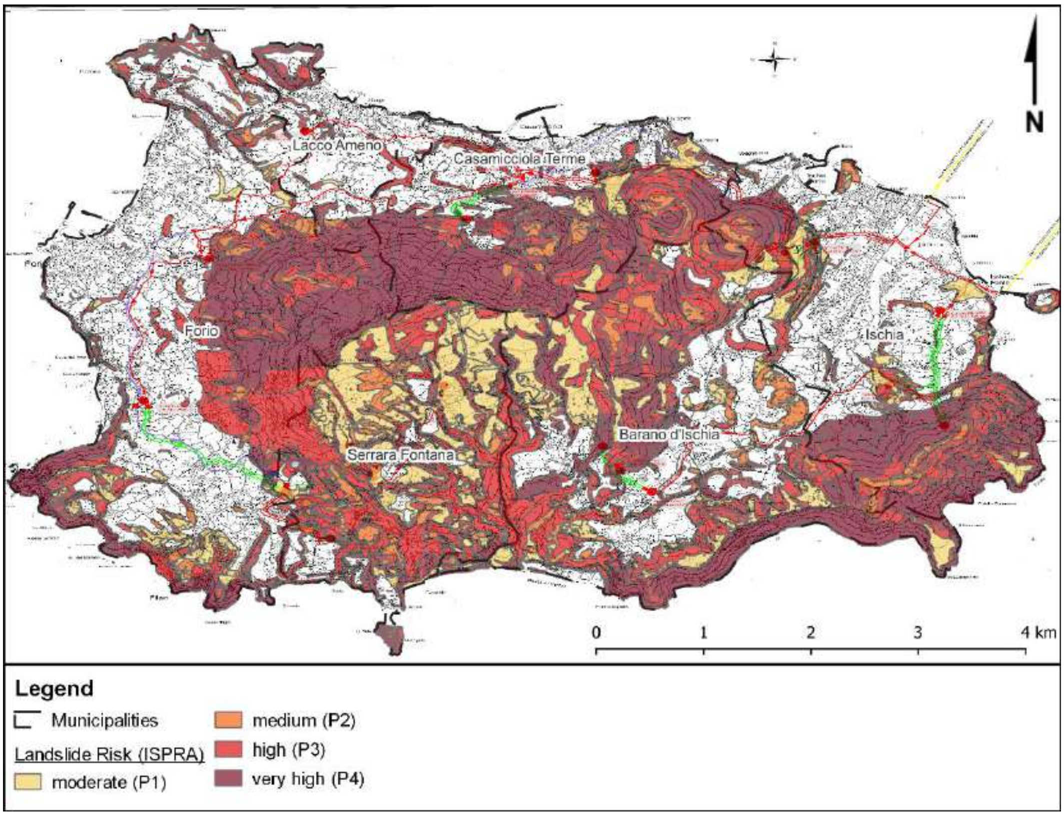


Figure 3-30 Overlay of drinking water distribution network with landslide risk.

While the overall damages in monetary terms to the drinking water supply mentioned by the stakeholders have not been as high as for the wastewater network, the impacts on the population were very serious in a way of being cut off from water supply for a longer period and requiring to be evacuated from their homes (1,000 people for 4 months in 2020).

The interruption of the semi-circular island network at one point would disconnect the entire stretch after this point, making the island's water supply very vulnerable to damages. Many parts of the main supply lines are located in landslide prone areas and are thus at risk of being damaged interrupting the main supply line (see Figure 3-30).

Overall, 18,492 m of drinking water pipeline are at risk. This number includes the full length of the pipelines from one tank to the next even if not all areas fall under landslide risk. If majority of the pipeline is under the landslide risk boundary it was categorized as high risk. The pipeline was categorised as medium risk if some of pipeline was connected to a landslide risk boundary, but more in the moderate risk areas or with a large portion of pipeline adjacent to the boundary. With respect to the buffer tanks, according to the above definition, there are 6 tanks in areas at high to very high risk and 7 at moderate to high risk.

The municipalities in which drinking water distribution are mainly affected are shown in Figure 3-30 and listed below:

1. Serrara Fontana (most affected)
2. Casamicciola Terme
3. Lacco Ameno
4. Ischia
5. Barano d'Ischia

As a disclaimer, these are "high-level" measurements of the pipelines that are only intended to provide rough estimates for the purpose of this study and need to be studied in greater detail for a more precise analysis. As seen in the legend, diameter thickness ranges from 60-350 mm.

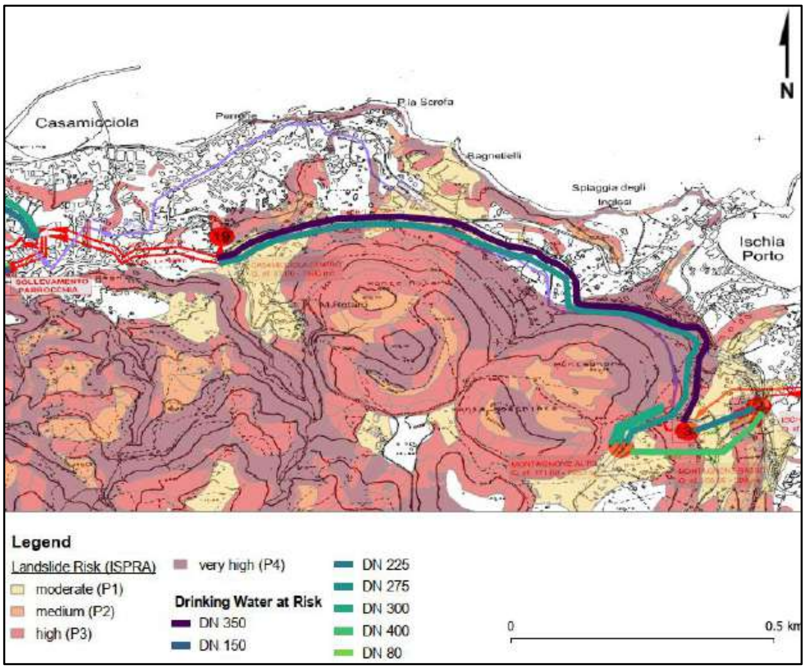


Figure 3-31 Drinking water pipelines at risk: Zoom in at Ischia and Casamicciola Terme. (DN = Diamater nominal, pipeline diameter [mm])

ii. Water supply and sewerage infrastructure prone to floods

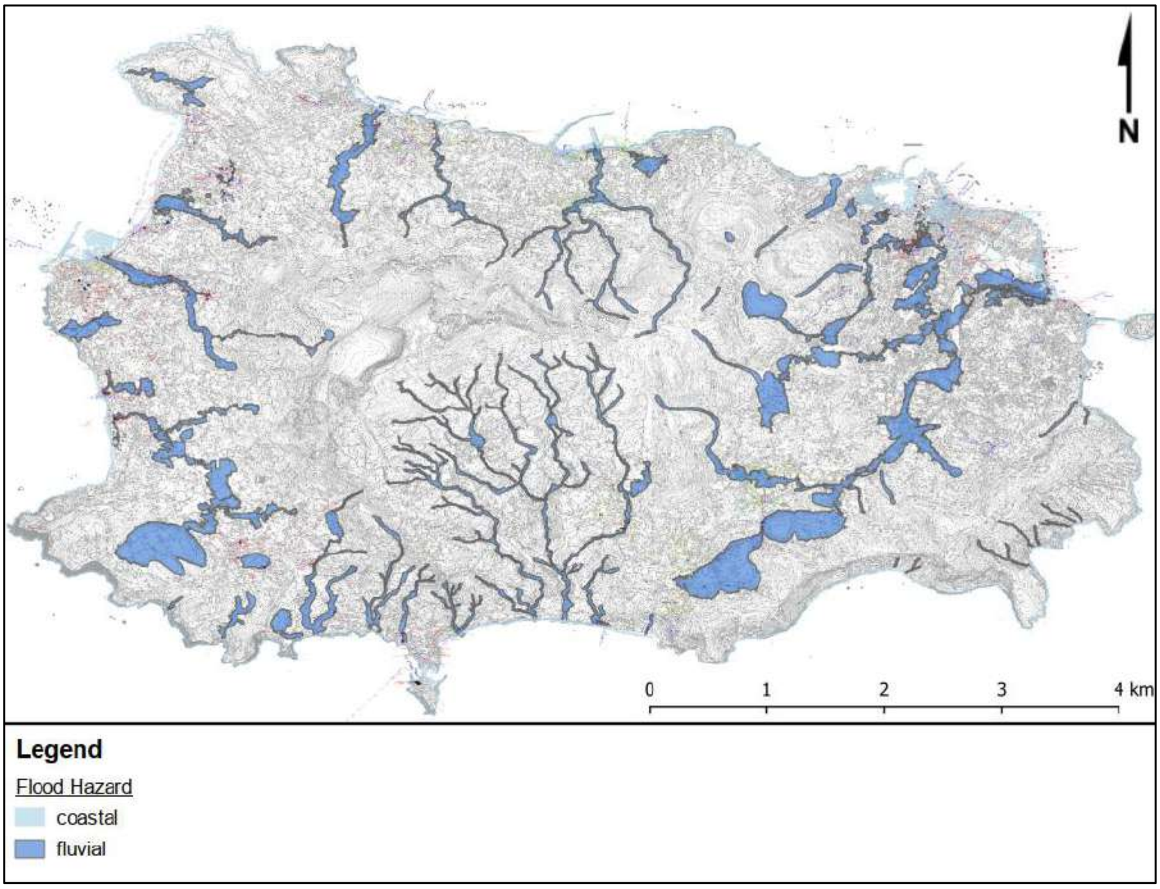


Figure 3-32 Overlay of wastewater network and drainage network with flood risk map

Over 30% of the drainage system including stormwater pipelines (Tratto di bianca) and mixed sewer system (Tratto di mista) cross regions that are prone to floods (see Figure 3-32). These are thus at risk of overflowing, and it is presumed that in the past, they have not adequately contributed to protecting surrounding settlements from flooding.

The municipalities which are mainly affected (from most affected to least affected) are listed below:

1. Ischia (most affected),
2. Forio,
3. Barano d'Ischia (see zoomed in Figure 3-33),
4. Serrara Fontana,
5. Casamicciola Terme,
6. Lacco Ameno

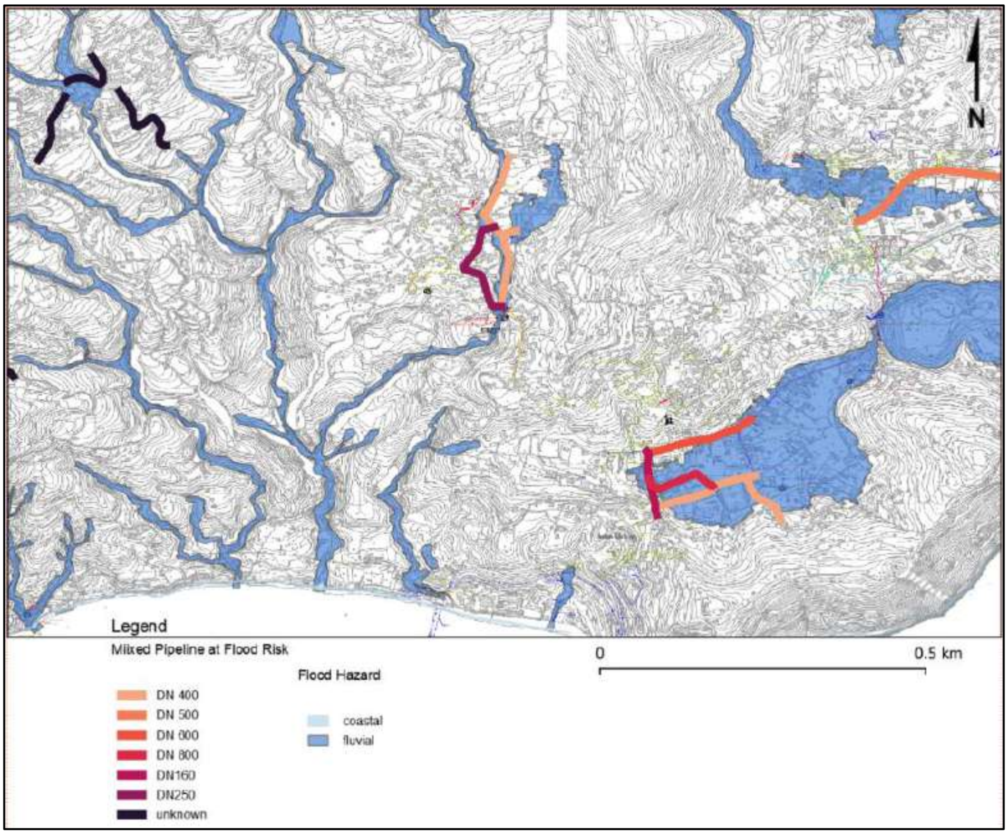


Figure 3-33 Drainage system at flood risk: Zoom in at Barano d'Ischia (third most affected municipality by floods)

Overall, approximately 9,133 m of mixed sewer pipeline (Tratto di mista) cross areas prone to floods and 8,170 m of drainage line (Tratto di bianca). Whenever a drainage pipeline passes through a flood-prone area, it was assumed that the entire drainage line carries a risk of flooding for surrounding settlements. Figure 3-33 accordingly illustrates the stormwater drainage pipelines at risk for the Barano d'Ischia municipality. In this municipality, there are no single stormwater drainage pipelines that are at risk, which is why they are not found in the Figure and thus legend of the Figure; however, single stormwater drainage pipelines at risk exist in other municipalities.

Like the maps and estimations provided in the chapter on landslides, these are "high-level" measurements of the pipeline lengths that are only intended to provide rough estimates for the purpose of this study and need to be studied in greater detail for a more precise analysis. As seen in the legend, diameter thickness ranges from 160-600 mm. In some cases, the diameter was not included and thus there is a category called "unknown".

3.4.7 Vulnerability Assessment

Summarising the vulnerability of the different water sectors to climate hazards, considering the exposure under projected changes of the hazards in 2050, and the sector sensitivity, it can be concluded that increased temperature and precipitation change create the highest risk for the availability of water resources and feasibility of agriculture, that are highly exposed and vulnerable to these hazards without additional adaptation activities. Landsides pose the highest risk to wastewater, especially if collected combined with storm water. Water supply is also highly affected by landslides though not exposed to the same extent as the combined sewer systems: pipelines are endangered directly by landslides to a lesser extent.

Climate hazard	Exposure				
	Water Resources	Water Supply	Irrigation	Wastewater	Sector average
Heat	3	1	3	1	2
Drought	3	1	3	1	2
Landslides	1	2	2	3	2
Coastal Flooding	1	1	1	2	1

Figure 3-34 Exposure of the water sectors to the relevant climate hazards

Climate hazard	Sensitivity				
	Water Resources	Water Supply	Irrigation	Wastewater	Sector average
Heat	2	1	2	1	2
Drought	2	1	2	1	2
Landslides	2	3	2	3	3
Coastal Flooding	1	1	1	2	1

Figure 3-35 Sensitivity of the water sectors to the relevant climate hazards

Climate hazard	Vulnerability				
	Water Resources	Water Supply	Irrigation	Wastewater	Sector average
Heat	3	1	3	1	2
Drought	3	1	3	1	2
Landslides	1	3	2	3	2
Coastal Flooding	1	1	1	2	1

Figure 3-36 Vulnerability of the water sectors to the relevant climate hazards

3.4.8 Potential & recommended adaptation activities

i. Water resource management

- Diversify water resources

A first adaptation activities for water resource management is achieved through the diversification of water sources. This includes the identification and assessment of alternatives to the piped connections from the mainland, including local resources. Focus should be placed on vulnerability to various climate change factors such as changing rainfall events, patterns, increased evapotranspiration, network interruption and saline water intrusion.

- Protect local water resources on the island

Since groundwater is extracted throughout Ischia, sustainable groundwater management by protecting local water resources on the island through protection zones for surface water bodies and aquifers, would also be an important adaptation activity. This could maintain groundwater sources as a safe emergency source. Several wells used in the past could be used for this purpose.

- Improve rainwater catchment and recharge of aquifer

Another adaptation activity could involve the improvement of rainwater catchment and aquifer recharge. This process would require identifying catchment and suitable infiltration areas and conducting feasibility assessments on various Managed Aquifer Recharge (MAR) technologies, such as infiltration ponds and infiltration wells. Improving local accumulation of water through rainwater harvesting structures for irrigation could also be impactful since 60% of water is used for garden irrigation.

- Enlarging the stormwater drainage system to address flooding

In flood prone areas the diameter of storm water drainage pipelines could be increased. This would not only protect the surrounding settlements being damaged by the water but also facilitate better drainage of stormwater for further use, e.g. infiltration at other locations. Overall, approximately 9,133 m of mixed sewer pipeline (Tratto di mista) cross areas prone to floods and 8,170 m of drainage line (Tratto di bianca) in total 17303 m of storm water pipeline. The costs for this adaptation activity have been estimated at up to 12.00 M€ for increasing the diameter by 50mm. Further information regarding cost estimations, utilized equations, and assumptions can be found in the Appendix 6. This is a very basic estimation of this option, possibly some storm water drainage systems could require a different planning and possibly catchment management and aquifer recharge in the water shed could make this measure unnecessary.

- Improve management of water resources

While the assessment of water resources of the mainland catchment for the piped water supply to Ischia is out of the scope of this study, improving rainwater catchment on the mainland would also be an important element of the larger management of water resources.

ii. Water Supply

- Redundant systems for supply network in areas of risks for landslides

The installation of redundant systems for supply networks in areas at risk for landslides would increase the resilience of the supply network. In these risk areas, alternative network connections with new pipelines that are placed in safe areas would provide additional connections which ensure the supply in case of interruption of the main line. In this case, a total of 9,427 m of pipeline would need to be added. Figure 3-37 shows how this could look like for Ischia and Casamicciola Terme. The estimation of additional pipeline lengths was determined by roughly rerouting pipeline lengths that are located in areas prone to landslides through areas that were less likely to be at risk. To facilitate the installation of the new pipeline, efforts were made during the assessment of its potential length to ensure its alignment along roads whenever feasible. In this scenario, a total of 5,623 meters of new pipeline could be installed alongside roads.

In addition, as part of this relocation, the relocation of 12 buffer tanks would be necessary. These estimations do not consider other factors like topography, infrastructure or other water distribution criteria. For a more precise estimation, these areas would need to be studied further, and new pipeline lengths would need to be designed based on an in-depth study. For the overall layout an additional pipeline linking the southern dead ends would provide additional safety so that water can be sourced from both sides of any interruption to the closed network circle (see petrol line in Figure 3-37). The new connection would require 2,177 m of new pipeline (part of the above figure for the total length of the pipeline to be added). This new connection, however, still traverses areas that are under landslide risk as this area of the island is highly prone to landslides. Details about how the pipeline lengths were determined are provided in Chapter 3.4.6.

The costs for this adaptation activity have been estimated at up to 4.09 M€. This includes 3.78 M€ for rerouting sections of the drinking water pipeline that are vulnerable to landslides to more secure areas, and approximately 0.31 M€ for the integration of the two primary drinking water network lines into a single circular network. Further information regarding cost estimations, utilized equations, and assumptions can be found in the appendix 6.

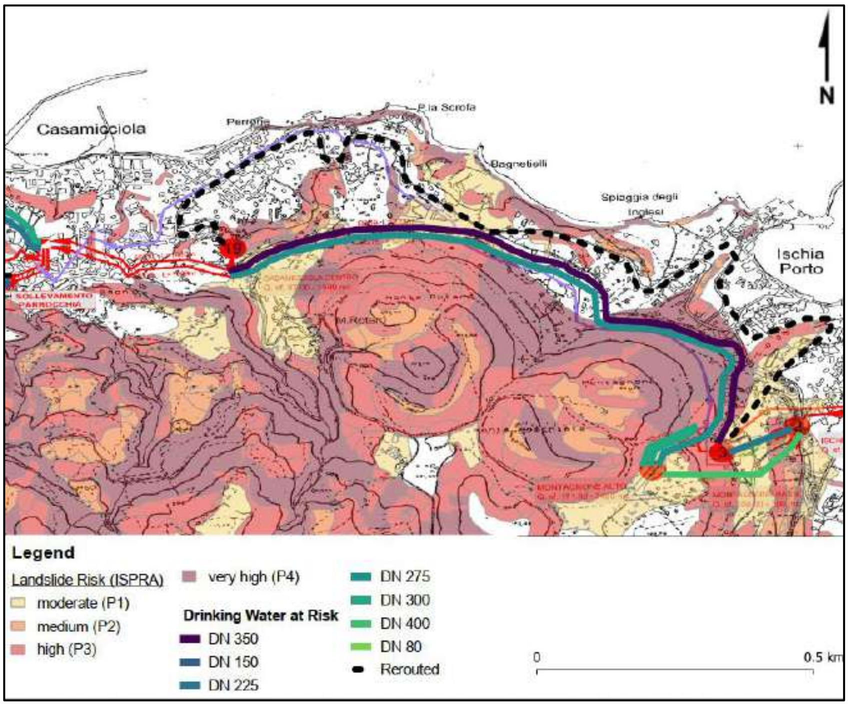


Figure 3-37 Possible rerouting of water supply network for Ischia and Casamicciola Terme.

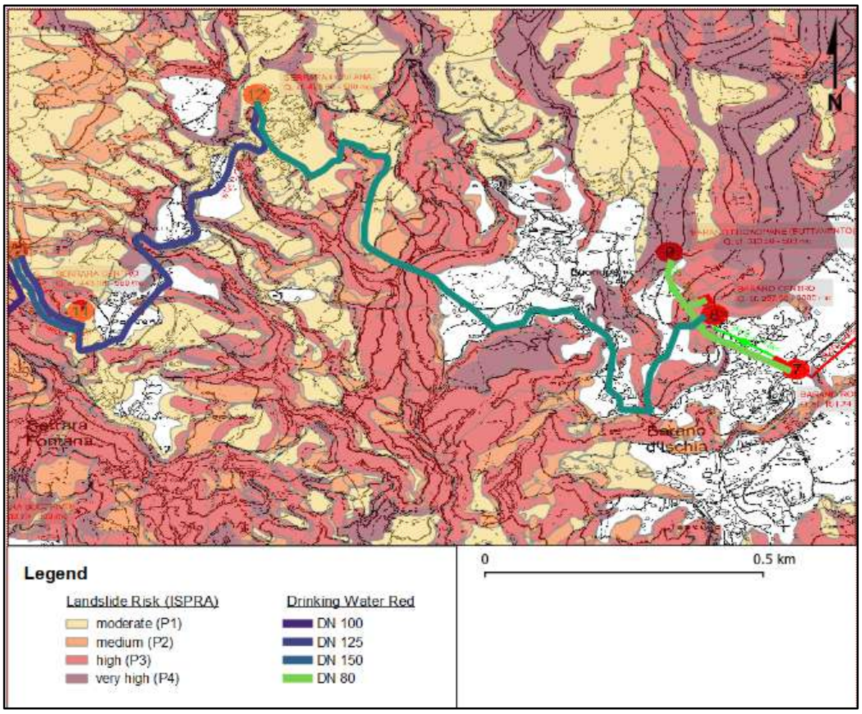


Figure 3-38 Possible connection of both drinking water networks into a circular network.

- Increase decentral buffer storage systems which can be used during interruption of central network

Identify suitable locations for additional buffer tanks which can bridge supply potential interruption breaks. The existing system of buffer tanks can either be enlarged or additional tanks can be setup increasing the decentral temporary independence and additionally ensuring sufficient supply in fluctuating demand scenarios.

- Emergency treatment systems for sudden interruptions

Emergency treatment systems should be in place in case of interruptions to water supply. Small, decentralized treatment systems for essential drinking water provision from locally available water resources can reduce the need to relocate households to hotels in emergency situations. In cases where there is no reliable access to fresh water sources, reverse osmosis for desalination of water could be an option.

- Improve network monitoring and maintenance

Minimise leakages to reduce overall water loss and installation of additional valves with options for shutting down small parts of the network in case of damages to the network (existing network is 60 years old and requires repair). Currently it is being discussed to improve the monitoring system for quicker identification of leaks to reduce the water loss, this idea can be further nurtured with a robust feasibility study.

iii. Wastewater and Irrigation

- Setup separated sewer system

To address the clogging of the sewerage system and avoid the damages caused, storm water drains would need to be separated from the mixed sewer system. An ongoing project idea (for 15 years), that has been stalled due to lack of funds, is to create three different wastewater lines. The stormwater and the thermal spring water lines (white) would go directly into the sea as they do currently in the mixed sewer. These would be separate from the black wastewater sewerage line so that mud does not enter, and clogging is prevented. In total, 9,685 m of mixed sewer system are located in areas at high or medium landslide risk, which means that an additional stormwater drainage pipeline of the same length would need to be implemented to transform the mixed sewer system at risk into a more resilient separate sewer system. Details about how this pipeline length was determined are provided in Chapter 3.4.6.

One example where a redesign of the mixed sewer system is needed is the culvert under via Monte della Misaricodia:

During the field mission to Ischia, it emerged that the 3 gorges from where the landslide entered the Casamicciola Terme are being cleaned and hydraulic prevention measures are being installed to the gorges. The culvert running under the via Monte Della Misericordia has not been redesigned and its capacity to receive the waters coming from the three gorges has not been assessed.

It is also a mixed sewer receiving wastewater from the houses along the road. Therefore, from a touristic point of view, the outlet of the pipe is not in a optimal location (next to the Casamicciola Terme port by the beach) and could be transferred further to the sea. Redesigning the corresponding culvert would cost approximately 0,43 M€.

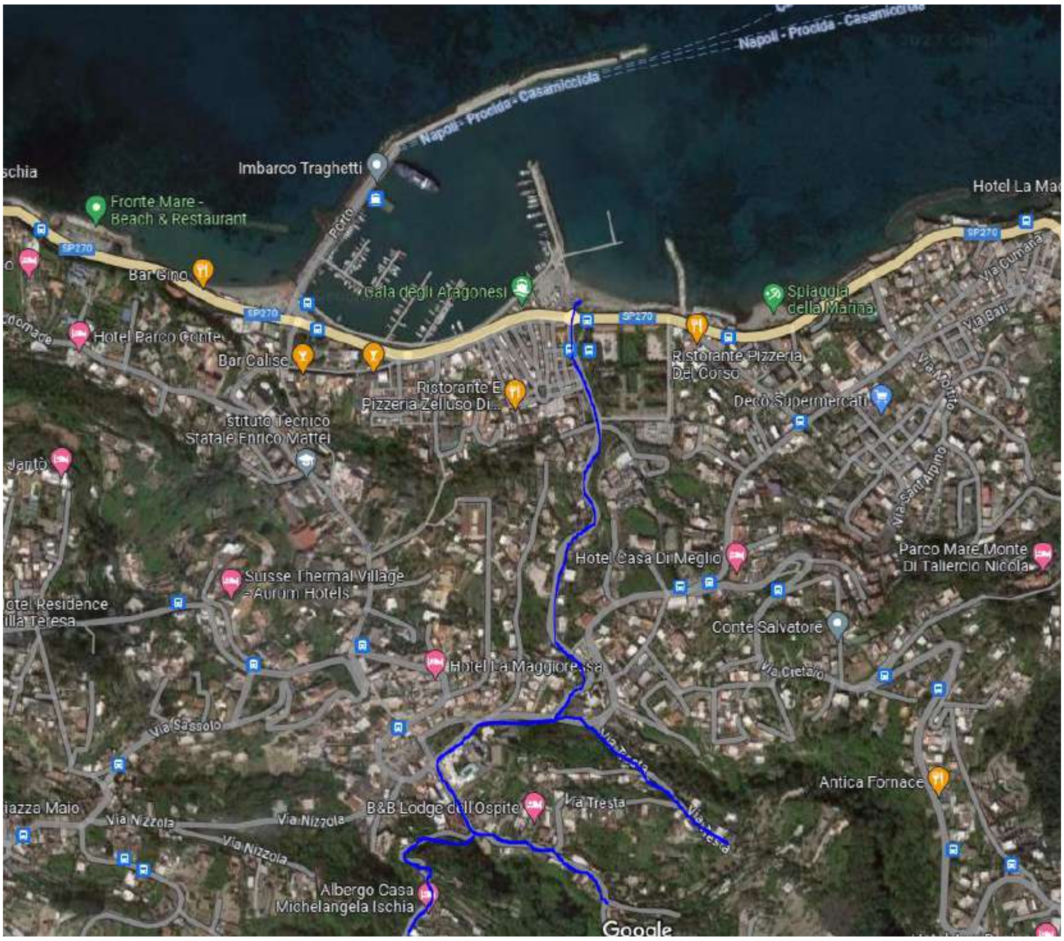


Figure 3-39. Wastewater channel requiring redesign in Casamicciola Terme.

As a long-term adaptation activity, it is recommended to transform the entire mixed sewer system of the Ischia into a separate system. In this case, an additional 15216 m of new pipeline would need to be installed. Please note: this estimation was conducted based on a simplified, rough determination. A more detailed assessment on the ground would be needed for more precise numbers, especially for the cost estimation.

The costs for transforming the mixed sewer system at risk and to areas with low or no landslide risks, into a separated sewer system have been estimated at up to 4.22 M€ and 5.53 M€, respectively. Further information regarding cost estimations, utilized equations, and assumptions can be found in the Appendix 6.

- Increase share of sewage treatment

Overall, there is a demand to expand sewer coverage and establish wastewater treatment plants to increase the availability of water for reuse, as currently only 60% of the wastewater is being collected. The reuse could substitute usage of potable water and thus reduce pressure on its abstraction.

- Consider decentral Nature-based solutions (NBS) for wastewater treatment

Decentralized NBS, like constructed wetlands and reedbed filters, for wastewater treatment should also be seriously assessed and considered since these solutions do not require extended sewerage systems and can provide co-benefits like aquifer recharge and habitat restoration. Targeted treatment by segregating black and grey water can create more opportunities for reclamation and reuse, optimising the utilisation of available water sources.

- Climate resilient agricultural and gardening practices

Options for climate resilient agricultural and gardening practices can be assessed. More efficient irrigation technologies can be implemented. Crop diversification, drought resistant crop selection and regenerative farming techniques, like organic farming and permaculture practices, can also reduce the water required for agricultural production and make a more efficient use of the water resources. This can additionally reduce non-point source pollution from agriculture, thus protecting the quality of local water resources.

Overview of cost calculations of selected adaptation activities:

Table 3-18 Overview of selected adaptation activities with cost estimate

Adaptation activity	Criticality	Cost estimate
Rerouting drinking water pipelines from areas prone to landslides to areas with lower risk	High	3,78 M€
Connecting the two main drinking water network lines into one circular network	High	0,31 M€
Transforming mixed sewer system at high landslide risk into a separated sewer system	High	2,77 M€
Transforming mixed sewer system at medium landslide risk into a separated sewer system	Medium	1,45 M€
Transforming the mixed sewer system in areas with low or no landslide risks into a separated sewer system	Low	5,53 M€
Enlarging the stormwater drainage system crossing areas prone to floods by 50 mm	High	11,90 M€

3.5 Energy supply

3.5.1 Introduction

The inhabitants of Ischia use energy in industry, manufacturing, agriculture, forestry, fishing, heating, transportation, and common infrastructure such as water, sewerage, and street lighting. Ischia became connected to mainland electricity in 1967 through four high-voltage underwater cables from Cuma on the Campania coast to Lacco Ameno in Ischia, acquired by ENEL S.p.A.

As for energy consumption for heating purposes, natural gas is used, partially at network level (the network on the island is currently serving only part of the households across some municipalities) and partially through individual tanks at household level.

Moreover, the municipality of Serrara Fontana is planning to build a pilot geothermal plant with an organic cycle electricity production plant, which will be able to generate electricity and heat without producing emissions into the environment. The pilot plant will use geothermal fluids as a source. There are also several public and private initiatives for photovoltaic panel installation, under specific requirements to meet the strict local permitting procedures, mostly related to the preservation of the status of cultural heritage of the island. For this reason, no large PV fields can be installed, and the solar systems are limited to individual households.

The analysis hereby presented has been based on the publicly available information concerning the electricity network. The site-specific information related to the distribution network, its characteristics and the actual location of transformers and overhead cables has not been made available in due time, although requested to the energy distribution company through local authorities. This poses a significant barrier to the proposition of detailed site-specific adaptation activities against the identified climate related risks, which have been assessed at overall level.

3.5.2 Electricity network in Ischia

Ischia was connected to mainland electricity in 1967 through four high-voltage underwater cables from Cuma on the Campania coast to Lacco Ameno in Ischia, acquired by ENEL S.p.A.

The traditional electricity power system includes the generation stations, step-up transformer, transmission lines to substation step-down transformer, and customer distribution cables as shown in Figure 1. Inside Ischia, there is no generation station, as electricity is transferred through the high voltage underwater cables from the mainland directly to Ischia Island.

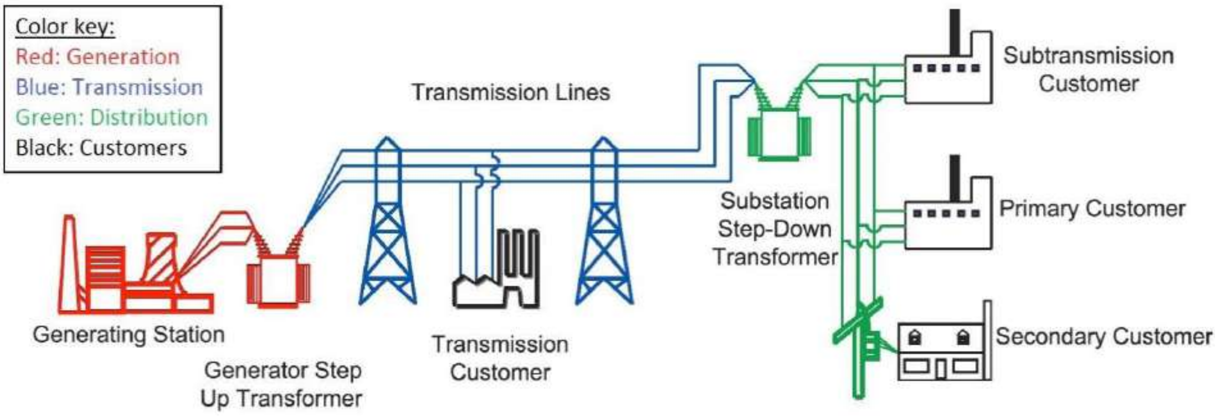


Figure 3-40. Overview of the traditional electric power system

Power outages caused by natural disasters can cause accidents, disrupt economic activity, and make it difficult to respond to emergencies until the electrical supply to vital services is restored.

In the short, medium, and long terms, the climate will change, increasing the number of risks to the infrastructure supporting the energy supply. In conclusion, the following sections list the primary identified threats for energy supply.

3.5.3 Landslides

As precipitation and instances of heavy rainfall occur more frequently, there is an increased possibility of large-scale mass movements. Landslides may damage plant components, resulting in decreased energy output, plant shutdown, and restricted access to the plant site for repair.

The accompanying map (Figure 3-41) shows the buildings at danger of mass movement based on GIS data, with an emphasis on the locations of infrastructure for energy distribution.

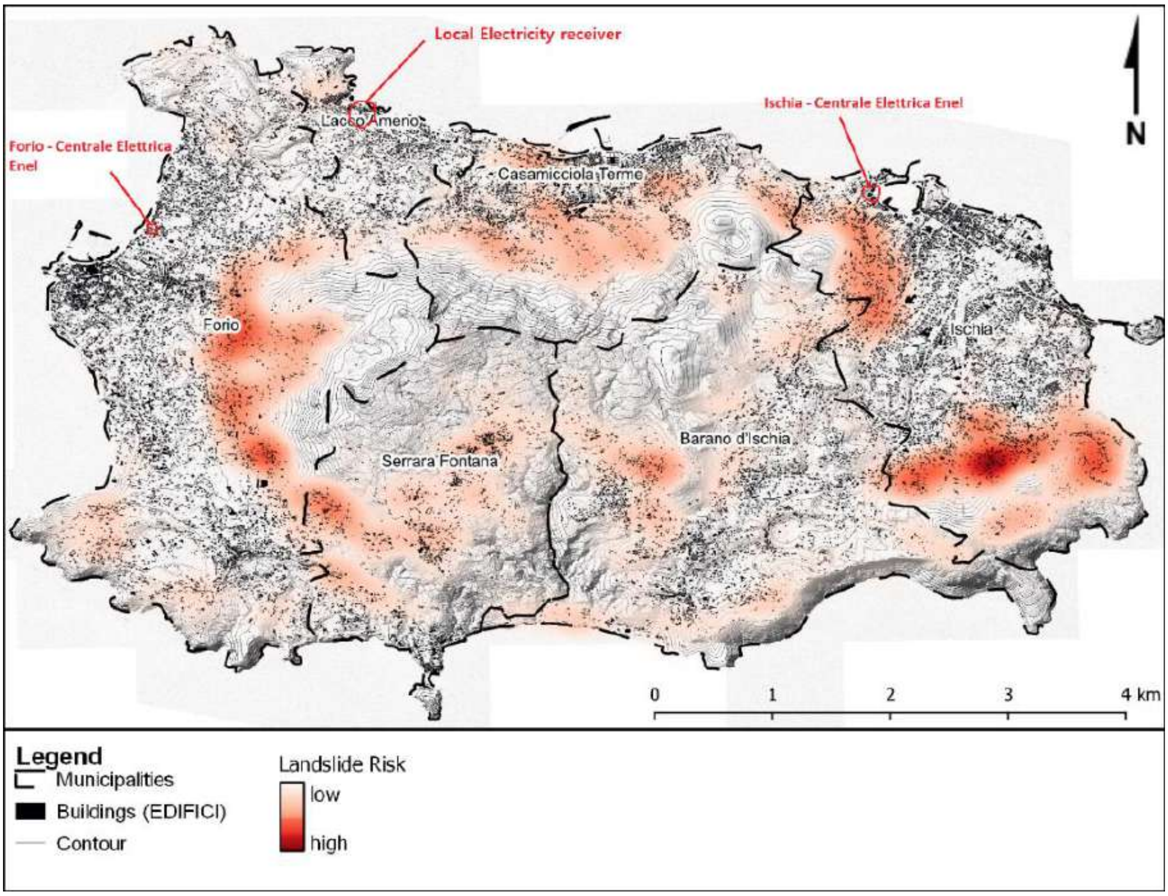


Figure 3-41. Landslide risks on electricity stations based on GIS-data.

As shown in Figure 3-41, the three mentioned locations for electricity distribution centres and the local receiver have a low landslide risk based on the GIS data presented. There are some risks related to the electricity transmissions lines between the electricity distribution centres and the customers at different buildings through Ischia as shown in the same map.

In general, landslides can cause towers/poles to fall and structural damage from falling plants and trees.

3.5.4 Fluvial flooding

Power shortages and floods are often related. Transmission tower foundations are weakened by erosion brought on by flooding. When electrical equipment comes into touch with water, serious damage—often explosive—may result, whereas moisture and dirt entry need time-consuming repairs on submerged equipment.

Some electrical equipment components can experience catastrophic failures in the presence of even limited amounts of moisture and filth because water is an excellent conductor of electricity.

Substations are more vulnerable to flooding because of their widespread use and significant concentration of delicate equipment. The scale for measuring damage and service interruption caused by flooding on substation equipment is shown in *Table 3-19*.

Table 3-19. Substation equipment flood damage and failure modes

Damage scale	Description
Slight/minor	• Shut off preemptively. • Tripping
Moderate	Inundated, repairs economically feasible
Severe	Inundated, beyond economically feasible repair
Catastrophic	Explosion

Flooding is a natural occurrence that is influenced by geography and precipitation and may happen everywhere, including flat places like flood plains and estuaries as well as valleys with streams and rivers. As a result, energy supply infrastructures may occasionally be submerged, which frequently results in damage or even destruction of the system. Based on GIS data, the following map (*Figure 3-42*) displays infrastructures at danger of flooding.

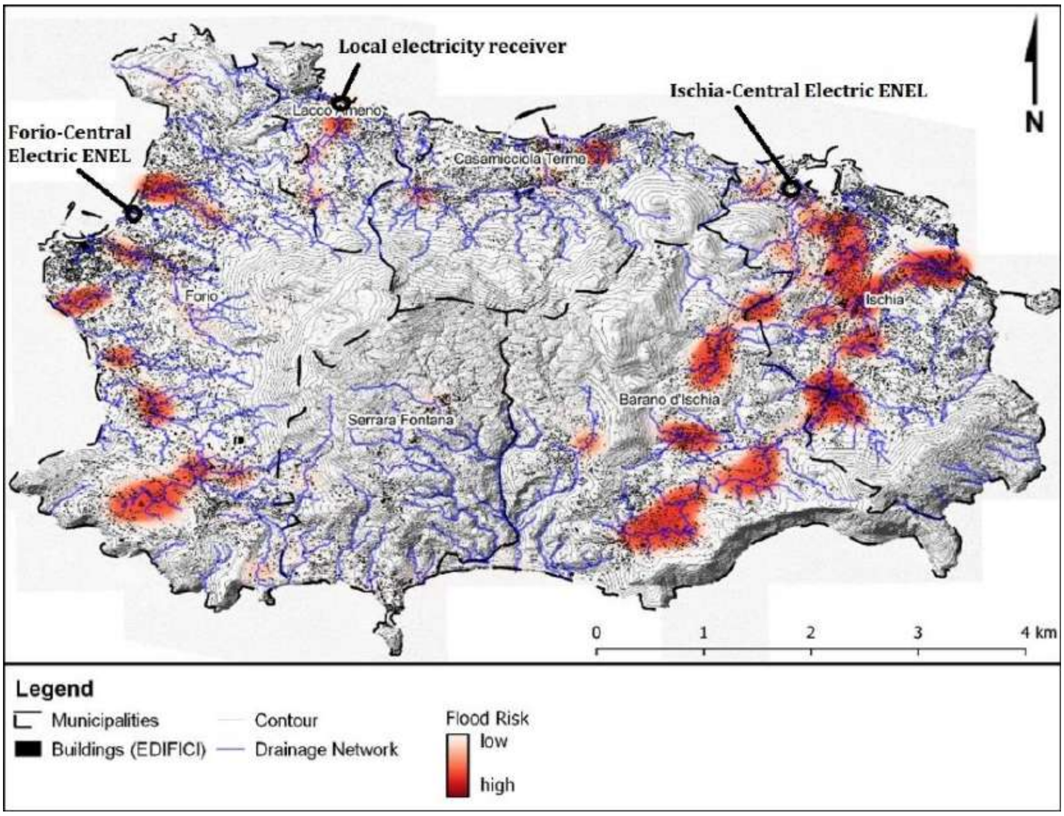


Figure 3-42. Fluvial flooding risks based on GIS-data.

Based on the above map, the infrastructure for central electricity from ENEL has a minor flooding risk while the infrastructure of the local receiver that is located in Lacco Ameno has a moderate flooding risk. This analysis is a general screening of possible risk sections for electricity networks and does not reveal yet the actual risk in the main electricity distribution cables.

3.5.5 Wildfire

In the rainy season, Ischia has vegetation, which dries out in the dry season. Climate change will affect the time of this and perhaps even the sorts of plants. Numerous studies in California[39] have demonstrated that burning vegetation has a negative impact on soil stability and increases landslides and debris flows.

[39] Ren D, Leslie LM. Climate warming enhancement of catastrophic southern California debris flows. Sci Rep. 2020 Jun 29;10(1):10507. doi: 10.1038/s41598-020-67511-7. PMID: 32601392; PMCID: PMC7324592.

Burning also affects wooden parts of the electrical infrastructure as well as bituminous materials, particularly uncontrolled flames. It will be crucial to keep wildfires to a minimum.

Utility lines, especially high-voltage lines, can start fires in a variety of ways. Electricity can arc between a line and a tree if tree branches are too close to power wires. Sparks can be ignited by outdated equipment. Power wires may droop and come into contact with trees or dry grass when it is really hot outside. Strong winds have the potential to destroy equipment or knock electricity lines onto nearby tree branches. Electricity is a crucial component of infrastructure and the backbone of many other services. When electricity goes out during a crisis, individuals might not be able to get vital information because cell phone coverage can be lost if transmission towers are not powered by backup generators. Electricity is also required for wells and water treatment water pumps.

In the following map (Figure 4), infrastructures under wildfire risks based on GIS data are presented. This map considers historic wildfires from the EFFIS dataset as well as Corine landcover showing the landcover category of the island (including areas prone to wildfires (i.e.: different types of forests).

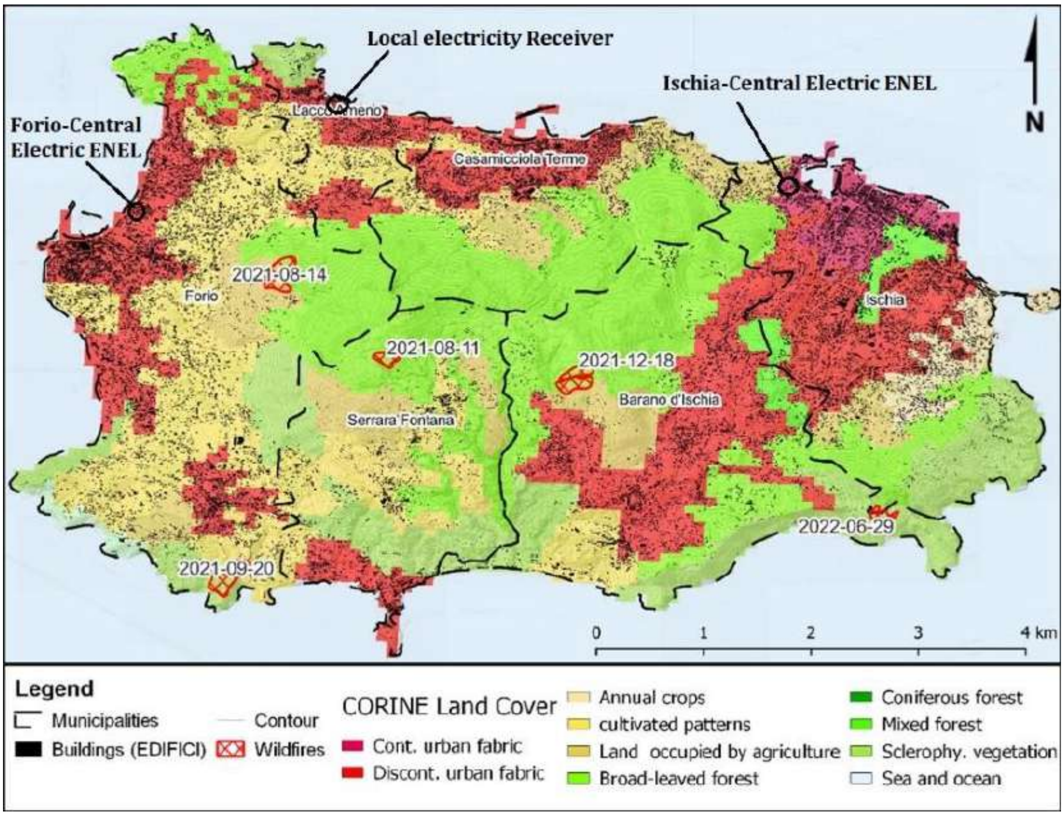


Figure 3-43. Wildfire risks based on GIS data.

3.5.6 Sea level rise

As mentioned in the previous sections, climate change will result in rise in sea levels and flooding. The combined impact of the expected sea level with storm surge and wave set-up is another issue that must be examined. These are the regions that are susceptible to the risk of submersion because of the combined impact of sea level rise and wave & storm surge effects on low-lying locations, as shown in Figure 5.

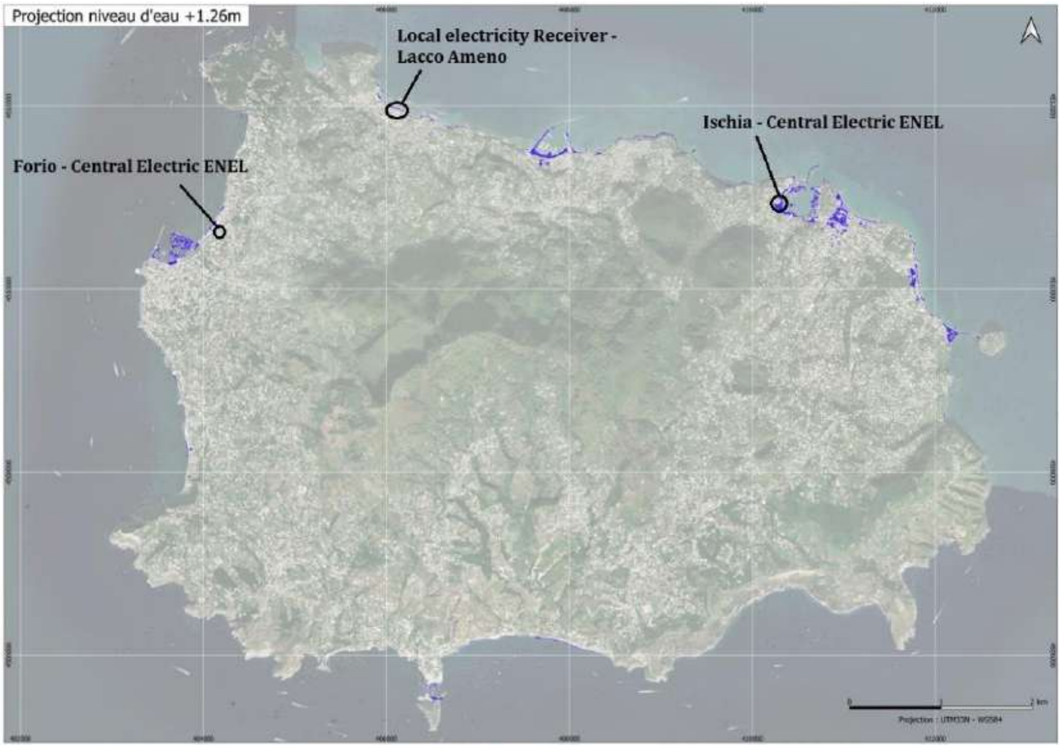


Figure 3-44. Risk of submersion due to sea level rise and wave and storm surge actions in low-lying areas.

In the previous map (*Figure 3-44*), electricity infrastructures under sea-level risks based on GIS data are presented. The electricity distribution centre in the Ischia region is under high exposure for the risk of submersion while the other distribution centres in Forio and Lacco Ameno have a low exposure for this risk. It needs to be noted that this analysis is a very general screening of possible risk and does not reveal the actual risk in the field, since some adaptation options might be already in place. The performance of the digital elevation model at the low areas is a further challenge to this analysis.

3.5.7 Increased temperature

The effects of increased temperature on the electric distribution network relate to sagging, as the increase in air temperature leads to thermal expansion of the transmission/distribution wires, which reduces the distance to earth. This may result in risks of electrocution, and interaction with trees and/or vegetation, which can lead to fires.

Furthermore, prolonged higher temperatures will have a direct impact on facilities such as concrete infrastructure (structural stability) and has a negative effect on the efficiency of power lines. Damages from wildfires are expected to be more frequent and intense in a warmer and drier climate.

Heat waves can increase peak electricity demand, mainly due to air conditioning. Overloading transformers increase internal operating temperatures, as heat is a by-product of their normal operation.

Frequent overloads caused by severe heat waves weaken transformer insulation and, in extreme cases, can lead to thermal runaway. These conditions can lead to substation fires and the destruction of network infrastructure and power lines.

1.3.2.6. Other climate hazards

The increase in frequency of heavy precipitations affect Energy Transmission and Distribution Networks as it can result in damage to poles and power lines, also increase in accidents caused by storms. The accumulation of water in the ground can damage power poles and lines directly, for example by causing poles to collapse, and indirectly (trees fall more easily due to uprooting caused by flooding). Storms, windstorms and lightning can damage power lines and transmission and distribution infrastructure, resulting in power outages and blackouts.

Both effects can cause direct damage to transformers, including the loss of HVAC systems, control rooms and communication systems, as well as foundation erosion.

Windstorms and related weather events can damage power transmission and distribution infrastructure and cause power transmission and distribution lines to fail. Falling trees due to high winds can also have an impact on energy networks.

Coastal erosion, storm surges and sea level rise can damage and disrupt transmission and distribution infrastructures located near the coast. Silting of rivers and streams: transmission and distribution lines can also be affected by silting of rivers and streams and other erosion processes caused by changes in the hydrology of catchment areas.

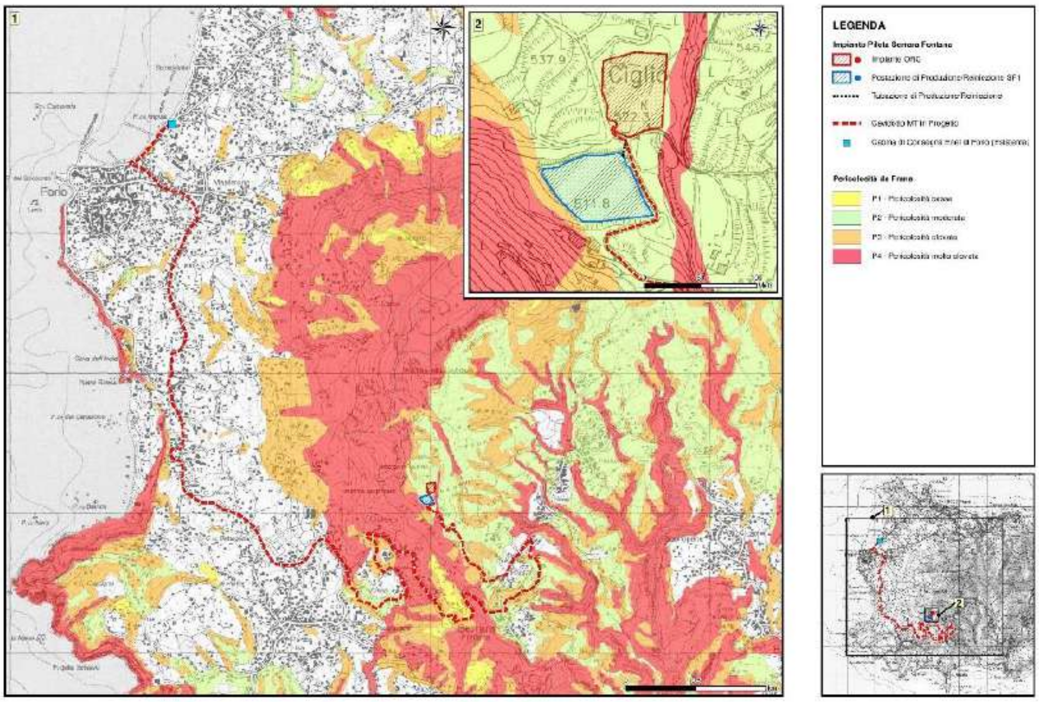
3.5.8 Geothermal plant

Ischia is characterized by an interesting potential for the exploitation of the geothermal source for energy generation. Many research studies have been carried out in the recent period to screen possibilities for industrial applications under this perspective.

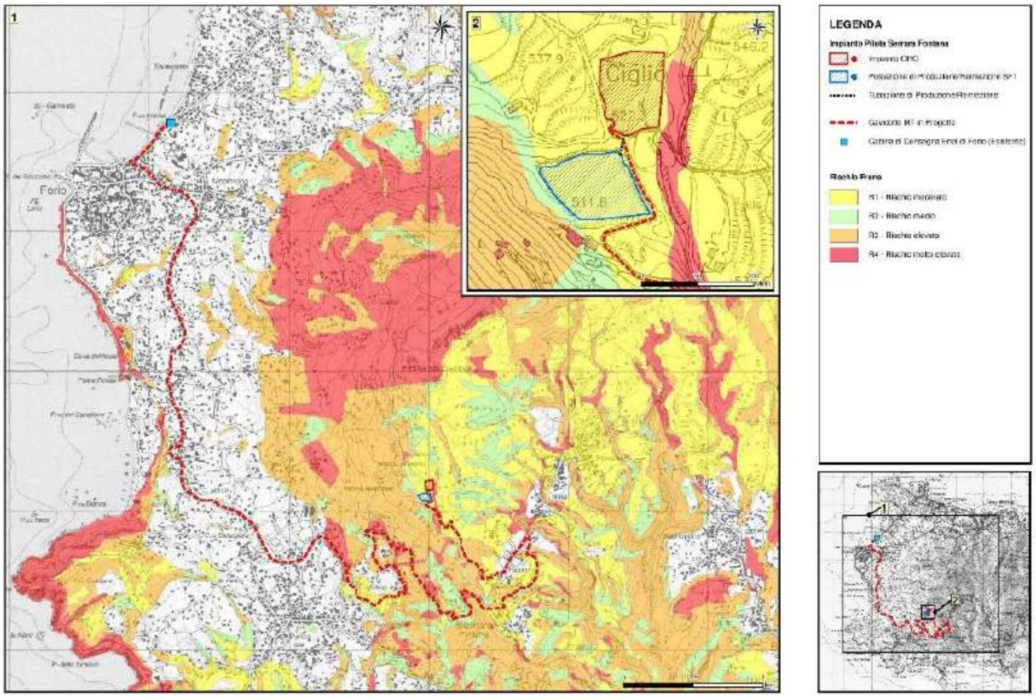
One of the most mature initiatives is in the municipality of Serrara Fontana, where the local administration and investors are planning to build a pilot geothermal plant with an organic cycle electricity production plant, which will be able to generate electricity and heat without producing emissions into the environment, with a rated capacity of approximately 5 MW net electrical output. The electricity produced in the ORC plant will be fed into the Enel Distribution network via a new Medium Voltage line, approximately 10.2 km long, completely underground and built along the existing road, which will start from the generator present in the plant and arrive at the Enel Distribution delivery cabin located in the Municipality of Forio. The electricity line will affect the municipalities of Serrara Fontana and Forio.

i. Geothermal plant landslide hazard

Figure 3-45 (a) shows the landslide hazard areas identified by the Plan for the Hydrogeological Structure (PAI) in the area affected by the planned works. The relative risk levels are shown in *Figure 3-45*.



(a)



(b)

Figure 3-45. (a) Landslide Hazard Areas –(b) related Risk levels (PAI Regional Basin Authority of Central Campania)

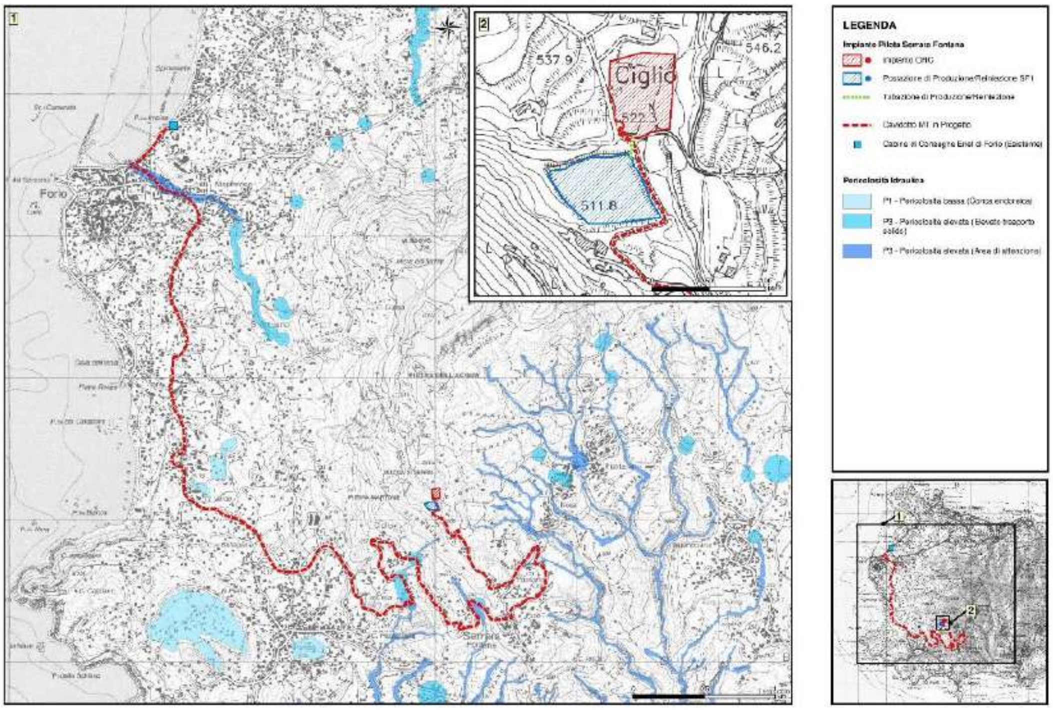
As emerges from the analysis of *Figure 3-45*, the areas identified for the construction of the Serrara Fontana pilot plant (SF1 station and ORC plant) fall into class P1 - low landslide hazard which corresponds to an R1 - moderate risk level. Interventions in areas with moderate landslide risk are regulated by Art. 24 of the Plan Rules. As regards the project of the 30 kV electricity line connecting the pilot plant and the Enel delivery cabin in Forio, as emerges from Figure 1, the route involves areas classified at different levels of danger and landslide risk. Considering the most restrictive condition corresponding to the involvement of areas at very high landslide risk, the creation of underground services on existing road routes is permitted.

ii. Hydraulic Hazards and Risks

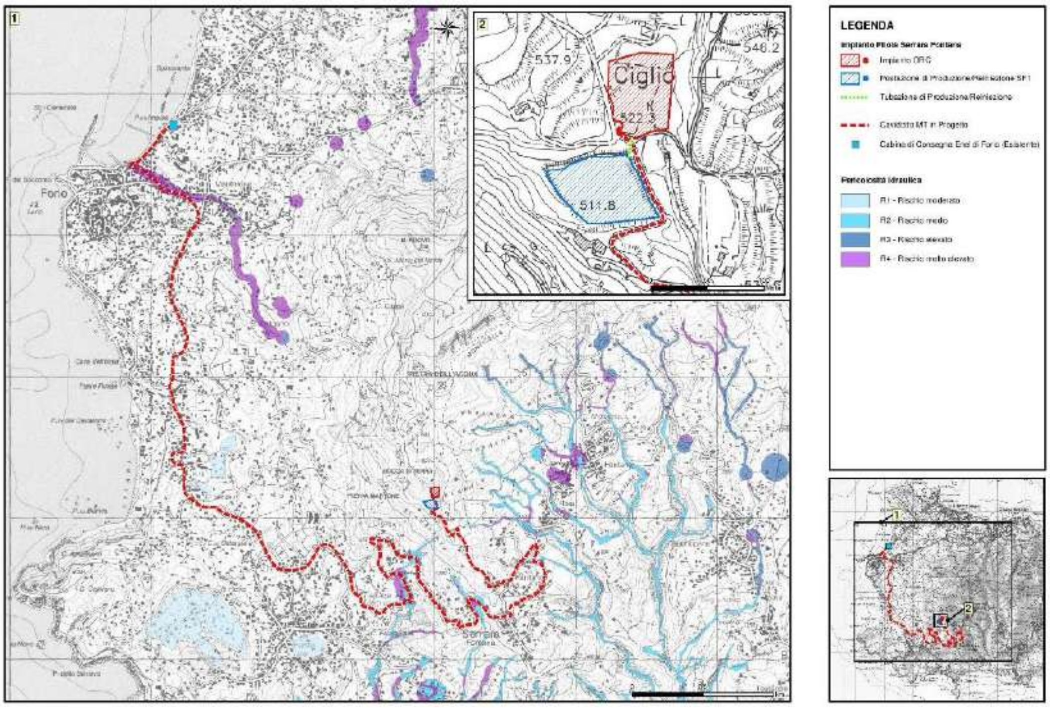
Figure 3-47 (a) and (b) respectively represent the hydraulically hazardous areas identified by the PAI and the related risk levels.

As visible in *Figure 3-47*, the stations of the Serrara Fontana pilot plant are in areas that the PAI does not identify as dangerous or at risk from a hydraulic point of view. Regarding the cable duct connecting the pilot plant to the Enel delivery cabin in Forio, as visible in Figure 7, the route of the electricity line crosses, for a total length of approximately 610 m, areas classified as P3 - high hydraulic hazard corresponding to a very high R4 risk level, identified by the PAI between the towns of Serrara Fontana and Sant'Angelo.

Regarding this, similarly to what was previously stated for landslide danger/risk areas, we would like to point out that article 12 of the Plan for the Hydrogeological Structure PAI ("Interventions permitted in relation to public network works and infrastructures and of public interest admits among the interventions permitted in the R4 areas the creation of underground services on existing road routes. The relevant hydraulic compatibility studies must be prepared only for underground services that involve significant works above ground.



(a)



(b)

Figure 3-46. (a) Areas subject to hydraulic hazard –(b) related risk levels (PAI Regional Basin Authority of Central Campania)

iii. Hydrogeological constraint

Figure 3-47 shows the areas subject to hydrogeological constraints and the areas involved in the project under study.

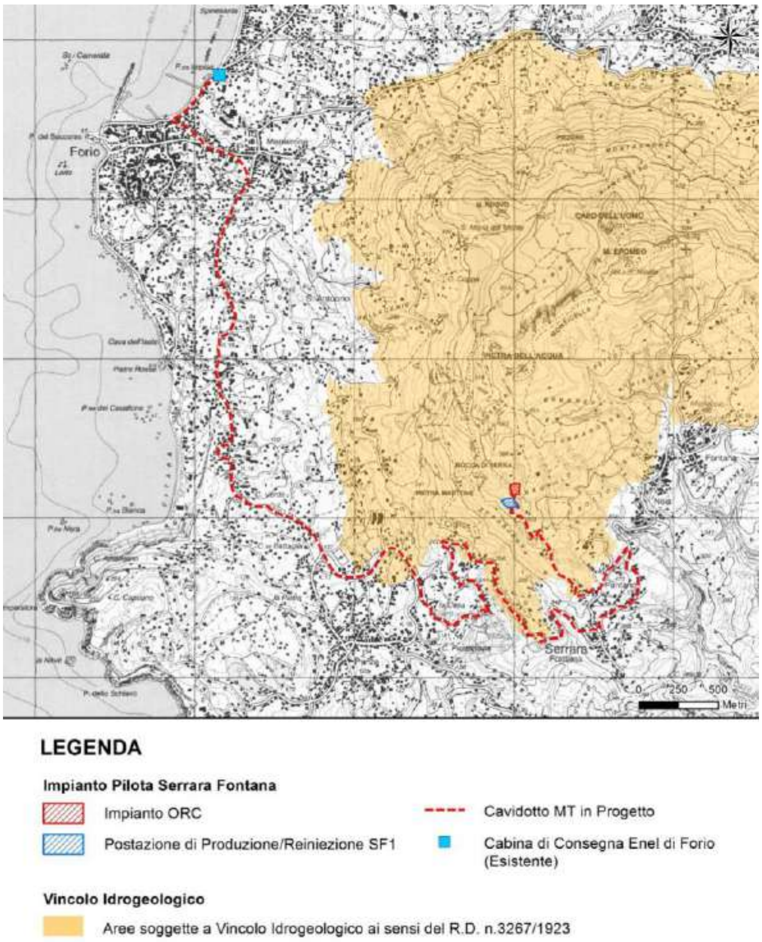


Figure 3-47. Areas subject to hydrogeological constraints

As shown in the *Figure 3-47*, the ORC plant, the SF1 production/reinjection station and some sections of the MT cable duct (in addition to the interventions to adapt the existing road system and the temporary water supply pipe) fall within areas subject to with hydrogeological constraints. Given the above, for some interventions in the project, the following is specified:

- the construction of the SF1 station and the ORC system does not involve significant waterproofing, as the waterproof areas correspond to approximately 20% of the total occupied surface, and therefore such as not to trigger a condition of imbalance in the current hydrogeological conditions of the sites;
- in the area of the ORC Plant, the implementation of interventions to make the area safe is planned, consisting of reinforced earth walls to be installed in the northern, eastern, and southern parts, and in the western part in a covered retaining wall with local stone, which will improve the stability of the perimeter fence;
- the MV cable duct will develop entirely along the existing road system and the depth (approximately 1.2 m) of the excavations for the installation of the cable is not such as to alter the hydrogeological conditions of the area.

In conclusion, considering the characteristics of the planned works, it is believed that they do not affect the degree of hydrogeological risk present in the area.

3.5.9 Gas network

i. Risk of wildfire for gas network

The majority of Ischia’s natural gas assets are found closer to the shore. However, it is anticipated that inland wildfires will burn with the most intensity. Moreover, the majority of aboveground assets are found in metropolitan regions, which typically have reduced wildfire risks. Therefore, because a large portion of the natural gas infrastructure is underground and close to the coast, where wildfire increases are expected to be less severe, the system will likely be less affected overall by future wildfire increases. The meters, or service connections, which are nearly invariably aboveground, are the main assets to be concerned about.

Steel is the most common material for aboveground pipes since it is inherently resistant to high temperatures. In places susceptible to wildfires, for example, extra coatings are placed on the pipelines to increase their resistance to air corrosion. Pipelines are occasionally carried over narrow gorges by use of cable bridges. Due to their extreme sensitivity to stress releases, these bridges are especially vulnerable to the effects of wildfires.

Within grid cells, there are aboveground regulators where an increase in the area burnt is anticipated. Since they link the distribution and transmission systems, regulator stations are essential resources. During wildfires, diaphragm failures at aboveground regulator stations might affect a significant number of consumers. Additionally, the aboveground equipment is supported by heat-resistant concrete pedestals.

Since most meters are above ground, they would be harmed by a wildfire. Only the client served at that meter point would be impacted by the damage. Moreover, in the event that the meter sustains damage, it is probable that the adjacent structure will also sustain harm. Consequently, the customer might not require service until the structure can be restored or rebuilt following the fire. However, when a large number of service connections are lost or destroyed, restoring service can take a while and might cost the utility a lot of money. It also can cause service disruptions that could affect consumers for weeks.

The utility company must physically cut and seal the pipeline that leads to a home in the event that a fire severely damages the residence, causing damage to the meters. Although the pipelines are excavated on the land, once the home is rebuilt, they will need to be replaced. Sometimes the utility may use valves to isolate the gas main that cuts off the gas supply to a whole street, or they will turn the gas main off at a single location. Additionally, wildfires can complicate operations by enticing consumers to turn off their gas in advance. Utility personnel must visit each home in order to examine appliances and reconnect gas.

ii. Risk of flooding for gas network

Since a large portion of the system is subterranean and even the aboveground assets have limited sensitivity to flood occurrences, the effects of flooding are anticipated to be minimal. The water crossings are the assets that are most prone to sustain damage. It is important to remember, nevertheless, that if supply is disrupted, there might be more substantial indirect effects even though direct effects would be minimal.

Water crossing damage is the main method through which floods might affect Ischia Island's natural gas infrastructure. Flooding, for instance, may cause scouring at water crossings, exposing subterranean pipes. Pipelines that are exposed are more vulnerable to floating, debris and other objects carried by floodwaters, and scouring or washouts. Sand and dry soils are more prone to scouring when there are floods.

During floods, aboveground regulator stations may have diaphragm failures that might affect many consumers. Nonetheless, the proportion of aboveground regulator stations is rather low. Theoretically, pumps may break down, leaving the regulator stations vulnerable to flooding. Prolonged exposure can also cause corrosion and raise the need for maintenance. Regulators should not expect significant effects overall, but the danger may rise with the increased frequency of floods.

There are generally a number of other direct effects that might happen. Floods can interfere with electronic equipment, communication, and monitoring, which can significantly impact operations. Furthermore, floods might obstruct workers' access to necessary regions by blocking right-of-ways or temporarily closing roadways. If a compressor station is ever undermined by floods, the downstream effects might pose the biggest threat to Ischia Island from inland flooding. The supply of natural gas might be severely disrupted by problems at this facility.

iii. Risk of landslides for gas network

Overall system impacts are anticipated to be minimal, while there is a chance that low-probability occurrences might have an impact. Even though many assets are in the vulnerable zones, landslide incidents are confined, uncommon for now, and only impact a small number of customers at a time. When landslides do happen, though, the effects are profound. Future increases in risk could necessitate taking action to safeguard important assets in vulnerable locations.

Service connections make up the majority of the exposed point assets. Landslide incidents can result in major interruptions at the local level, even if the overall exposure may be minor. While only a small number of customers may be impacted, their service may be entirely halted until repairs are done. When landslides cause damage to the natural gas pipeline, the affected customers are usually restricted to a small number of locations directly within the landslide region.

3.5.10 Vulnerability assessment

Consistent with the methodology adopted across all the sectors, climate change-related vulnerabilities and risks for Ischia Island are investigated. In order to visualize the vulnerability/risks, a risk matrix approach is used. The risk of a specific change is determined as a combination of hazard, exposure and sensitivity, and the vulnerability/risk is determined, as reported in Table 3-20.

Summarising the vulnerability to the different climate hazards considering the exposure under the expected projected change of the hazard in 2050 it can be concluded that wildfire and landslides create the highest vulnerability/risk for the energy supply infrastructures, as they are highly exposed to these hazards and are also vulnerable (without additional adaptation activities). Flooding poses a medium risk. Energy supply is also affected by increased temperature, sea level rise and other extreme events.

Table 3-20. The vulnerability level of the Energy supply sector to the relevant climate hazards

Climate hazard	Hazard change	Exposure	Sensitivity	Vulnerability
Heat	3	1	2	2
Wildfire	3	2	2	3
Landslides	2	2	1	3
Flooding	2	1	2	2
Coastal Flooding	3	2	2	2
Other extreme events	1	2	1	1

3.5.11 Potential adaptation activities

In many established and developing nations, the energy supply infrastructures (especially the electrical power grid) are the most important critical infrastructures and must be designed, operated, maintained, and managed to provide a dependable, secure, and resilient service supply. Critical infrastructures are extremely interdependent on one another due to their connections to the transportation network, water supply, internet, food security, among other considerations. Energy supply infrastructure facilities must often be modified using engineering principles and judgment to make them climate resilient.

As a general statement applicable to every asset, before any kind of risk mitigation and adaptation activities, management procedures should be created, put into practice, and tested thoroughly by systems operators. These procedures should identify the methods to be taken for risk mitigation, emergency repairs, and recovery, assign roles, identify available resources, and include collaboration and communication.

It is evident that Ischia will be affected by climate change in the future and adaptations to increase the resilience of the energy supply infrastructures to these changes will have to be introduced to stave off some of the particularly severe consequences.

Furthermore, it should be noted, that in Ischia stringent regulations are in place to state what kind of structures are suitable for the unique landscape and scenery of Ischia. Adaptation options should also be compliant with such regulations. A summary of typical climate change events and related possible adaptation activities is provided in Table 3-21. The table summarizes the set of potential applicable activities identified in the assessment and further described in the sub-chapters below.

Column 3 (Cost range) of the table, provides information on the expected ranges of cost for the potential adaptation activities, as far as possible.

Like in some other segments of this assignment, for the energy part it was not possible to carry out a detailed risk assessment, due to the lack of site-specific information concerning the electricity network. The list of potential adaptation activities is based on the knowledge of historical events and assessment on the risks for energy networks in populated areas. This can be also considered as a starting point for the final project identification and prioritization. It shall be noted that, in the majority of cases, the potential adaptation activity identified requires a thorough feasibility study as first mandatory step, in order to determine the most suitable technical solution and the related cost range. Hence, only through detailed design, the actual effort (sizing and cost) can be realistically estimated.

Following the overall table with a summary of all the potential adaptation activities identified the analysis includes a deep dive on some of the most promising activities that are suggested for prompt implementation. Since the adaptation activities are in many cases related to the overall built environment where the energy network is integrated, the proposed solutions are not tailored specifically to the energy network itself but are related to the intended environment. All the remaining adaptation activities are described in the sub-chapters below.

Table 3-21. *Climate change risks and related possible adaptation activities with their potential financial risk*

Climate change risk	**Potential adaptation activity**	**Cost range**
Wildfires	Utilities should take extra caution when mowing grass, pruning trees, and removing other dry material that might catch fire next to electricity lines.	n.a. Operational actions to be implemented in the current routine
	Undergrounding electricity cables in highly dangerous locations.	60-150 k€/km
	Managing the flow of electricity via overloaded and potentially overheated power lines, thanks to monitoring and management systems (through sensor) to favour prompt interventions.	Design needed from feasibility study onwards
	Rooftop and community solar projects can lessen the demand for additional high-voltage transmission lines needed to transport power.	1,000 €/kWp of PV installed
	Making structural adjustments to the electrical grid, e.g. creating small local hubs	1-10 M€

	against large, centralized energy power plants and related lines.	
	Larger or upgraded cooling systems (including air cooling) may be explored.	Design needed from feasibility study onwards
	Use of refractory electrical equipment.	Design needed from feasibility study onwards
	Ensure that emergency services receive adequate training on responding to wildfires.	n.a. Operational action
Floods	Electricity providers may cut off electricity to buildings in flood zones with an early warning system, limiting damage.	n.a. Operational action to be agreed with the operators
	Pre-emptively cutting electricity to vulnerable substations located in the flood zone.	n.a. Operational action to be agreed with the operators
	Elevating, building levees, and moving important infrastructure out of flood locations.	Detailed design needed
	Burying electrical infrastructure, including power cables and distribution substations.	60-150 k€/km
	Locating the substation above flood levels, levee protection, and elevating sensitive equipment.	Detailed design needed
	Improve flood and drought resilience by creating hydropower water reservoirs and adapting to storm surges and sea level rise through barriers with tidal turbines.	Design needed from feasibility study onwards
	Raising embankment height to avoid over-flooding.	Order of magnitude of M€, depending on site conditions. Design needed from feasibility study onwards
	Increasing the size and number of drainage structures	Design needed from feasibility study onwards
	Improve robustness of installations to withstand storms and flooding.	Design needed from feasibility study onwards
	Develop an emergency response capability to help mitigate the effects of flooding at the sites.	n.a.
Increased temperature	Increase the height of towers/poles	5-15 k€/each
	Use specific conductors with higher operating temperature limits.	Design needed from feasibility study onwards
	Increase the minimum design temperature of new overhead line routes.	n.a.
	Improve cooling systems	Design needed from feasibility study onwards
	Use high-quality transformers	10-15 k€/each

Other climate hazards	Underground cabling protects transmission and distribution networks' infrastructure from heavy rainfall	60-150 k€/km
	Monitoring and improving storm response efforts and specifying lightning protection for pole mounted transformers.	n.a.
	Design of new overhead lines to a higher temperature rating through specifying taller poles to allow for more conductor sag.	n.a.
Sea level rise	Adjust design criteria for transmission lines, use stainless steel material to reduce corrosion from water damage.	n.a.
	Increase transmission tower height.	10-15 k€/each
	Building protective walls for the electricity distribution infrastructures and the local electricity connecting point.	1M - 10M€ depending on locations
	Building erosion protection to the electricity cables.	100-300 k€
Landslides	Increased use of sonar to monitor soil movements.	n.a.
	Availability of spare parts/components in sufficient amounts.	n.a.
	Insurance covering weather-related damage (including extreme events).	100-300k€ subscription
	New protective structures against landslides	10-20 M€ per location
	Improve robustness of transmission cables/poles and other transmission and distribution infrastructure.	10-50 k€/km
	Regular inspection of vulnerable infrastructure such as wooden utility poles.	n.a. Operational actions to be implemented in the current routine

i. Adaptation activities for wildfire risks

Utilities should take extra caution when mowing grass, pruning trees, and removing other dry material that might catch fire next to electricity lines. They have the option of burying their wires in highly dangerous locations. Technology also aids in danger identification. Sparks on an electric wire can be found using sensors. Testing of newer devices aims to find electrical current changes that might signal overloaded wires before sparks happen. On hot days, it may be possible to prevent issues with power lines by properly managing the flow of electricity via overloaded and potentially overheated power lines.

Making structural adjustments to the electrical grid is another option, where power is produced closer to the customer, from the community to the neighbourhood to the individual's house, rather than depending on massive, centralized power plants with high power, long-distance transmission lines.

For instance, rooftop and community solar projects can lessen the demand for additional high-voltage transmission lines needed to transport power over great distances and across dangerous wilderness areas.

In areas where water availability is predicted to decrease, larger or upgraded cooling systems (including air cooling) may be explored for thermal power; in areas where greater flooding is predicted, designing structures to be waterproof may be a possibility.

ii. Flood adaptation activities

Electricity providers may cut off electricity to buildings in flood zones with an early warning system, limiting damage. Early notice allowed transmission system operators and distribution system operators in the impacted area to activate their emergency response and business continuity plans, which was a key factor in the resilience of the electrical grid.

Pre-emptively cutting electricity to vulnerable substations located in the flood zone is one of the most efficient measures power providers take when a flood is about to occur. This avoids the catastrophic harm caused when water contacts live machinery.

The best mitigation techniques were elevating, building levees, and moving important infrastructure out of the flood locations. Another possible adaptation activity is to bury electrical infrastructure (underground cabling), including power cables and (eventually) distribution substations. Examples of successful strategies include locating the substation above flood levels, levee protection, and elevating sensitive equipment.

iii. Adaptation activities for increase in temperature and other risks

For the risks from increase in air temperature, increasing the height of towers/poles is recommended as through this, the power lines can sag without exceeding the minimum distance required by the regulations to avoid the risk of electrocution and interaction with vegetation. Furthermore, it is recommended to use specific conductors such as conductors with higher operating temperature limits and 'low-sag' conductors based on the lower coefficient of thermal expansion of the conductor's steel core. Also, increasing the minimum design temperature of new overhead line routes is recommended as an adaptation activity for increase in air temperature.

The transformer is considered a vital component in the electricity network, therefore, there are some adaptation activities that must be considered such as improvement of cooling systems and utilization of high-quality transformers. The best way to avoid and/or adapt to extreme climatic conditions such as prolonged heat waves is to use adequate cooling systems. State-of-the-art cooling systems and regular maintenance can effectively prevent premature ageing and structural failure caused by high internal temperatures. High-quality transformers can maintain high efficiencies even when overloaded and prevent energy losses that cause internal temperature rises, thus avoiding structural and insulation problems and the risk of thermal runaway.

Underground cabling protects transmission and distribution networks' infrastructure from heavy rainfall and extreme weather events. Underground cabling also protects power lines from heat waves and thermal expansion.

3.5.12 Recommended adaptation activities

Table 3-22. Underground cabling

Locations: pilot cases in the areas of historical wildfires & heavy rainfall	Photo
	

Adaptation	Protection of the infrastructure from heavy rainfall, storms, windstorms and heat waves by underground cabling.	Criticality	Only small portions of the entire network can be refurbished and shall be carefully selected through detailed surveys when detaile information is available.
Historical Events	Wildfires, heavy rainfall and flood	Cost Estimate	60-150 k€/km

Table 3-23. *Protective measures against fluvial and sea floods.*

Locations: Lacco Ameno (mainland cable connection point), Ischia (Enel electricity substation)			
			
Adaptation	Protective structures against flooding (embankments and drainage systems) in favour of the entire set of assets in the target area	Criticality	High Note: In order to confirm the risk level for these assets, a more detailed assessment utilizing a more advanced digital elevation model and flood modelling is required.
Historical Events	moderate exposure according to GIS maps and surveys	Cost Estimate	Not possible to estimate with current information available.

3.6 Tourism

3.6.1 Tourism in Ischia

According to the Ischia tourism association, the annual revenue of the Ischia tourism is 320 M€, employing 12 000 people directly and indirectly 80 – 85 % of all the about 65 000+ people living on the island. The tourism sector is also responsible for about 80 – 85 % of the total GDP of the Island of Ischia.

There are 325 hotels in Ischia and about 1800 other units that can accommodate tourists. The island has been receiving during the last 15 years, on average, about 3,5 million tourists annually. In 2022, 2,7 million tourists visited the island. The peak of the tourist season is in August, when there are 350 000 tourists visiting the Island.

3.6.2 Main climate vulnerabilities for tourism sector

It is obvious that if landslide events and rock falls take place more frequently than before, it has a detrimental effect on the tourism business of the Ischia Island. This is caused not only through damage to infrastructure, injuries or even deaths, but also through the reputation of the island and its safety. Another critical aspect for the tourism sector is the transportation which is heavily related to operativity the ports of Casamicciola Terme and the Ischia Porto as practically all the tourists arriving to the Island use these two ports. The latter one is already at risk of submerging during high water events (Acqua Alta) and will be even more so in the future (see chapter about ports and coastal structures).

Increasing temperatures can cause health problems to tourist groups that are more vulnerable, like elderly tourists and tourists with health conditions affected by the high temperatures.

The public transportation of the Island is suffering, among other things, from the poor erosion protection of the main and secondary roads. During the field missions, several sections of the island's main ring road had been narrowed down due to small scale landslides, coastal erosion and risk of rock falls.

Only about 60% of the wastewater in the Island of Ischia is being treated in a wastewater treatment plant. More severe flood events can cause further damage to the water treatment results. This means that the sea water nearby the sewer outlets can be polluted and aesthetically displeasing, especially during the high tourist season. The separated sewers proposed to replace the mixed sewers in the water section of this report can solve this issue at least partially. This could also support flood management, as floods could otherwise cause damages to tourist-related infrastructure and cause injuries or deaths of tourists.

There are also several sites related to tourist resorts or beaches and other recreational areas and facilities that are directly impacted by landslides, rock falls, floods or coastal erosion where the vulnerability is further increased by the more frequent heavy rain events and the increasing sea level.

Increasing wildfire frequency can also affect tourist safety and the smoke from the fires can cause health issues or at least odour and aesthetic issues.

3.6.3 Observed climate impacts and the effect of past events

According to the Ischia tourism association, the landslide that took place in Casamicciola Terme area decreased the number of tourists in the land slide vicinity by 30 % annually and by 15% annually for the whole island. Therefore, it can be calculated that the loss of revenue of such event taking place is roughly 48 M€ for the tourism sector.

Almost all hotels in Ischia have already invested in air conditioning due to the increase in temperature and the demand from clients. While there are complaints about hot weather from the tourists during the hot season, overall the Ischia tourism association considers climate change to prolong the tourist season in early spring and late autumn.

The event on November 22nd took place during low season and therefore the loss of revenue was limited. If such event were to take place during the high season, the loss of revenue could be expected to be significantly higher. It should be noted though that precipitation mostly takes place in Ischia outside the busiest tourist season in late autumn and winter.

There are also hot spring resorts and other tourist areas affected by erosion problems on the Island. Some parts of resorts have had to be closed. Some touristic paths and roads have had to be closed fully or partly or are under the risk of severe erosion.

3.6.4 Recommended adaptation activities

iv. Physical adaptation activities

- Poseidon hot spring resort site (40.71574543306944, 13.861280352219108) has been already affected by debris flow during the last years, affecting the business of one of the most valued hot spring resorts of Ischia. Forio municipality have had to also close a tourist path from the thermal resort to the lighthouse (Figure 3-48). The municipality of Forio has requested an intervention to save the street on summit of mountain that connect the lighthouse and to reinforce the slope to avoid other debris flow to open the touristic path.

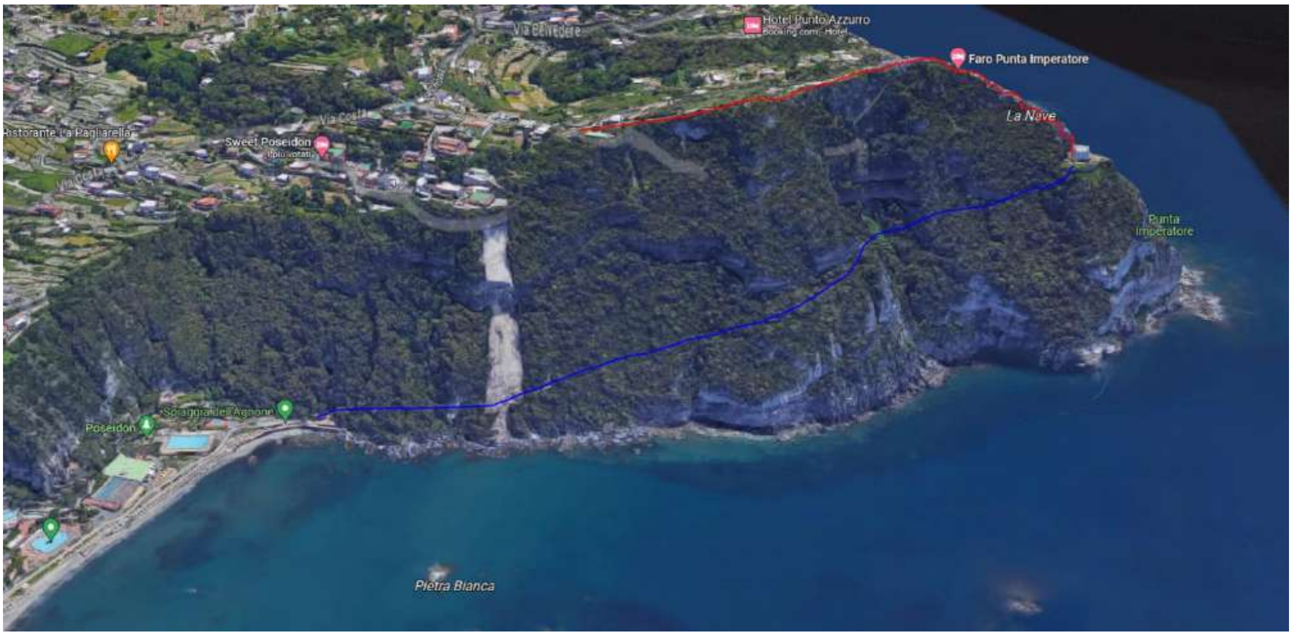


Figure 3-48. Tourist path from Poseidon resort (blue) and road to lighthouse and restaurant (red) (Google Earth).

The roughly estimated cost for stabilizing the top of the hill to protect the road to the lighthouse by shotcrete, anchors, steel mat, gabions and reinforced earth is 1,08 M€, depending on the required works. However, more precise studies are required to confirm the required adaptation activities and their cost estimate.

The roughly estimated cost for installing rockfall barrier for the tourist path is 0,11 M€ The roughly estimated cost for installing rockfall barrier and rock netting above the Poseidon resort is 0,48 M€ totalling 1,68 M€.

- Negombo hot spring resort (40.75810413694621, 13.878267408771672) is suffering from rock falls in their premises from the cliff above the resort (Figure 3-49). As a result, they have had to close a part of the pools and recreational facilities of their resort. The beneficiary has already mapped the boulders that are in risk of falling down and marked them.

Figure 3-49. Negombo resort with rock fall location and closed facilities (Google Earth).

The recommended adaptation investment in this case is to remove or anchor the marked boulders. The roughly estimated cost for this is 0,2 M€. For additional safety, it is recommended to also install rock catching nets in two heights that are estimated to cost 0,8 M€ making the total estimate for adaptation activities 1.0 M€

- Spiaggia Di Varulo (40.75690462510912, 13.884582932477171) is a popular beach west from Casamicciola Terme without road access where tourists arrive by boat. The beach is surrounded by steep cliffs that suffer from rock falls. In order to protect the site from further rockfalls, it is recommended to install rock netting for the area of 1000 sqm which is estimated to cost 0,12 M€.

Figure 3-50. Spiaggia di varulo beach and cliffs (Google Earth).

- Coastal cliffs and bays North from Cimetero di Lacco Ameno are under the threat of coastal erosion. The bays here are also locations where the tourists come to anchor their boats and to spend the day swimming in the sea. To protect swimming tourists from rock fall, a rock netting seems to be the suitable adaptation activity. From a very rough estimate, 2000 m² rock netting would be required with an estimated cost of 0.28 M€ (including 15 % engineering service costs). To protect the upper scarp from erosion and the cemetery from eroding downwards, a more detailed assessment would be required.

Figure 3-51. Touristic bays north of the Cemetery of Di Lacco Ameno (Google Earth).

- Cliffs nearby the spiaggia del Maronti are surrounded by touristic facilities (Coordinates: 40.70, 13.90). The area West of the site has been protected by netting, but the Eastern and Northern parts of the cliff are not protected and causing a rock fall risk to the nearby hotels and other buildings. To protect inhabitants, staff and tourists from rock fall, a rock netting seems to be the suitable adaptation activity. From a very rough estimate, 4000 m² rock netting would be required with an estimated cost of 0.55 M€ (including 15 % engineering service costs).

Figure 3-52. Spiaggia del Maronti cliffs (Google Earth).

In addition to the project schemes identified during the field mission and discussions with the local stakeholders and the Struttura Commissariale, a more comprehensive list of tourism related physical adaptation scheme candidates was provided by the local municipalities. This list contains various project to adapt against landslides and floodings in Ischia. It was not possible for the assignment team to assess all these locations and their criticality, and it is therefore recommended to study further the provided schemes.

v. Soft adaptation activities

- Hotels should be prepared for evacuating the tourists to predefined safe sites during a landslide or flood event or other hazards and the coordination with the early warning system organized. The information about the safe sites should be available in each hotel in multiple languages (e.g. English, French, Russian, and so on according to the tourist amounts) in addition to Italian. The hotel staff should also organize evacuation rehearsals. The preparedness of the hotels should be monitored by local authorities.

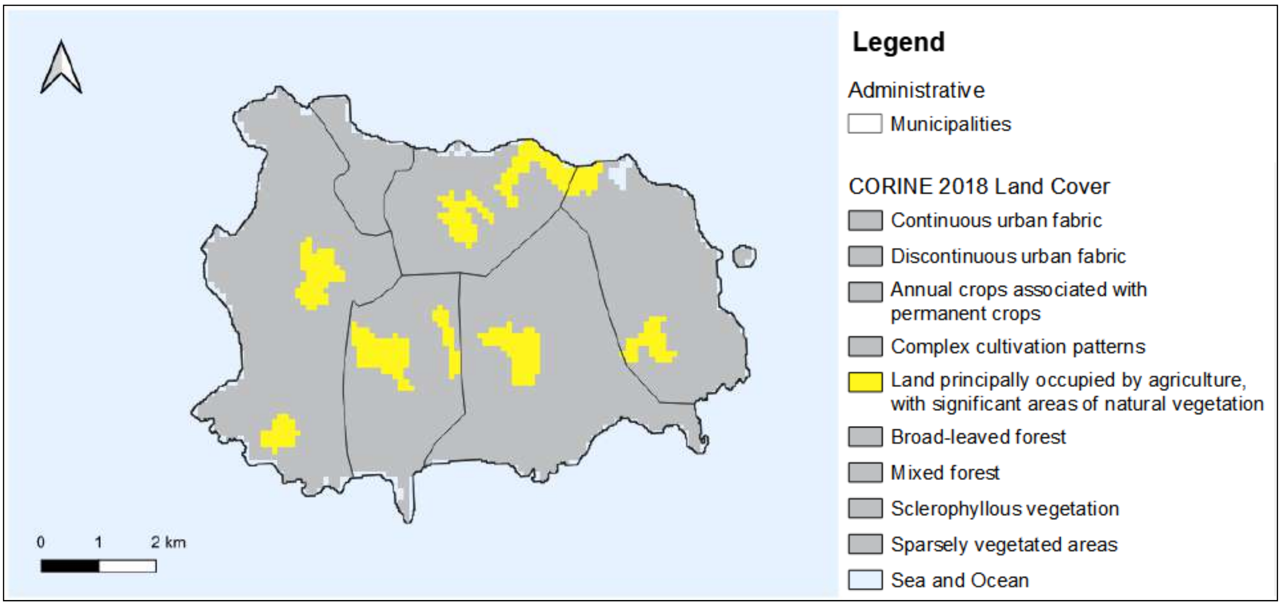
- Major ports in Ischia should be prepared to handle large amounts of people in an organized and safe manner in the case of an emergency. It should be ensured that the port area has enough room reserved for people to wait for evacuation safely and the possible means to close nearby roads or other areas to organize the safe passage of people waiting to board the ships. There should also be a plan for ports to use for evacuation, based on the location of the hazard (landslide, flood etc.).

  Plans should be developed to provide people with water and shelter if needed and drills organized to increase the capacity of the local authorities and hotels, to reduce the uncertainties and to improve the operation based on observations.

3.7 Agriculture

3.7.1 Agriculture in Ischia

Almost 9% of the volcanic soils of the island of Ischia are occupied by agriculture as presented in the map below (Figure 3-53). Agriculture’s contribution to the island GDP is estimated by local stakeholders consulted at 10%, although it’s contribution to employment is considered rather low. Viniculture is the most important form of agricultural production in Ischia.



- Total area of ischia is around **47,919,997 m2**
- Total area of 'Land principally occupied by agriculture, with significant areas of natural vegetation' on Ischia is **4,220,002 m2**
- % of Ischia covered by 'Land principally occupied by agriculture, with significant areas of natural vegetation' is **8.8%**

Figure 3-53. Land principally occupied by agriculture, with significant areas of natural vegetation. Source: Corine 2018 Landcover

The following section analyse the climate vulnerabilities and key potential impacts on viniculture on the island of Ischia, as well as recommendations to increase the sector's resilience to climate change.

3.7.2 Focus on viniculture

Viniculture has been an important socio-economic and cultural activity in the island of Ischia dating back to 700BC, and the island was indeed known as "Enaria", or the land of wine[40]. Ischia lies between latitude 4 degree and 51 degrees in the Northern Hemisphere, where grapevines have been historically cultivated[41]. The island has been at the forefront of producing one of the finest quality wines, attributed mainly to the volcanic soil, Mediterranean climate, and proximity to sea.

There are four major grape varieties used for making wines on the island- Biancolella and the Forastera varieties for white wines and the Guarnaccia and the Piedirosso for red wines. White wines account for nearly 80 per cent of the wine production on the island[42]. The main variaety of the island is Biancolella, which is considered one of the best white grapes in Italy. It is a low productive variety that is well adapted to the heat and dry conditions very common in the current Mediterranean climate.

Majority of the vineyards can be found around the hilly areas along the slopes of Mount Epomeo, the highest peak in Ischia, which expose them to extreme weather events (like heavy rain and precipitation-driven landslides) that will be more frequent and intense in a climate change context. Yet, vineyards are mostly cultivated in terraces, which confers the vineyard a good capacity to cope with these climate events.

The figure below shows some examples of locations in the island where vineyards are planted.

[40] https://www.ischiareview.com/wines-of-ischia.html
[41] OIV. 2019 Statistical Report on World Viticulture; International Organisation of Vine and Wine: Paris, France, 2019.
[42] Saunders, P. (2004). Wine Label Language. Firefly Books. pp. 169–170. ISBN 1-55297-720-X.

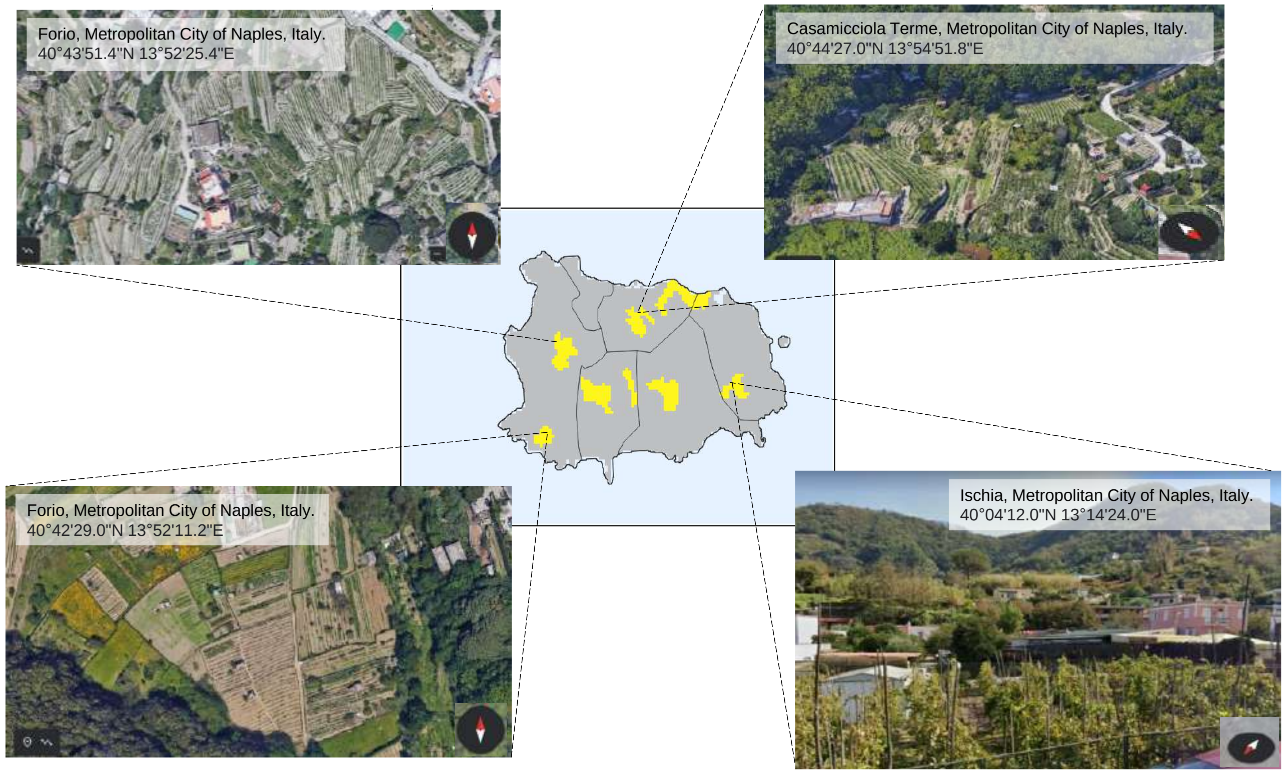


Figure 3-54. Vineyard's distribution in Ischia.

3.7.3 Main climate vulnerabilities of viniculture

Among the agriculture crops, grapes are one of the most sensitive to changes in temperature and rainfall. High quality grapes, used for making fine wines are mostly grown in places supporting a delicate balance of heat and precipitation. Cultivation of grapes is highly sensitive to climate change and has impacts on vine phenology, grape composition, wine microbiology, and chemistry. Viniculture is also sensitive to heatwaves, wildfires, heavy precipitation, unexpected spring frosts, and drought. Mediterranean climatic regions (warm and dry summers; cool and wet winters) are suitable for viniculture, however changing climate is having a huge impact on the wine production in the region. Ripening of grapes leads to increase in sugar due to photosynthesis. Levels of sugar at harvest is a crucial element for producing a good quality wine. Quality of wines can be affected by too high or too less rains and high or too low temperatures. Soil composition also plays an integral role for grapevine development. Grape varieties cultivated for white wines are particularly sensitive to slight temperature rise. Overall, grapevine and hence wine quality is determined by an interplay between climate, topography, soil, water, biodiversity, biotic factors, and agro-management practices[43], all of which are highly sensitive to changing climate.

3.7.4 Observed climate impacts on viniculture in Ischia

Recent extreme events across the globe like heatwaves, droughts, and floods have created havoc for wine makers. Most of the wine growing regions in the world, including the Mediterranean Basin are climate hotspots experiencing faster than average rise in temperatures and erratic rainfalls, which is having an adverse impact on the grape cultivation in the major regions.

Local stakeholders consulted stated that no specific climate impacts had been observed in Ischia viniculture in the past years, except for an increase in air humidity (which is generally linked with higher air temperatures) that contributed to the proliferation of flavescence dorée, a vector-borne disease that can cause significant damages to vineyards. Currently there is no cure for flavescence dorée**,** and the only way to manage its spread is by uprooting infected plants, using fungicides and insecticides or implementing physical barriers such as nets or hedges or to reduce the vectors. According to local stakeholders consulted,

[43] Winkler, A.J. General Viticulture; University of California Press: Berkeley, CA, USA, 1974

last year's increase in air humidity and subsequent flavescence dorée sprout, led to 40% production losses in viticulture in Ischia.

3.7.5 Potential climate impacts on viniculture in Ischia

There is a wide agreement that with climate change, many vinicultural zones, especially in the Mediterranean climatic regions, may become unsuitable for viniculture:

- A study by Lallanilla et al. (2011) concluded that large portions of Europe on the Mediterranean coastline, especially Italy, Greece, and France, may become completely hostile to grape production by 2050.
- According to Hannah et al[44]. (2013) the area suitable for viniculture is projected to decrease by 25% to 73% in major wine producing regions by 2050 under the RCP8.5 scenario and by 19% to 62% in the RCP4.5 scenario. This may see shifting of viniculture to higher altitudes.
- A study published by the Proceedings of the National Academy of Science[45] (2020) stated that if temperatures rise by 2°C, wine growing regions could shrink by 56% and by 85% under a 4°C scenario (Morales-Castilla et al., 2020).
- Results of another study by Cardell et al. (2020) done using the IPCC RCP 2.6, 4.5 and 8.5 scenarios supported this assumption and showed that viniculture or wine production will be negatively impacted in Southern Europe[46].
- Santos et al. (2020) also estimates that the current winemaking regions in Southern Europe may see a decline in viniculture suitability, mainly due to **drier seasons and higher temperatures**. Amongst these, the regions of Sicily, Puglia, and Campania (where Ischia is located), will very likely suffer from severe water deficits that could also affect the quality and quantity of wine production[47].

Timely, suitable, and cost-effective adaptation strategies adapted to the local conditions are required for management of viniculture and to maintain the quality of wines in the major wine producing areas. More efficient water management practices would also be required in some of these areas, as well.

Potential climate change impacts on viniculture are:

1. **Heatwaves:** Temperature is considered one of the most crucial elements driving the growth and development of grapevines. High temperatures could affect the physiology of the plant as well as yields depending on the variety's tolerance to heat. Temperature increases can have an important impact on the grape production and wine quality.

   High temperatures generally advance the onset of fruit ripening and impacts other phenological stages. This can lead to reduction in vine photosynthesis and slow sugar accumulation during ripening. Severe heat stress may cause significant decrease in photosynthetic productivity and impact other biochemical processes. For instance, heatwaves during the veraison–maturity period can impact sugar accumulation as well as of the production of other substances (including of volatile compounds) that contribute to the colour, flavour, aroma, texture, astringency, and stabilization of wine and play an essential role to its quality[48].

[44] Hannah. L.; et al. 2013. Proceedings of the National Academy of Sciences Vol. 110 | No. 17 April 23, 2013. Available here: https://www.pnas.org/doi/suppl/10.1073/pnas.1210127110
[45] Morales-Castilla, I. et al. (2020). Diversity buffers winegrowing regions from climate change losses. Proceedings of the National Academy of Science. January 27, 2020.
[46] Cardell, M.F., Amengual, A. & Romero, R. Future effects of climate change on the suitability of wine grape production across Europe. Reg Environ Change 19, 2299–2310 (2019). https://doi.org/10.1007/s10113-019-01502-x
[47] Santos, J.A. ; et al. Appl. Sci. 2020, 10(9), 3092; Available at : https://doi.org/10.3390/app10093092
[48] Greer, D.H.; Weedon, M.M. The impact of high temperatures on Vitis vinifera cv. Semi lion grapevine performance and berry ripening. Front. Plant Sci. 2013, 4

High temperatures can also lead to desiccation, increasing bitterness and browning in wines from damaged grapes. Another major concern due to high temperatures is the reduced acidity, due to slow sugar accumulation[49]. Hotter summers are also shortening the growing seasons[50].

Local stakeholders consulted stated that the grape varieties used in Ischia (i.e., Biacolella) show good performance under current heat and dry conditions. With climate change, the number of days with daily maximum temperature greater than 29.2°C, are projected to increase up to +14 under RCP 8.5, which could lead to up to 49.6 days with high values for maximum temperature.

2. **Extreme rainfall:** Grapes need optimum amount of rainfall and extreme precipitation events, especially before harvest, can lead to diseases and disturbance in sugar/acidity balance. For the RCP8.5 scenario, an increase in extreme rainfall was observed, especially during the autumn and winter season. This trend was also found in the RCP4.5 scenario. Excessive precipitation at the maturation stage (in Autumn) is unfavourable, due to sugar dilution or bunch rot[51]. Extreme precipitation events could also result in soil erosion, especially in high slope areas. Yet, this risk is reduced by the fact that in these areas, terraces are used to cultivate vineyards in Ischia.

3. **Droughts/dry spell:** A study by Cardell et al[52]. (2019) predicts increase in water requirements, due to decrease in precipitation and high evapotranspiration due to warming climate and shows reduction in grape production due to thermal stress and dryness during growth season. There are currently no irrigation systems in place in Ischia.

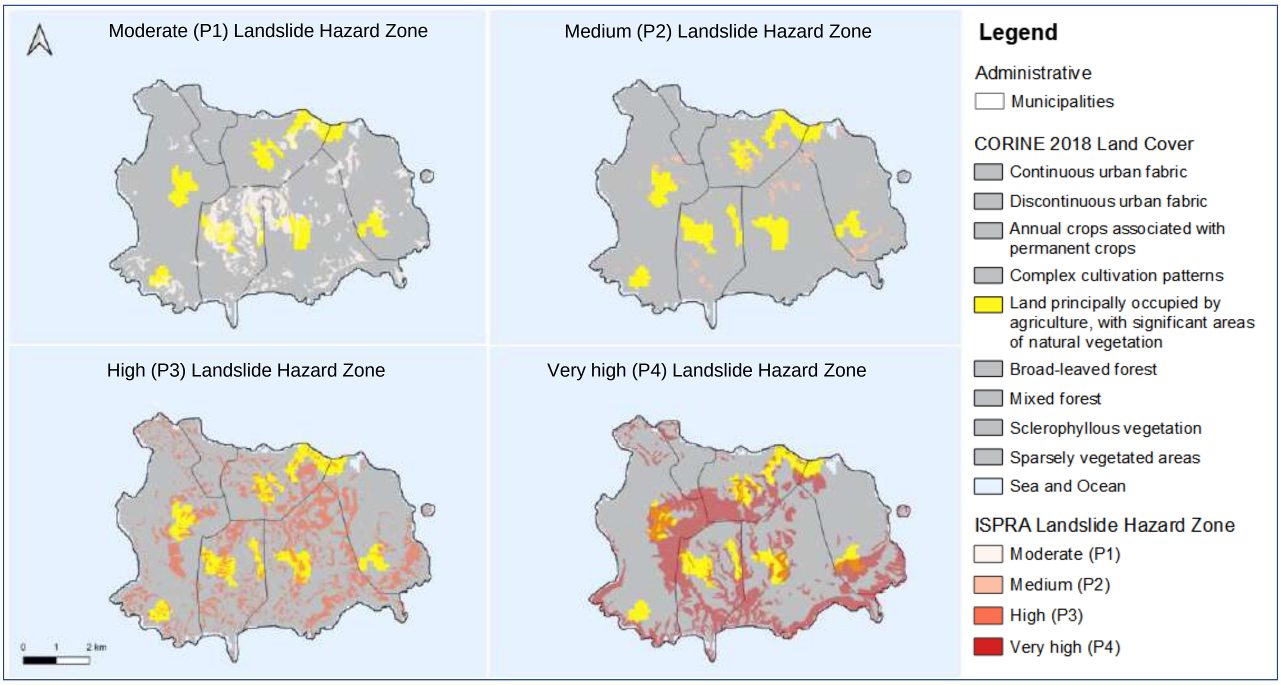
   Climate models show a decrease in the values of seasonal rainfall, especially during the summer period for RCP4.5 and RCP8.5 scenarios. In RCP8.5 scenario, there are also short-term reductions in the spring and winter seasons.

   Climate projections are indeed showing hotter and drier conditions in Ischia in the years to come. Yet, when temperatures are higher, the atmosphere has the ability to hold a greater amount of water vapor. In other words, warm air can contain more moisture than cold air. This is why, during dry and warm periods, it is possible to have **higher levels of humidity in the atmosphere**, that could favor the development of some diseases, like mold and mildew. Also, although humidity does not directly favour the spread of flavescence dorée, it’s one of the factors that can contribute to it.

4. **Landslides:** Landslides can cause damage to the vineyards and agriculture buildings and assets, damage to roads as well as market access disruptions that can result in loss of yields, crop losses, retrofitting costs, decrease in revenues and could also jeopardise the sustainability of the agriculture production. A study done as part of the project reveals that the island of Ischia is prone to landslides and vulnerable areas are likely to be affected more frequently in the future. The study shows that probability of landslides during extreme rainfall events is higher. Vulnerable zones show up on the slopes of Mount Epomeo, where majority of the grapevines are located around the hilly slopes. Some of the coastal areas (South-East) are also under landslide risk. There is a 90 per cent probability of a serious landslide within one year under historic climate (2002-2022) and 75-110 per cent with future climate scenario (2040-2060). The study further states landslide risk is likely to increase by climate change and landslides like events (which happened in 2022) are likely to occur more often.

   The map below shows agriculture land areas in landslide risk zones, that are mostly occupied by vineyards. More than 70% of the land principally occupied by agriculture are covered in landslide-prone areas **of which almost 53% are high or very-high landslide risk areas**.

[49] Managing grapevines during a heat spike, Oregon State University
[50] Italy’s wine industry is being tested by the effects of climate change in its vineyards (The Washington Post)
[51] Molitor, D.; Baus, O.; Hoffmann, L.; Beyer, M. Meteorological conditions determine the thermal-temporal position of the annual Botrytis bunch rot epidemic on Vitis vinifera L. cv. Riesling grapes. OENO One 2016, 50, 231–244
[52] Cardell, M.F., Amengual, A. & Romero, R. Future effects of climate change on the suitability of wine grape production across Europe. Reg Environ Change 19, 2299–2310 (2019). https://doi.org/10.1007/s10113-019-01502-x



- Total LS Zones (1-4) covering 'Land principally occupied by agriculture...' on Ischia = 3,096,149 m2 / **73.37%**

- LS Zone 1 covering 'Land principally occupied by agriculture...' on Ischia = 756,025 m2 / **17.92%**
- LS Zone 2 covering 'Land principally occupied by agriculture...' on Ischia = 105,610 m2 / **2.50%**
- LS Zone 3 covering 'Land principally occupied by agriculture...' on Ischia = 909,842 m2 / **21.56%**
- LS Zone 4 covering 'Land principally occupied by agriculture...' on Ischia = 1,324,672 m2 / **31.39%**

Figure 3-55. Agriculture land areas in landslide risk zones. Source: Corine 2018 Landcover and ISPRA Landslide hazard zone

5. **Hail:** Damages to grapes, yields reduction in the following year and exposure to and development of various wood diseases in the plant. Impacts to the quality of the final product: The closer we get to the time of ripening and harvest, the more hailstorms can affect the quality of the final product. It can also lead to very low level of sugar accumulation in the grapes, poor lignification of the shoots, and the destruction and fall of the leaves in an unnatural and premature manner, preventing the plant from reabsorbing the chlorophyll produced during the year. Vines are more exposed to the winter cold, as they do not have time to adequately accumulate the reserve substances needed for the following year.

6. **Frost**: Negative temperatures around/after budburst (as well as hail events) could negatively impact the development of buds, leaves, and inflorescences, and may also affect the plant physiology and yield. Climate change phenomena have allowed temperatures to rise during predominantly cold months, causing plants to flower earlier than a few decades ago, making them more vulnerable to frost.

3.7.6 Assessing climate vulnerability of viniculture in Ischia

The risk assessment is based on the previously explained definition that describes climate vulnerability as a combination of the exposure to a climate hazard and its sensitivity to the potential impacts of climate change.

Hazards

As mentioned above, main hazards affecting viniculture are heatwaves, increased humidity, extreme rainfall, drought, landslides, hail and frost. The table below contains an assessment on how these hazards will evolve in Ischia in the long term, according to the results of the climate data and projections.

Table 3-24. Hazard change for agriculture.

Climate hazard	Hazard change (from 1 small to 3 large change)	
Heat	High	3
Drought	Medium	2
Storm precipitation	Medium	2
Hail	No data	0
Landslides	Medium	2
Frost	Low	1
Coastal flooding	High	3

Exposure

The table below present the degree of exposure of the viniculture production in Ischia to the different climate hazards.

Table 3-25. Exposure for agriculture

Climate hazard	Exposure (from 1 small to 3 large change)	
Heat	High	3
Drought	High	3
Storm precipitation	Medium	2
Landslides	Medium	2
Frost	Low	1
Coastal flooding	No exposure	0

Sensitivity

The different component of the viniculture sectors have been identified, as well as their sensitivity to changes into the key climate variables they are exposed to. The results are compiled in the sensitivity matrix below.

Table 3-26.Climate sensitivity for agriculture

Climate hazard	Vineyard	Quantity of produce	Quality of produce	Productive infrastructure	Value chain	Sector average
Heat	2	3	3	1	1	2
Drought	2	3	3	1	1	2
Storm precipitation	1	2	2	2	2	2
Landslides	2	2	2	3	3	2
Frost	1	2	2	1	1	1

Vulnerability

Finally, the level of vulnerability of the different components and of the viniculture sector has been estimated through combining the exposure and sensitivity matrices. The results are presented below. These could guide the identification and selection of adaptation options that could be put in place first.

Table 3-27. Vulnerability for agriculture

Climate hazard	Vineyard	Quantity of produce	Quality of produce	Productive infrastructure	Value chain	Sector average
Heat	3	3	3	2	2	3
Drought	3	3	3	2	2	3
Storm precipitation	1	2	2	2	2	2
Landslides	2	2	2	3	3	2
Frost	1	1	1	1	1	1

3.7.7 Possible adaptation activities for viniculture in Ischia

Based on the results of the vulnerability assessment above, the following adaptation options could be recommended:

1. **Protection from heat:** Temperature plays a critical role in grapevine production and high temperatures can cause extensive damage as discussed in the above sections. Various practices have been documented for protection of grapevines from heatwaves and sunburns. Some of the agro-management practices include use of heat and drought tolerant grape varieties, adopting effective viticultural techniques suitable to the local conditions, use of shade nets, evaporative cooling, use of sunscreen materials, particle films, use of Kaolin clay and designing vineyards in a way to reduce exposure to sun and extreme heat. Given the touristic attractiveness of the island, any structural option that could have an impact in the island's landscape is to be carefully considered or even avoided.

2. **Pest and disease management:** Climate change can increase the risk of pests and diseases to grapevines, thereby demanding increased measures for controlling the risks of diseases. This process requires use of continuous monitoring, as controlling pests and diseases is a dynamic process.

3. **Irrigation:** Providing adequate irrigation to improve crop yield and quality of grapes, during heat stress or dry spell to meet the defined grapevine water requirements. Drip irrigation is one of the most effective methods implemented to conserve water and provide adequate irrigation to the grapevines. These can be maximised using automated and smart irrigation systems.

4. **Soil Management:** soil management techniques for higher yield and conserving moisture have been well documented and are essential for grapevine production and for maintaining water and nutrient balance. Ischia farmers already use some of them, like mulching.

5. **Long-term adaptation strategies:** Farmers need to continuously adapt to changing conditions by implementing the best suitable long-term strategies. Awareness and cross-learning across regions can help in adopting the best viniculture management practice. Several long-term strategies have been documented, however, the adaptation in Ischia will depend on several factors including use of technology, socio-cultural practices, and awareness. Some of the long-term strategies include:

    - **Changes in training systems:** This is an effective adaptation strategy which includes trellising and pruning activities to prevent grapes from ripening under high-temperature conditions. Training systems that delay ripening will be beneficial for future climate conditions.

    - **Changes in planting density:** closely linked to the training system, this can be an effective strategy for changes in planting density and/or trunk height. Higher planting densities can be effective for temperate humid climates with deeper root penetration and larger soil volume.

- **Row orientation:** this could be an effective strategy to reduce fruit exposure to sun at different times of the day. Some documented practices include using an east-west orientation to reduce exposure to sun.
- **Selection of suitable grape varieties:** selection of grape varieties is largely temperature dependent and hence long-term strategy may include changes in grape varieties. Selection of appropriate varieties will depend on climate projections using suitable time horizons. A study found out that northern European wine making regions may benefit from wide varieties from Southern Europe, while southern Europe will have to shift to varieties well adapted to very warm and dry climates[53]. Also, **cultivar diversity** can reduce projected losses of current winegrowing areas under a 2 °C warming scenario, from 56 to 24% and from 85% to 58% under a 4 °C scenario (Morales-Castilla, 2020). Yet, any change in the grape varieties will inevitably lead to changes in the wine itself and should be carefully considered. Local stakeholders don't see an urgent need to change the wine variety, as the ones used in Ischia are well adapted to the current climatic conditions in the island, but they could be open to consider this option in the future, if needed be.
- **Rootstock selection:** rootstock selection is important and influences a vineyard's resistance to extreme heat and droughts, as well as higher air humidity conditions.
- **Seasonal Forecast and early-warning systems:** They help anticipate potential climate events (i.e., warmer summer) and give valuable information to the farmers so they can take informed decisions on the agricultural practices they will apply and when to apply them. The VISCA (Vineyards´ Integrated Smart Climate Application) project is developing seasonal forecasts to help vineyards' adaptation to climate change.

Support for adaptation pilot patches of vineyards can be used to test various abovementioned adaptation solutions for a few years. Consequently, possible reduction in the production value of wine would be stopped or attenuated earlier. The pilots should be a coordinated effort and the results and lessons should be available for the entire sector on the Ischia Island.

3.8 Forestry and Nature based solutions

3.8.1 Forests in Ischia

The Northern Slope of Mount Epomeo and its vegetation

Due to its complex topography, shallow soil depth, and unmanaged forest types, Mt. Epomeo represents the most challenging forest land on the island of Ischia. The northern slope of Mount Epomeo displays a diverse mosaic of vegetation communities, with only certain areas characterized by natural forest stands, notably on steeper slopes, cliff faces, and within gorges (Figure 3-56). In these peculiar geo-morphological contexts, the evergreen holm oak (Quercus ilex) emerges as the dominant oak species, frequently associated with European hop hornbeam (Ostrya carpinifolia) and manna ash (Fraxinus ornus) around the cliffs, occasionally supplemented by black poplar (Populus nigra) and aspen (Populus tremula) in the gorges. Invasive tree species like black locust (Robinia pseudoacacia), tree of heaven (Ailanthus altissima), or wild fruit-bearing plants (e.g., Ficus carica) escaped from the nearby agricultural areas that increased the environmental hemeroby. In addition, legacies of the Mediterranean xerophytic oak forest with pubescent oak (Quercus pubescens) are sporadically enclosed within other forest types on steep slopes. Chestnut (Castanea sativa) forest type covers fewer steep slopes from the upper to the lower elevation, where the forest borders urban settlements. Following are summarized general considerations arising from the spatial location of the forest types, identified along the northern slope of Mount Epomeo, supplied by potential nature-based solutions for vegetation cover restoration and landslide risk mitigation.

[53] Stock, M.; Gerstengarbe, F.W.; Kartschall, T.; Werner, P.C. Reliability of climate change impact assessments for viticulture. In Proceedings of the VII International Symposium on Grapevine Physiology and Biotechnology, Davis, CA, USA, 31 Augest 2005; Volume 689, pp. 29–39

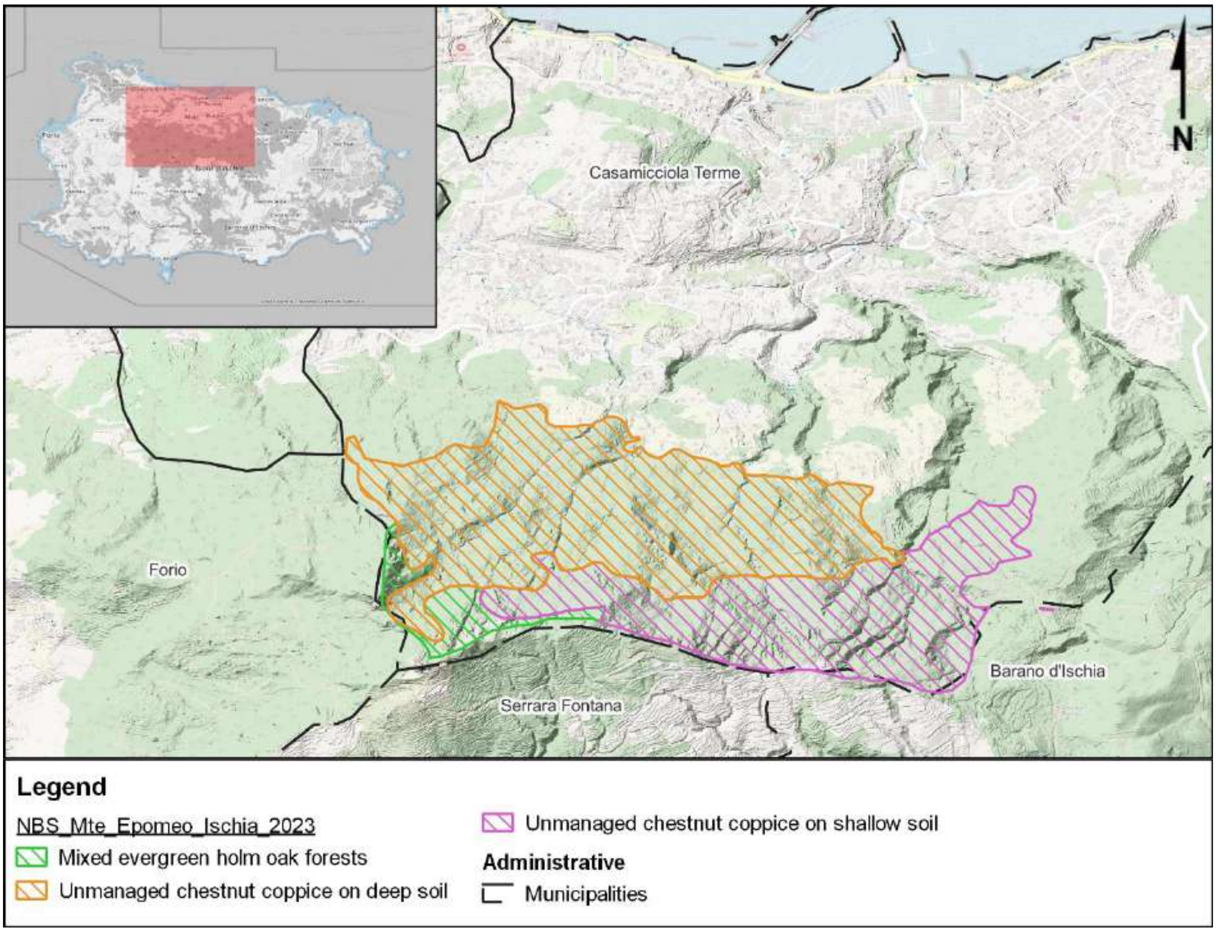


Figure 3-56. Map of the Mt Epomeo forest types.

i. Mixed evergreen holm oak forests (uppermost vegetation layer)

This mixed forest vegetation, predominantly featuring evergreen holm oak, covers the face, edge, and base of the mountain cliff of the northern flank of Mount Epomeo. Here, on November 26, 2022, a sudden landslide event uprooted trees and totally erased the shallow soil layer at the base of cliff (Celario basin). Elsewhere, tuff walls, unaffected by excessive surface water flows or small collapses, are covered with dense carpets of moss or wrapped in prostrate ivy.

The forest stands at the base of the Mt. Epomeo cliff consist of deciduous trees, including pubescent oak, European chestnut, European hop hornbeam, and manna ash, alongside the evergreen holm oak. From a regenerative and structural standpoint, these stands resemble coppice stands comprising multi-stem trees of even age, likely cut around 1970-1980, approximately 50 years ago. Single-stem trees are commonly dispersed on less steep slopes, while steeper slopes and cliffs are predominantly occupied by the evergreen holm oak, characterized by highly gnarled stem shapes.

Figure 3-57. A clear example of vegetation growing in the rocky substrate of Mount Epomeo (Erica arborea at the top left and Quercus ilex at the top right). The bottom photo was taken downstream of the cliff of Mount Epomeo.

At the base of the cliff the soil substrate is shallow, never exceeding 30 cm, followed by very compact tuff rock layer, unexplorable for roots. In this soil substrate, all tree and shrub species are characterized by sub-superficial roots horizontally oriented. Therefore, trees developed a peculiar root system arranged preferentially along contour lines rather than upslope or downslope.

Shallow soil and root systems, combined with the precarious biomechanical stability of trees are the main risk factor in the upper altitude range of the forests. Instability of trees and shrubs at the base of the volcanic cliff is exacerbated by a disproportional in the aboveground biomass/underground biomass ratio.

ii. Unmanaged chestnut coppice on shallow soil (mid vegetation layer)

At present, the chestnut coppice extends from the upper mountain cliff of Mount Epomeo to lower elevations, covering less steep slopes compared to the previous mixed evergreen holm oak forests.

Numerous areas within the chestnut forests are undergoing a gradual transition towards native meso-xerophilous forest communities, characterized by the presence of European hop hornbeam (Ostrya carpinifolia) and manna ash (Fraxinus ornus) tree species. Coppicing activities were discontinued around 50 years ago. The current state of the unmanaged chestnut coppice stand is marked by stools randomly distributed in space. In each stool, the average stem diameter and height of shoots measure 19 cm and 15.5 m, respectively.

Figure 3-58. Examples of uprooted ash and chestnut trees, highlighting the shallow and atrophied root system. In the bottom left, the measured soil depth is approximately 30 cm.

This stand structure is a consequence of the historical interruption of coppicing, contributing to self-thinning phenomena driven by resource competition and shoot mortality on the stool. Additionally, elevated levels of sprout mortality have been observed, linked to chestnut blight disease. The depth of chestnut tree roots never surpasses 25-30 cm, remaining sub-superficial with a predominantly horizontal distribution. The absence of a taproot is attributed to the compactness of the underlying tuff rock layer. This lack of a physical-mechanical connection between root systems and the rocky substrate renders chestnut trees vulnerable to uprooting and toppling, especially under water-saturated soil conditions and turbulent wind stress.

iii. Unmanaged chestnut coppice on deep soil (lowermost vegetation layer)

Likewise, to the unmanaged chestnut forest, coppicing in this stand has been interrupted since 1980, approximately 50 years ago. However, the tree roots explore soil deeper than 70 cm (Figura 4), and their contribution to soil stability is more prominent. Nevertheless, we cannot exclude physical-mechanical discontinuity between the roots and the tuff rock substrate. Additionally, a greater root depth emerges from the higher average height of plants of 18 m compared to chestnut stands growing on shallow soil. From a structural perspective, the coppice is composed of stools randomly arranged with 2-3 large-diameter shoots, overtopping smaller live and dead shoots.

Past interruption of coppicing has favoured natural mortality phenomena caused by competition among shoots on the same stump and widespread chestnut blight disease. Mortality was recorded in 66% of chestnut sprouts, while uprooting frequency accounted for 10%.

Figure 3-59. In the unmanaged chestnut coppice soil depth is approximately 70 cm.

Forest vegetation of the Cretaio area

Particularly noteworthy is the Cretaio pine forest: in this human-made pine forest, *Pinus pinea* L. (stone pine) is the predominant tree species, with the sporadic presence of *Pinus pinaster* Aiton and *Pinus halepensis* Mill. (Figure 3-60). Such forests have been extensively infested by the insect *Marchalina hellenica* in recent decades. Shrub species belonging to the Mediterranean maquis, such as strawberry tree, heather, broom, myrtle, etc., are more prevalent where the pine tree density is low and where the holm oak forest, particularly dense in the crater, is absent. The presence of managed forest vegetation and the relatively moderate slope of the area inherently reduce the likelihood of landslides. However, the frequent wildfires that have occurred in this area in recent years pose a challenge to forest management and contribute to diminishing the fitness of the forest vegetation in its ability to provide protective services. In this context, management options should be addressed to prevent future forest fires.

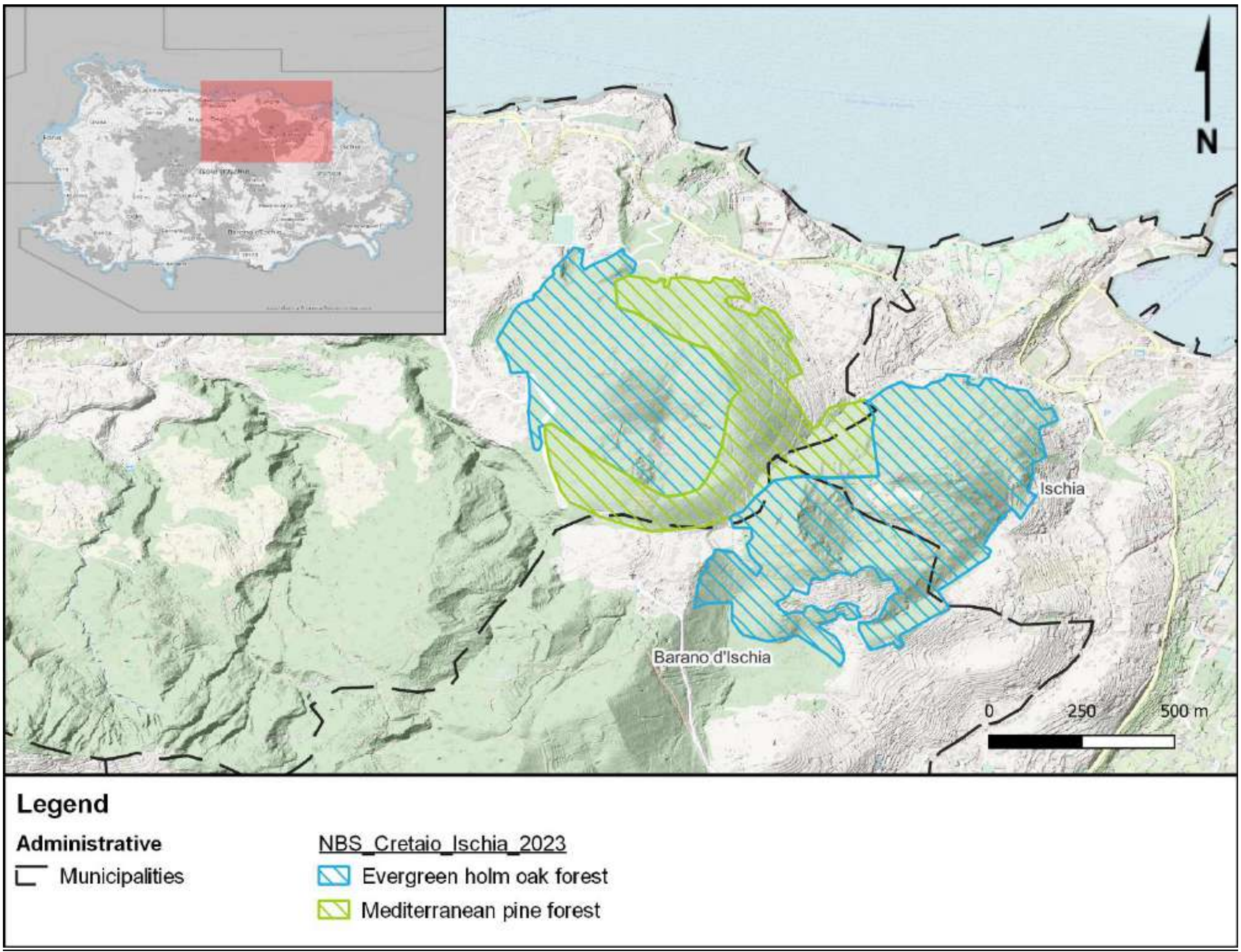


Figure 3-60. Cretaio area forests.

Forest vegetation of Mount Vezzi area

The forest vegetation of this area is characterized by mixed deciduous species dominated by chestnuts (Figure 3-61). For this type of forest vegetation, the same considerations apply as those made for the forest vegetation of Mt. Epomeo, where the presence of the chestnut coppice, if left unmanaged, can jeopardize the stability of the vegetation and thus significantly contribute to slope instability. In 2006, this forest was struck by a severe landslide like those found elsewhere in M.te Epomeo. Some agricultural areas of Mount Vezzi are abandoned and progressively colonized by mixed forests with evergreen holm. In the forest, management practices should prevent the ontogenetic ageing of the chestnut coppice, promoting its renewal, and preventing chestnut tree from reaching excessive stem sizes or showing signs of chestnut blight, which could further compromise their stability.

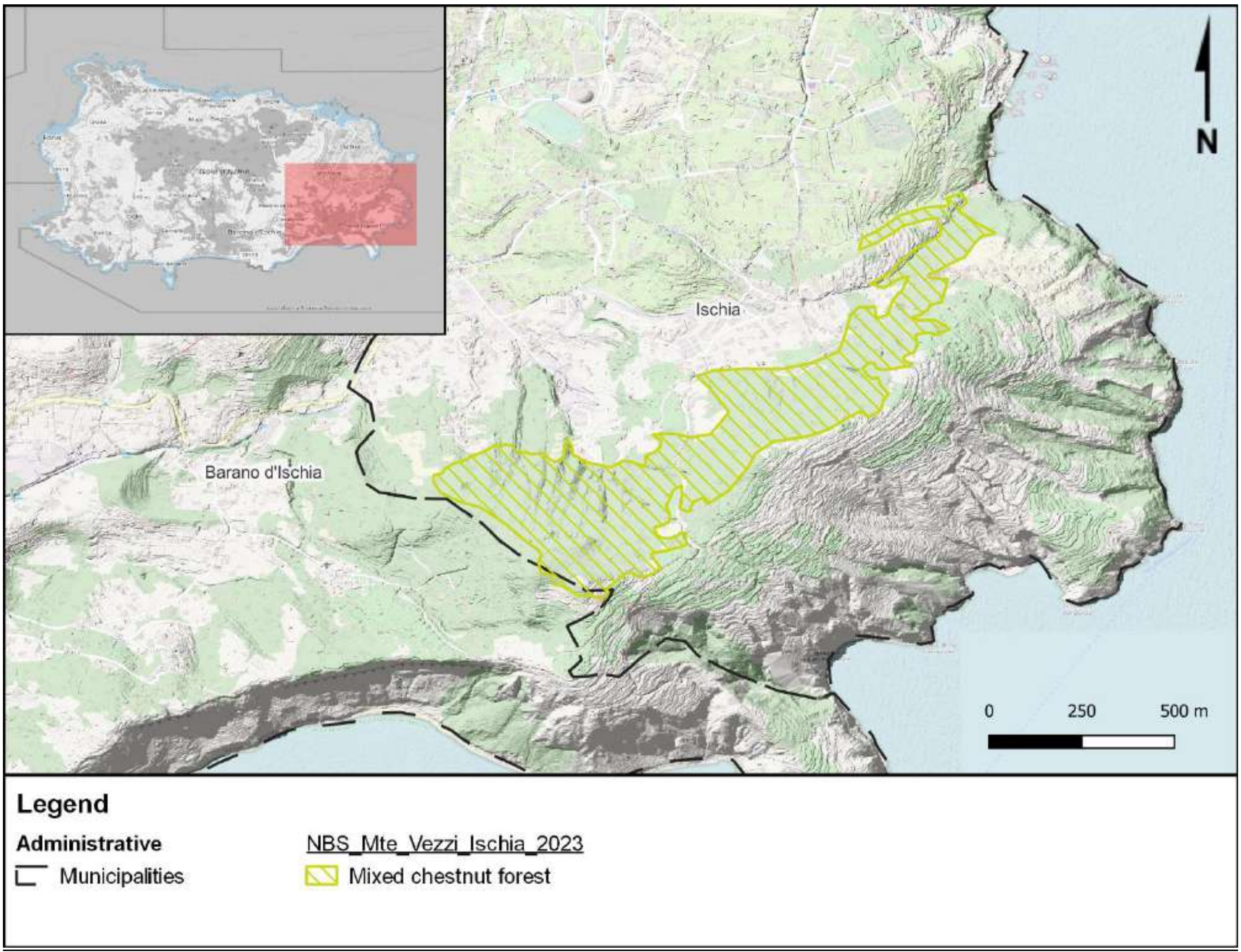


Figure 3-61. Monte Vezzi forest areas.

3.8.2 Air temperature

The projected increase in mean temperature across all emissions scenarios by 2050, both annually and seasonally, could exert severe stress on forest vegetation, making it less resilient to biotic and abiotic disturbances. Of particular significance is the summer water stress. The rising air temperature, coupled with reduced summer precipitation, makes forest vegetation more susceptible to the spread of wildfires, which, in these areas, represents a primary disturbance factor. Prolonged summer water stress would further enhance the susceptibility to pathogen/disease spread, such as chestnut blight, which appears highly virulent on the north-exposed slope of Mt. Epomeo, compromising the vitality of tree individuals and inducing mortality. This phenomenon leads to a general decrease in vegetation resilience and compromises stability in the face of adverse weather events.

3.8.3 Wildfire

Wildfire risk depends on a number of factors, including temperature, soil moisture, and the presence of trees, shrubs, and other potential fuel. All these factors have strong direct or indirect ties to climate variability and its change. Future change in air temperature enhances the drying of tissue and organic material (i.e fuels) that burns and spreads wildfire. There is no direct correlation between the starting of wildfires and warm temperatures, and then temperatures are related only indirectly to wildfires. In the Southern Mediterranean area more than 90% of wildfires are caused by people and then warmer temperatures and drier conditions can help fires spread and make them more severe.

3.8.4 Changes in precipitation patterns

From a hydrological perspective, the canopies of trees and shrubs, along with the litter on the ground, create a precipitation interception action, slowing down the falling speed and gradually absorbing excess water by the soil. This action prevents soil compaction and erosion due to impact. On the herbaceous level, there is a partial halt of surface water flow, preventing erosive phenomena. Another, no less important, effect is the transpiration process of plants, leading to a decrease in soil water content by releasing water vapor into the atmosphere. From a purely physical standpoint, the bracing action of each individual trunk results in greater soil stability upstream.

Future precipitation scenarios for Ischia Island predict a rainfall increase during the Autumn-Winter and a decrease in the Spring-Summer seasons. Under this scenario, tree vegetation is expected to be stressed by soil water shortage followed by a decrease in growth. However, some Mediterranean tree and shrub species are well equipped to cope with summer drought conditions, except chestnut trees which suffer prolonged drought periods. Future impacts related to the increase in autumn-winter precipitation are strictly related to the tree species and their phenology. Indeed, broadleaved deciduous tree species' rainfall interception during the fall-winter season decreases rapidly. Noteworthy, past landslides in Ischia have occurred in the chestnut forest and took place in the autumn-spring time window under a leafless condition.

3.8.5 Wind

Although annual extreme wind speed is projected to experience no significant change under all scenarios, it's important to note that tree canopies have a destabilizing effect concerning wind resistance. Envisioning a tree as a sail, the weight it places on the root system and, consequently, the soil, increases with the strength of the wind opposing it. This growing load can promote slope-cutting phenomena. Management of the forest overstory allows for the reduction of the height-to-diameter ratio of individuals, thereby increasing their stability against wind forces. A particular role in the forest cover-wind interaction is played by the shape and size of the clearings.

3.8.6 Recommended nature-based solutions

i. Recommendations for mixed evergreen holm oak forests in Mont Epomeo

To mitigate possible landslide risk, it is essential to manage the aboveground wood biomass. Reducing the aboveground biomass load and preserving the functionality of the trees' root biomass should be the primary solution. Managing biomass helps to mitigate adverse factors related to soil-tree slope instability, among them: i) aboveground biomass overload and ii) uprooting/toppling of trees. Therefore, an appropriate intervention should be coppicing of live and dead trees on the cliff edge, face, and its base.

ii. Recommendations for nature-based solutions for Unmanaged chestnut coppice on shallow soil in Monte Epomeo (mid vegetation layer):

The physical and mechanical discontinuity between chestnut tree roots and the compacted tuff layer is exacerbated by the disproportionality of the aboveground/underground biomass ratio. Reducing the aboveground biomass load and preserving the functioning of the belowground roots biomass is an appropriate approach to mitigate the risk of future tree uprooting and toppling in the chestnut forest type.

A potential silvicultural option could be the coppicing of small forest areas (<5 ha) at short time intervals (minimum rotation 12 years according to regional law) without the release of standards, representing a suitable approach to mitigate the risk related to the aboveground biomass overload. Simple coppice is a nature-based solution for sustainable forest management in which trees are systematically and repetitively cut and regeneration is vegetative, by means of sprouting or suckering (often from the stump, alternatively from roots). This practice maintains the root system vital, with the possibility of repeating the practice countless times.

The reduced size of the cuts below 5 ha allows for a reduced impact of the erosive phenomena that could arise in the immediate periods following the cut; however, the reconstitution of the new forest cover occurs within 1-2 vegetative seasons, re-establishing the optimal conditions for stability. Also, according to the slope degree, the shape and extent of logged forest surfaces should be spatially distributed to reduce surface water flow and prevent erosive processes. We anticipate that in areas where chestnut trees face challenges in promptly regenerating the stand, the forest is likely to transition gradually toward its original and indigenous formation, characterized by ash and hornbeam species. Should this transformation not occur within a timeframe consistent with forest cover scenarios, intervention may involve promoting the planting of native shrub species like Phillyrea angustifolia, Ruscus aculeatus, Myrtus communis, and Erica arborea.

iii. Recommendations for nature-based solutions for Mount Vezzi area

Risk mitigation could be achieved by reducing the aboveground biomass overload while preserving the functioning of the belowground roots biomass. Therefore, managing chestnut forests through coppicing of small forest areas (<5 ha) at short time intervals (minimum rotation 12 years according to regional law) should represent a suitable solution to mitigate the risk related to the aboveground biomass overload. Considering the type of silvicultural operation, the estimated overall cost for the forested surface of about 31 ha account for 0,106 M€ (included in the Monte Vezzi investment).

iv. Recommendations for nature-based solutions for Cretaio area

Wildfire prevention actions aim to manage fuel conditions by reducing future hazard, decreasing the ease of fuel ignition and the efforts in fire suppression, affecting both size and severity of the fire, i.e. the magnitude of significant negative wildfire impacts on wildland systems.

In the Cretaio pine stands, forest fuel management involves modifications on the two layers of live and dead fuels (ladder fuels, crown fuels) in the structure of a forest stand, namely: i) selectively removing or modifying live/dead and ladder fuels to reduce their vertical arrangement and horizontal continuity. Therefore, selective thinning represents the suitable silvicultural prevention of wildfires effective in reducing both ladder fuels and canopy bulk density.

The estimated overall cost of silvicultural fire prevention operation is approximately 0,136 M€ for the about 46 ha of the Mediterranean pine forest.

v. Cost estimate

The table below presents the cost estimate for the recommended nature-based solutions examined in the preceding paragraphs. At present, the cost estimate is a rough estimate. Therefore, a more accurate assessment is needed before implementation to take into account the profit of selling merchantable wood assortments (roundwood, fuel wood).

Description of forest restoration approaches	**Unit cost (€/ha)**	**Total surface (ha)**	**Total Cost (€)**
Edge and wall cliffs coppicing			
Restoration of unstable mountain cliffs covered by native vegetation and degraded by trees and/or shrub roots and other factors. This restoration intervention involves felling the trees and shrubs, removing uprooted trees and shrubs, and precarious clastic rocks. Additionally, it includes sectioning the fallen tree stems and branches and transporting wood materials to the timber yard, where they are temporarily stored. This intervention shall be realised according to the temporal and spatial criteria established by a local forest management plan.	**5,324.30**	**6.2070**	**33,047.93**
Cliff base coppicing			
Coppicing in unmanaged chestnut forests involves felling, limbing, and sectioning of trees and shrubs, followed by stacking the wood material. The branches and the stem wood materials are concentrated for subsequent transport to the timber yard. This intervention shall be realised at the base of the cliff and in small forest units according to the temporal and spatial criteria established by a local forest management plan.	**4,351.90**	**10.8483**	**47,210.72**
Unmanaged chestnut coppicing on shallow soils			
Coppicing of the chestnut coppice forest with phytosanitary purposes. The activity consists of felling dead trees and collecting wood material in areas with high slopes and shallow soils. The forest operations include sectioning of trees and shrubs and transporting and chipping the wood material outside forests to the timber yard. This intervention shall be realised in forest units according to the temporal and spatial criteria established by a local forest management plan.	**3,408.75**	**32.5451**	**110,938.11**
Unmanaged chestnut coppicing on deep soils			
Coppicing of the chestnut coppice forest with phytosanitary purposes. The activity consists of felling dead trees and collecting wood material in areas with deep soils. The forest operations include sectioning of trees and shrubs and transporting and chipping the wood material outside forests to the timber yard. This intervention shall be realised in forest units according to the temporal and spatial criteria established by a local forest management plan.	**3,408.75**	**64.5313**	**219,971.07**
Total surface and cost of the forest restoration		**114.1317€**	**411,167.83€**

3.9 Recommended cross sectoral adaptation activities related to Hydro-geological hazards

Affecting several sectors, as shown in the sectoral assessments, hydro-geological hazards (i.e., floods and landslides) are considered the main climate hazard on the Island of Ischia. To adapt the planned and existing infrastructure as well as the society of Ischia to these hazards, several structural and non-structural activities have been identified.

Structural activities are individual for each of the different sectors and are therefore roughly described in this section. The following sectoral sections provide more insight on the sector specific measures. The **non-structural activities** are valid over all sectors and are:

- Spatial and landscape planning and detailed landslide and flood hazard mapping
- Island-wide Natural Hazard Event Cadastre, Inventory and Documentation
- Island-wide Natural Hazard Monitoring, Early Warning and Alarming system

3.9.1 Areas for cross-sectoral adaptation activities

Hydro-geological hazards are events that are not restricted to a single point or location and thus, affect larger areas and mostly several sectors. In the following, to hazardous location are described, where cross-sectoral adaptation activities are described.

vi. Monte Vezzi area

The Monte Vezzi area (40.71, 13.94) (Figure 3-62) has been recognized as one of the most likely locations of landslides taking place and the area has already seen past landslides. Many of the farms at the area have been abandoned, the terrace structures or other infrastructure not maintained, and forestry management is not currently performed. To protect the infrastructure underneath from floods and landslides, the following measures are recommended:

- Verification of the stability of the ridge, satellite-based investigations/monitorings and geodetic surveys on surface as well as subsurface.. Measure and monitor Soil moistureHydrogeological risk mitigation works through:
  - Building of natural watersheds
  - Creation of flow barriers positioned at various heights respecting the morphology of the slope
  - Building of walkways and restoration of terraces where present, by rebuilding the “dry retaining walls”
- Protection of the edges and furrows created by the landslide of May 2006, through the application of nets and biomats with integration of the existing vegetation
- Construction of a reinforced earth basin for the collection of any flows
- Development of a forest management plan and temporal and spatial organization of the forest vegetation coppicing (more details in chapter 3.9.6).
- The cost estimation, provided by the local municipality, for the works mentioned above is **14.6 M€**

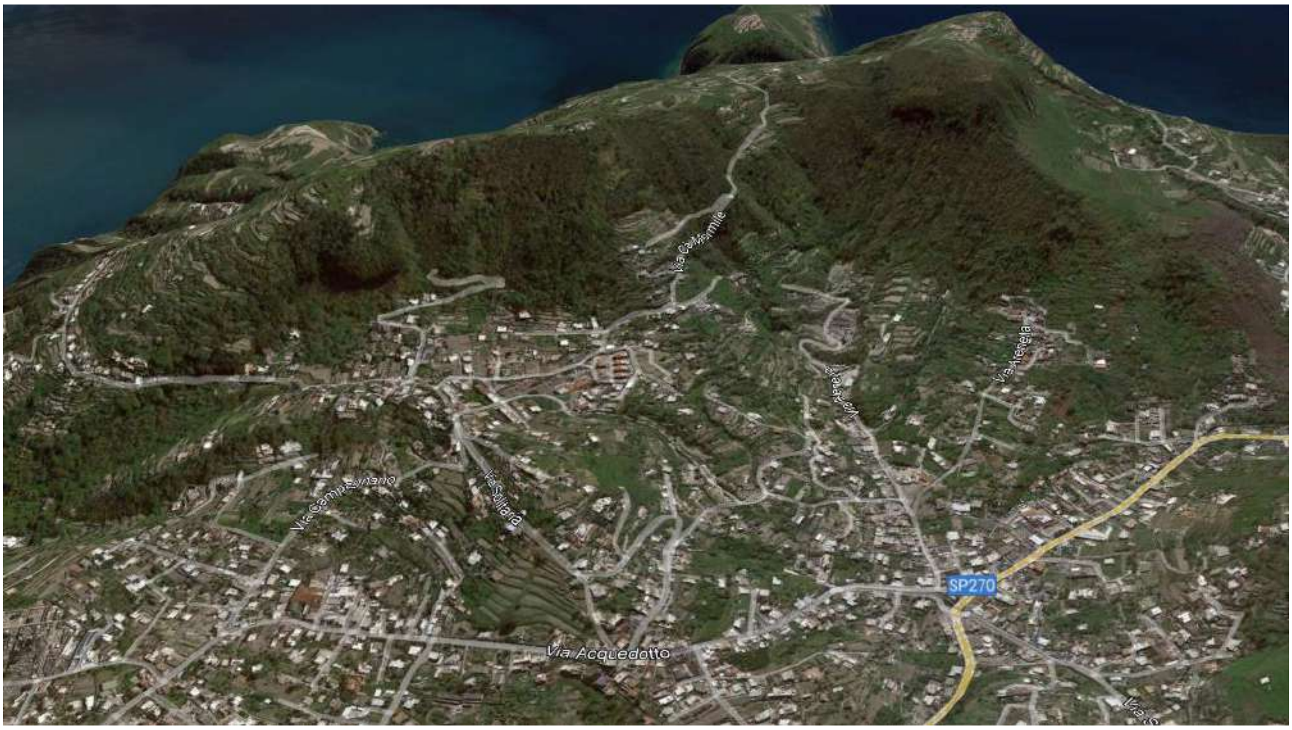


Figure 3-62. Monte Vezzi and the nearby infrastructure and housing areas at the south-eastern part of Ischia Island (Google Earth).

vii. Cretaio area

The Cretaio area (40.73988281390738, 13.926763647810743) (Figure 3-63) has been recognized as one of the most likely locations of landslides taking place and the area has already seen past landslides. The area has similarities with the abovementioned Monte Vezzi as it is also largely forested and has some terrace structures. To protect the infrastructure underneath from floods and landslides, the following measures are recommended:

- Verification of the stability of the ridge, satellite-based investigations/monitorings and geodetic surveys on surface as well as subsurface.. Measure and monitor Soil moisture
- Hydrogeological risk mitigation works through:
    - Building of natural watersheds with the creation of hydraulic structures
    - Creation of flow barriers positioned at various heights respecting the morphology of the slope
    - Building of walkways and restoration of terraces where present, by rebuilding the "dry retaining walls"
    - Drainage of Slopes, reduce pore pressure
- Construction of a reinforced earth basin for the collection of any flows
- Development of a forest management plan and temporal and spatial organization of the forest vegetation coppicing (more details in chapter 3.9.6).
- The area under the Cretao hills and has also been recognized as a flood risk area from both fluvial and coastal floods with needs for additional flood prevention measures (Figure 3-64).
- The cost estimation, estimated by comparing the site to the size of the Monte Vezzi site, for the works mentioned above is **15 M€**

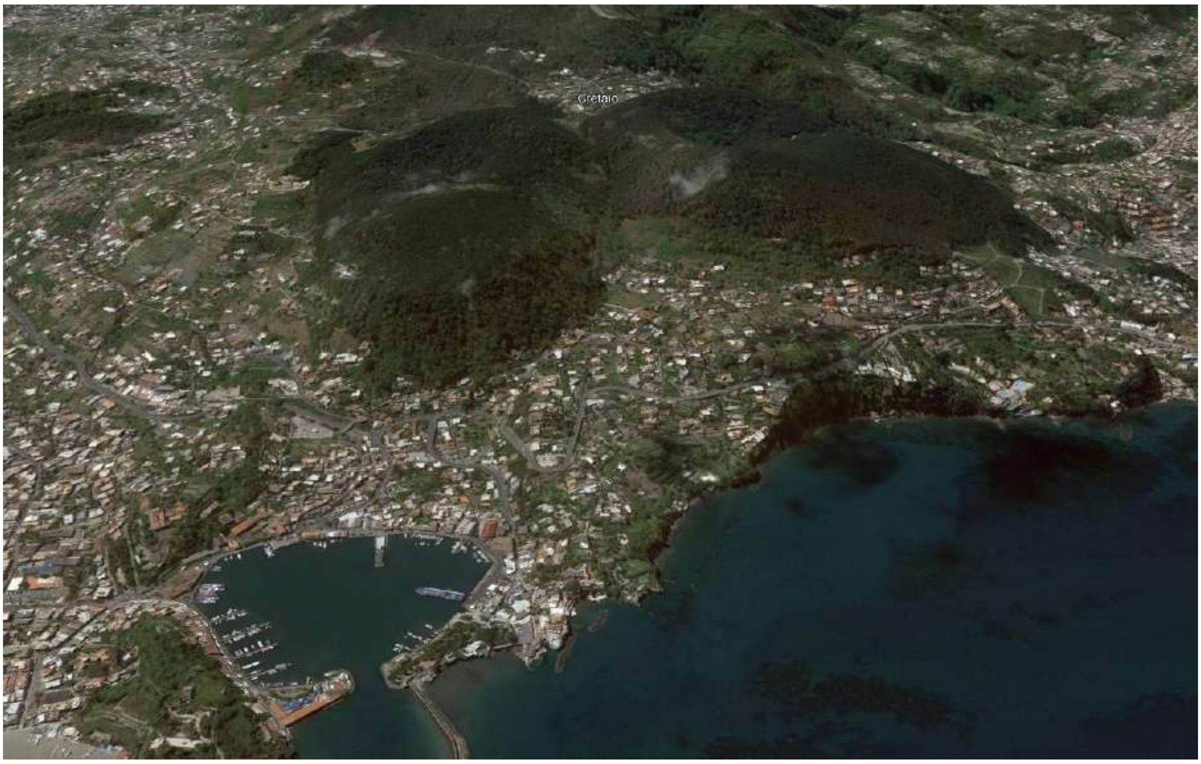


Figure 3-63. Cretaio area hills over with Ischia port area below them (Google Earth).

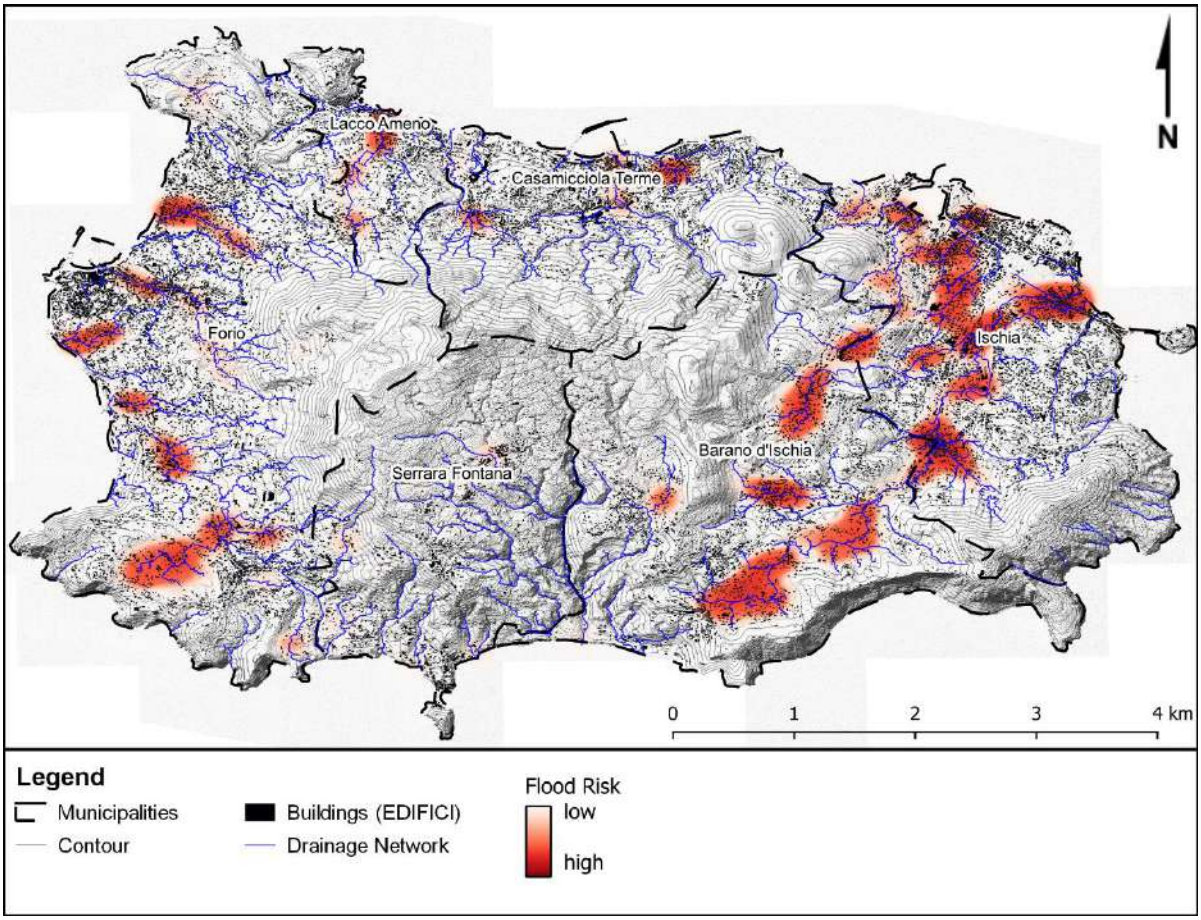


Figure 3-64. Ischia flood risk heat map with buildings.

viii. Forio area

The Forio area towards the higher central part of the island (40.73988281390738, 13.926763647810743) (Figure 3-63) has been recognized as one of the most likely locations of landslides taking place and the area has already seen past landslides. The area differs from the two previously mentioned areas as it is partly less forested and has suffered more from rock falls than landslides and is higher from its top part. To protect the infrastructure underneath from floods and landslides, the following measures are recommended:

- Verification of the stability of the ridge, satellite-based investigations/monitorings and geodetic surveys on surface as well as subsurface.. Measure and monitor Soil moisture Hydrogeological risk mitigation works through:
    - Building of natural watersheds
    - Creation of flow barriers positioned at various heights respecting the morphology of the slope
- Construction of a reinforced earth basin for the collection of any flows
- The cost estimation, based on the approximate size of the area and compared against the estimation of Monte Vezzi, for the works mentioned above is **15-30 M€**

Figure 3-65. Forio landslide and flood risk area (Google Earth).

3.9.2 Structural Activities

In the report "Piano commissariale di interventi urgenti" common structural measures are listed for Casamicciola Terme. The report distinguishes measures that are located on the rocks, slopes and in river streams. This report provides new design information for the proposed measures but does not assess the planned measures in detail.

For rock fall mitigation, the report suggests removal by dredging or blasting or also slinging of isolated boulders. Furthermore, passive activities would be rockfall barriers such as rock fall nets, which need to be properly anchored and placed in the field. Other structural measures would be rock fall embankment dams.

For landslide mitigation, the report suggests reinforced soils, gabion walls (made of double twisted mesh woven from drawn stell filled with stones) or drainage.

For debris flow mitigation, measures in river streams are proposed. For instance, debris flow barriers or breakers, groundsels (to stabilize the riverbed and reduce erosion), wave breakers and weirs. Furthermore, flood and debris flow retention basins (with a larger dam construction) and dissipation areas are proposed.

Generally, it can be stated that the proposed measures are able to mitigate the natural hazard risk both under current conditions and under conditions of climate change in case they are properly designed. Therefore, only few adaptation activities are presented for Casamicciola Terme in this report.

Once installed, the structures need to be properly maintained (includes regular inspections, e.g. annual, or after heavy rainfall periods) and repaired in case of damages due to natural hazards. All inspections and works on adaptation activities shall be well documented, e.g., in the form of a GIS database for instance. In combination with a natural hazard event cadastre, the maintenance documentation allows for a functionality testing of mitigation measures. In case of indications that the implemented measures are insufficient, adaptations shall be made based on a re-evaluation of intensity and spatial distribution of natural hazards.

In addition to the abovementioned 3 hotspot areas, the local municipalities have collected a list of interventions including several sites where improvements for riverbeds and other hydrology related works are requested. It was not possible to inspect those sites within this assignment but it is recommended to study the list in more detail together with the local stakeholders.

3.9.3 Spatial and landscape planning and detailed landslide and flood hazard mapping

Priority should be given to risk avoidance based on spatial and landscape planning. If this is not possible, structural adaptation activities shall be placed. The island of Ischia has a very dense settlement, also in the steeper areas. Spatial planning could be an option to reduce the risk related to geo-hydrological hazards. For effective spatial planning, more detailed mapping of flood and landslide risk than currently available (in the ISPRA maps and in the risk maps generated for this study) should be carried out to identify the areas at risk in more detail. Such risk mapping for hydro-geological hazards would require more detailed numerical modelling for specific high-risk areas identified in this study (e.g. the areas listed in Chapter 3.9.1 above). Based on that information planning for construction and protection can be carried out.

For existing buildings and other assets, such detailed studies of areas at risk allow the assessment of the effectiveness of potential structural protection measures, and the related uncertainties and residual risk. Such an assessment should also include cost benefit analysis for different risk reduction measures, including relocation of existing structures. If the risk for existing structures and residents cannot be mitigated with viable adaptation and protection measures, relocation as a possible adaptation activity should also be considered. As the land area available for new construction projects is limited on the island, this could also mean relocation of certain functions to the mainland.

Spatial and landscape planning also includes aspects of agricultural and forestry management. Agricultural measures can include the protection and restoration of terraces (as proposed for the areas listed in Chapter 3.9.1 above). Forestry measures can include the measures described in the report "Piano commissariale di interventi urgenti" for the Casamicciola Terme, Monte Vezzio and Cretaio areas, and measures as described in Chapter 3.8 (Forestry and nature-based solutions).

3.9.4 Island-wide Natural Hazard Event Cadastre, Inventory and Documentation

Knowledge about past events is an important source of information for hazard assessment and integrated risk management. Thus, an island-wide Natural Hazard Event Cadastre, Inventory and Documentation is proposed. As a starting point, the existing database of landslides could be used and further integrated into the proposed Natural Hazard Monitoring system.

The island of Ischia is susceptible to various types of natural hazards, as witnessed by several events in the past. Knowledge about past events is an important source of information for hazard assessment and integrated risk management. Furthermore, it helps to validate and (re-)evaluate modelled results, to determine potential endangered areas and to estimate the probability and intensity of hazardous events. A good documentation (including photographs) and understanding of certain events will facilitate the risk dialogue with the relevant stakeholders. The documentation might also be used for raising awareness on natural hazards and required mitigation measures among the local communities.

It is therefore proposed to develop an event cadastre on observed events describing the type of hazard, time, location, size/intensity, spatial distribution, description, and possible trigger mechanisms. In a first step, major past events (e.g., documented by scientists) should be documented in a retrospective manner by analysing archives, reports, satellite images or interviewing contemporary witnesses. The existing database (compare Figure 1-17) and scientific papers are therefore a good starting point. The second step should be a systematic documentation of newly occurring events. For instance, each municipality could nominate a responsible person, that documents landslide events into the cadastre.

It is recommended that the event cadastre be incorporated as a GIS-layer into an integrated island-wide software solution (e.g., integrated into an Integrated Data Management Platform (IDMP) as described below). The application allows creation of inventory maps showing a collection of events that have occurred at different locations. This cadastre could also be used for interpretation of the current landslide situation. For instance, higher activity of smaller events in a particular area (e.g. rockfall, debris flow, smaller landslide) might be an indicator for a larger event (rockslide, deep-seated landslide) to occur in the near future.

3.9.5 Natural Hazard Monitoring, Early Warning and Alarming system

The proposed Natural Hazard Monitoring, Early Warning and Alarming System could inform different sectors and the society of Ischia about the current situation related the hydro-geological hazards. The system and its potential components are described below. The proposed activities are suggestions made by AFRY, which are based on knowledge and experience gained from projects worldwide.

For climate & natural risk management and monitoring, different types of earth observation data (e.g., precipitation measurements, soil moisture measurements, satellite images, etc.) must be generated, stored, processed, visualized and interpreted.

The earth observation data describes different processes and parameters related to hydrological and geological hazards and typically originates from different sources. Hence, an integrated data management platform that collects all the relevant data shall be in place. The proposed software solution shall be a database system, which is web-based, has a modular structure, allows for GIS application and is easy to use by a graphical user interface (GUI).

The Integrated Data Management Platform (IDMP) shall include data and functionalities from the:

- island-wide event cadastre;
- island-wide hydro-meteorological and geo-hazard monitoring network;
- weather forecasting products;
- early warning and alarm system

and should serve as a Natural Hazard Monitoring, Early Warning and Alarming system.

The implementation of an IDMP can be stepwise: this means that in a first step, the system could be rolled out for Casamicciola Terme, which is the municipality that suffers the highest risk. For instance, the system could be built up on the existing tool at the Presidio Territoriale Comune di Casamicciola Terme. This tool already uses (1) video surveillance on the main channels that come from the mountain and reach the valley, (2) five rain gauges (i.e., Casamicciola Frana, Ischia, Piano Liguori, Monte Epomeo, Foria), which give information on the precipitation in real-time, (3) weather radar and (4) strain gauges and inclinometers that measure the movement of the slope near the state road. All data sources could be integrated into one single platform. In a next step, also other municipalities could have access to the system with a specific focus on their territory and specific hazard sources. The system shall be designed with a modular structure so that it can be extended easily and, if required, additional data from other sources (earth observation products and numerical models) can be integrated with reasonable effort.

The IDMP shall be designed and implemented in a way to support fast decision making in short-term planning (e.g., early warning), while allowing also for thorough analyses of data as needed for expert discussions during long-term decision making (i.e., large infrastructural investments). A central point is the usability of the platform, especially a GUI (Graphic User Interface) that allows for an integrated view on the different data layers is essential. The GUI shall also be informative, in the sense that for instance alarm levels of certain gauging stations should be visible. Furthermore, the IDMP shall be a decision support system with a reasonable degree of automatism (e.g., automatic e-mails of alarm messages), while efficiently supporting human-based and manual decision making.

The system shall be operated by an official authority and the access could be open to the municipalities and the public. The following figure illustrates the overall concept of the IDMP and shows users, data flows and data sources:

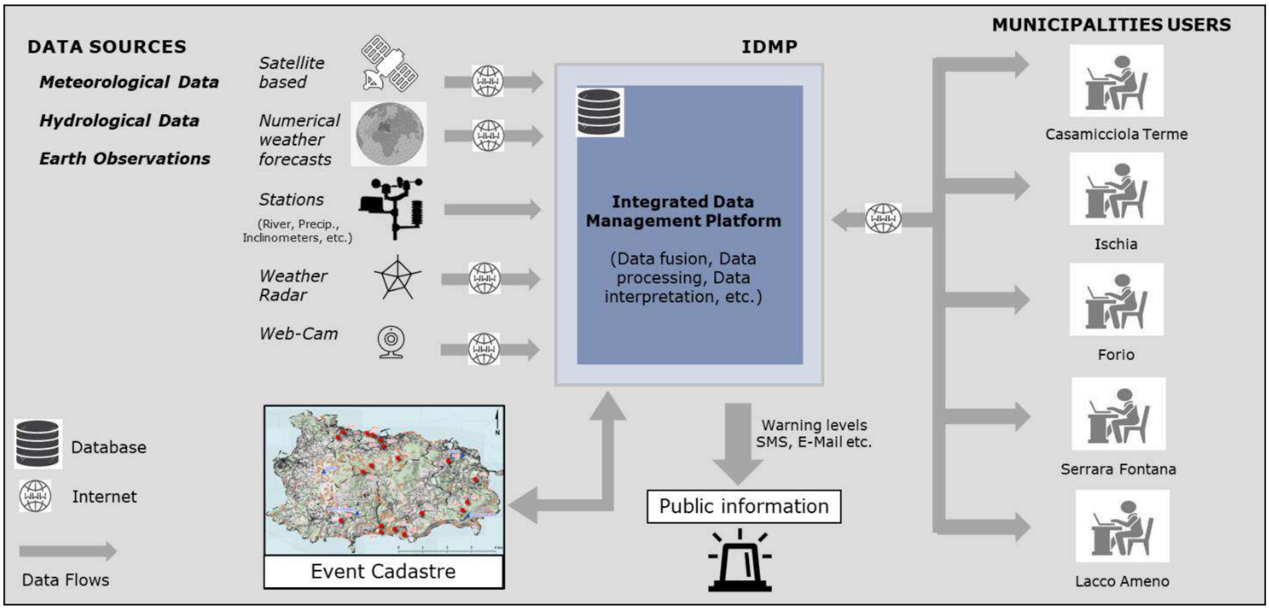


Figure 3-66 Concept of the IDMP showing main users, main data sources and data flows

The following points describe the components of the Natural Hazard Monitoring, Early Warning and Alarming system more into detail:

1. **Hydro-meteorological monitoring network**

Monitoring of hydrological parameters (river discharge) and meteorological parameters (precipitation, temperature etc.) on the Island of Ischia are of utmost importance for climate resilient decision making. This should include station data as well as remote sensing data or weather radars. Based on this data it is possible to gain information on the current hydro-meteorological state of the Island, which is an important reference for estimating the near-term future flood and landslide situation. Thus, the information collected through the monitoring network can be used for early warning and alarming systems but also for the proper design of flood and landslide protection measures.

Currently, four meteorological stations are operating on the Island of Ischia. Yet, the data is not available in real-time (or only available for a closed community).

Furthermore, it seems that no river gauging station is operating on the island. Thus, it is recommended to install river gauging stations at the larger creeks.

Each of the gauges should be equipped with automatic sensors and transmitted in real-time. Where possible also manual gauge reading should be done, serving as a back-up in case the automatic sensors or the data transmission are not operating. The automatic station data as well as remote sensing data from publicly available sources and/or commercial providers (e.g., spatial and temporal weather and snow information) should be integrated in a comprehensive monitoring system. This system could also serve as a platform for early warning or alarming.

The costs for installation of a geo-hazard monitoring system shall be considered in the CAPEX estimates of the investment plan. The operation of a dense network is considered a challenging task which will require substantial efforts in operation and maintenance. This has to be considered accordingly in the OPEX estimates of the investment plan.

2. Geo-hazard monitoring network

Monitoring of already identified and localised sources of geo hazards (e.g., hot spots such as Cava Cuccufrido (event 2022)) is of utmost importance.

For geo-hazard monitoring, various technologies shall be considered:

- webcams,
- radar sensors,
- inclinometers,
- trigger lines,
- satellite imagery or InSAR,
- drone imagery

The layout of the monitoring network and the required technologies suitable for the specific hazards should be specified in detail during subsequent phases of the project. A phased implementation of the network is proposed:

- Phase 1: Additional studies (e.g., detailed identification of other hot spots), location and type of monitoring technology should be defined.
- Phase 2: Development of a monitoring concept (ground-based and/or remote) and a system observing slope instabilities within the relevant areas.
- Phase 3: Extension of the monitoring network in case new or other geo-hazard sources are identified in the future.

Measured data collected by automatic sensors should be transmitted in real-time. In addition, visual inspections of critical hazard sources shall be conducted at regular intervals.

The automatic ground-based station data as well as remote sensing data (e.g., satellite images of glacial lakes or InSAR) should be integrated into a comprehensive monitoring system. The collected data – especially provided by hazard detection systems, such as trigger lines or web-cams – will be important information feeding into the early warning system.

The costs for installation of a geo-hazard monitoring system shall be considered in the CAPEX estimates of the investment plan. The operation of a dense network is considered a challenging task which will require substantial efforts in operation and maintenance. This has to be considered accordingly in the OPEX estimates of the investment plan.

3. Usage of weather forecasting products

In order to inform the inhabitants of the island on critical weather conditions, access to daily, weekly and seasonal weather forecasts is essential. These meteorological forecasting products:

- will allow for early warning of critical meteorological situations, increasing the preparedness related to various types of geo hazards (e.g., in case heavy rainfalls are forecasted machinery could be placed at bridges); and,
- could be coupled with a hydrological modelling system. This system would generate river flow forecasts that could be used for hydropower planning and scheduling as well as flood warning (with some limitations).

There are a number of commercial and non-commercial weather forecasting products available that could be valuable for the island.Selection of adequate products will be related with the technical and institutional set-up of the use of weather forecasts.

4. Early warning and alarming system

Sirens and other alarm signals must be in place to warn the communities in case of emergencies. Such emergencies are for instance:

- Floods,
- Debris flows,
- Landslides,
- Rockslides

The emergencies must be timely detected by an appropriate monitoring system. Weather and river flow forecasts should be integrated into the early warning and alarming system in order to increase general preparedness. Thresholds and alert types related to early warning and associated actions need to be defined in an **Emergency Action Plan**.

In general, the early warning and alarming should be managed and controlled centrally - for such purpose the proposed Integrated Data Management Platform would be suitable, in which all types of data are collected and processed. Based on defined thresholds, the central system shall send alarm signals, which shall be physical signals (e.g., warning lights, sirens) but also digital warnings (e.g., e-mail, SMS).

The alarming system shall be regularly evaluated and updated in case new sources of natural hazards are identified or additional monitoring data become available.

The CAPEX for the proposed non-structural activities are as follows:

Activity	**Type**	**Costs [M€]**
Spatial and landscape planning and detailed landslide and flood hazard mapping	Study	0.5
Natural Hazard Event Cadastre, Inventory and Documentation	Study	0.3
Natural Hazard Monitoring, Early Warning and Alarming system	Software, Material and Study	2.8

3.10 Design recommendations for Ischia's reconstruction

Resulting from sectoral as well as cross-sectoral analyses, some general design recommendations can be formulated that can contribute to reconstruction efforts that consider adaptation to future climate hazards. The main recommendations, described in more detail, below refer to hydraulic design, to the design of coastal structures and to temperature for buildings design.

3.10.1 Hydraulic design based on projections of future extreme precipitation (IDF curves)

The analyses of extreme precipitation projections described in Chapter 2.4.2 showed clear increases in future rainfall intensities. Table 2-12 in Chapter 2.4.2 provides ensemble-mean projections of increase in Maximum Annual Precipitation (MAP) obtained under different RCP scenarios from the EURO-CORDEX ensemble, based on the analysis of observed extreme events. For return periods up to 20 years, the different projections show an increase between 5% and 10%. For return periods of 50 and 100 years, the projected increases are higher, between 8% and 25%. Note that these values are ensemble mean results, and that results of single climate models also include substantially higher increases (see Appendix 5).

While these analyses have some limitations and include a high uncertainty (see discussion in Appendix 5), **they provide a state-of-the art science-based estimation of future increases in extreme rainfall over Ischia. It is therefore recommended to generally apply increase factors resulting from these analyses, in the range of 5% to 25%, in any current and future hydraulic design** (until newer assessments are available).

Hydraulic design parameters are used in many sectors for local drainage design and the definition of pipe dimensions, e.g. in:

- flood discharge design and flood protection measures (for this sector the use of increased precipitation input was already agreed in the framework of this project);
- wastewater (stormwater) networks
- road drainage (culverts, bridges, etc.)
- building drainages.

3.10.2 Coastal structures

For all maritime design, sea level variation including rise due to global warming but also barometric pressures and storm surges as same as wind/wave actions shall be considered.

It is recommended that all quays of the harbours around the island shall be at least at +1m above mean sea level to avoid submersion during "Aqua Alta" events. All harbour quays below +1m MSL shall be raised, if possible, with an adaptive solution (example with a floating dock) that can adapt to the slow variation of the sea level due to global warming (up to 26cm by 2050) but also seasonal and punctual ones with the local effects of storm surge. It is recommended to carry out wave agitation studies using proper numerical models to assess the waves actions that can generate submersion issues.

For the harbour’s breakwaters, it is recommended to carry out metoceanic studies relayed by wave propagation studies to extract the wave characteristics at the toe of the structures and by integrating the sea level rise due to global warming. The studies must be carried out according to the recommendations of Eurotop or the overtopping manual, or even using tests in a physical or numerical wave flume to determine the height of the breakwaters to be respected in order to avoid wave overtopping.

Design studies must also be carried out for rock structures, according to the recommendations of the rock manual and in particular using the Hudson and Van Der Meer formulas to ensure the stability of the structures regarding hydrodynamic constraints.

Concerning coastal erosion, morphodynamic studies in the short, medium and long term with diachronic studies of the evolution of the coastline must be undertaken in areas subject to erosion and including sea level rise and wave climate modification due to climate change.

3.10.3 Temperature design parameters for buildings

In Ischia the number of summer days, cooling degree days and warm spells are all projected to be increased significantly as the mean temperatures rises in all RCP scenarios. Also, the number of tropical nights is projected to be increased significantly. This will lead to cooling by natural ventilation being ineffective because the temperature does not decrease under 20°C during the three summer months. Prolonged higher temperatures might need the installation of additional cooling systems.

Passive adaptation activities such as sunshades can be utilized to provide glare protection and shade in order to reduce indoor heating load, but it is very likely, that active cooling and ventilation systems (air conditioning) are also needed to provide immediate cooling in periods of extreme heat and tropical nights to maintain tolerable indoor conditions. **It is recommended that new cooling systems at least in critical infrastructure should be designed according to RCP 8.5 temperature models.** This means that the RCP 8.5 temperature models should be considered in the design of the cooling capacity of new systems. The design parameters regarding cooling and ventilation systems could also be implemented in the design instructions for the island. It must be noted that cooling of buildings will affect the hygrothermal performance of the building envelope. The cooling and possible condensation will induce moisture related damages especially in older buildings with organic envelope materials. The hygrothermal performance of the envelope structures should be assessed when designing cooling systems.

3.11 Key findings on potential climate impact, sectoral vulnerability and possible adaptation activities

Chapter 3 of Part 1 of this report described analyses on potential climate impact, climate vulnerability and possible adaptation activities for each of the considered sectors and recommendations for cross-sectoral adaptation activities. The key findings can be summarized as follows:

Cross-sectoral adaptation to hydro-geo hazards

- Landslides and floods are considered as the main climate hazards. Due to their characteristics and widespread occurrence, they have the potential to impact several infrastructures and economic sectors at the same time.
- Structural adaptation activities can selectively reduce the hydro-geological risk. Yet, zero risk is not possible.
- Non-structural adaptation activities, such as improved spatial and landscape planning (including updated landslide and flood hazard mapping) based on and in combination with natural hazard cadastres as well as an island-wide natural hazard monitoring, warning and alarming system will improve the preparedness of the Island’s society to hydro-geological hazards.

Roads

- In general, roads in Ischia are suffering from the lack of continuous condition monitoring and maintenance. It is recommended to prepare systematic maintenance plans annually, using modern Road Asset Management System (RAMS), with the latest condition data.
- Well maintained roads are generally more resistant to any climate hazards than roads having structural weaknesses and pavement defects (i.e. building expensive protections to the road may not be justifiable, if road itself is in poor condition.
- However, in many locations it is easy to justify adaptation against climate hazards, especially in the higher category roads. Specific adaptation activities are proposed, based on findings from a field mission and information provided by the Struttura Comissariale and local stakeholders.
- In few locations, roads have reduced capacity due to inadequate protection, leading to a reduction in road width.
- A more detailed climate risk assessment for roads is recommended, and a methodology for such assessment is provided. More detailed risk assessment, including field inventories, can provide baseline information for further climate change adaptation activities.

Buildings

- The most significant risks to buildings are related to landslides. Precise risk assessments are recommended to the identified risk areas to determine the precise local activities and to prioritize the recommended projects.
- The municipality of Ischia was identified as a flood risk area. A more precise flooding study is needed to assess the risks and precise adaptation activities in this area.
- Drought will induce wildfires that threatens densely populated areas. Vegetation control and enhanced supervision during the driest season are recommended to reduce the risks of fires spreading to urban areas.

- Increasing temperatures will affect buildings and occupants. Passive adaptation activities such as sunshades can be utilized to provide glare protection and shade to reduce indoor heating load, but it is very likely, that active cooling and ventilation systems (air conditioning) are also needed to provide immediate cooling in periods of extreme heat. The possible adaptation need should be assessed separately for each building but the Ischia hospital as a critical infrastructure is brought up as a potential adaptation priority.

Ports and coastal infrastructure

- Coastal submersion is expected to reach the levels of 1.26 meters above sea level during a 100-year return period storm surge in Ischia by 2050 and + 2.26 m when wave run-up is also considered (relevant for areas without coastal protection structures). Especially the Ischia port is threatened by already current water levels and even more in the future. Urgent measures are required in Ischia Porto to increase the height of the eastern side quays.
- Coastal erosion is affecting Ischia especially on the south-western, western and north-western coasts of the island. Some touristic sites, roads and even the island heliport are being threatened by coastal erosion and adaptation recommendations for the most severe locations have been provided.
- It is likely that several other coastal structures also need to be redesigned and improved to take into account the increasing water level. However, the inaccuracy of the digital elevation model did not allow this mapping within this assignment.

Water supply and wastewater

- Water supply plays a significant socioeconomic role for the island of Ischia, particularly essential for its tourism industry.
- Primarily reliant on mainland sources, a main part of the island’s water supply and sewerage infrastructure is at high risk to landslides.
- About 9,600 m of mixed sewer pipelines are at risk of clogging and overflow, with around 5,600 m highly vulnerable and 4,000 m at medium risk, significantly impacting Barano d’Ischia. Moreover, around 18,500 m of drinking water pipelines are at landslide risk, particularly in Serrara Fontana.
- Additionally, more than 30% of the drainage system, encompassing stormwater pipelines and mixed sewers, are considered to fall short in safeguarding settlements from floods.

Energy supply

- The analysis of the energy sector, although affected by the missing provision of detailed maps of the electricity distribution network and therefore limited to the publicly available information and to the surveys carried out by the project team, allowed to depict the main potential hazards to the energy infrastructure of the island. Conversely, a number of potential adaptation options have been identified.
- The risks of landslides, flooding, wildfires, sea level rise and those connected to higher air temperatures can have a highly negative impact on the electricity infrastructure, which has substations on the mainland (exposed to flooding, landslide, temperature and sea level rise) as well as overhead cables reaching all the municipalities across the island (with related exposure to damages from wildfires, flooding, landslide).
- It is important to highlight that most of the identified potential climate change risks are shared with the overall built environment where the electricity network lies. The infrastructure would in general benefit from the potential adaptation activities applicable at district level. However, energy-specific adaptation activities have been identified, like the underground cabling for the distribution network.
- As for the underground gas network, where present, it may be affected by a minimum level of risk related to landslides, wildfire and flooding.

Tourism

- Several of the touristic sites and resorts of Ischia have been identified vulnerable to rock falls, landslides, and coastal erosion. The poor condition of infrastructure in Ischia is also causing problems for tourism due to longer travel times, safety problems and water quality issues.
- Most of the recommended adaptation activities for different sectors also provide improvements from the point of view of tourism. Several adaptation activity recommendations have been also provided for touristic sites and resorts of Ischia.

Agriculture

- Grape production and wine quality might be reduced due to temperature increase and reduced water availability, especially as Ischia's viticulture is rain-fed. The use of heat and drought tolerant grape varieties, adopting effective viticultural techniques suitable to the local conditions, use of shade nets or sunscreen materials not impacting the landscape and designing vineyards in a way to reduce exposure to sun and extreme heat are agricultural practices that could contribute to climate change adaptation. Soil management techniques for higher yield and conserving moisture, like mulching, could also be further promoted.
- Drastic grape production reductions could be caused by diseases, such as flavescence dorée, due to higher humidity levels in the atmosphere during dry and warm periods. A continuous monitoring is recommended, as well as early warning systems developing seasonal forecasts to help vineyards' adaptation to climate change, for example through the VISCA (Vineyards´ Integrated Smart Climate Application) project.
- Soil erosion and damage to vineyards agriculture buildings and assets as well as to connecting roads can result from extreme precipitation events and precipitation induced landslides. Continuing vine cultivation in terraces as is already the case on the island is a good adaptation activity, as well as accessing early warning systems like the VISCA project mentioned above.

Forestry and nature-based solutions

- Managing Mediterranean forests according to a management plan helps to mitigate landslide risk in the andic soils of Ischia.
- Mountain cliff forest vegetation requires management to control landslide initiation.

Design recommendations for reconstruction

- For all future hydraulic design, an increase of 5-25% of design rainfall assumptions based on observed rainfall (IDF curves) is recommended to account for higher precipitation intensities under climate change.
- Coastal protection structures require more detailed studies for an updated design (metoceanic studies, wave propagation studies, morphodynamic studies, detailed design studies), to consider future sea level rise.
- For buildings, passive cooling measures are recommended to adapt to increasing temperatures. Active cooling systems, at least in critical infrastructure like hospitals, should be designed with consideration of temperature projections.

Major possible physical climate vulnerabilities that require further studies to be confirmed

Several possibly major vulnerabilities were detected during the study, but they could not be confirmed due to the base data unavailability and the uncertainties in the high-level approach taken for the CRVA of the island.

- Electricity substation next to the Ischia Porta is located at a relatively low level but with the current data available it cannot be confirmed if the site is at risk. The same applies also for the other buildings in the area south, southwest from the Ischia seaport.
- Electricity station (cable connection to mainland) near the Ischia hospital is located near a flood risk area but the current modelling exercise cannot confirm if the site is at risk.

- The eastern part of Ischia port area is vulnerable to submersion, but the current accuracy of the digital elevation model does not allow to assess if the urban area around the port (south, southwest, west) is also vulnerable. The area under suspicion also includes a large electricity substation.
- Separate studies are required to determine the required landslide and flood related adaptation activities for several risky areas in Ischia. These areas include mostly houses, hotels, roads and other infrastructure.

PART 2: Climate Change Adaptation Investment Plan

4 Cost benefit analysis of adaptation activities

4.1 Introduction

The multi-hazard challenges of Ischia call for an integrated multi-disciplinary analysis of risks, drivers, and opportunities. Within the limited timespan and resources available, a remarkable amount of data, information, and insights has been produced for this report. Before setting out to present the foundations and results of cost-benefit analyses (CBA) per type of infrastructure and sector it is important to discuss the applicability and degree of guidance of a CBA in this case.

The prime issue is the framing of the CBA. Is the CBA to be used to assess the cost-effectiveness of several collections of system or sector specific investments or is the purpose to adapt the physical and economic functioning of Ischia such that it enables a sustainable development trajectory for the island in a changing climate, while ensuring it keeps with certain coping ranges regarding natural hazards. The experienced risks of natural hazards on the island of Ischia are as much the result of overuse of local resources as of the severity of the hazards (Copernicus 2023; The Guardian 2022[54]), notably regarding safe and sustainable use of land and water resources. Under the current de-facto local conditions, the expected incremental private benefits from adding real estate tend to be accompanied by an increase of expected natural hazard induced cost to society. Under those circumstances there is a broadly shared consensus view among economists that in as far as those private benefits are accompanied by societal costs, a tax (or other measure) is recommendable such that the balance of extra private benefits and societal costs is the highest possible, while accounting for equity effects.

A diverse investment portfolio to improve the resilience of infrastructure and sectors against natural hazards will eventually only structurally reduce risks if sustainable use of land and water resources is systematically pursued. This means that in addition to protective measures, maintenance, monitoring and warning systems, which are mentioned in this report, an overarching plan and supporting policy is necessary to ensure sustainable use of land and water resources. This can be partly realized via regulation and inspection, as is referred to sometimes in this report, but probably also needs intervention via economic drivers, for example by revising the real estate tax into a multi-attribute system which rewards sustainability augmenting operations and penalizes sustainability reducing operations. Elaboration of these considerations on an integrated policy approach, however relevant, go beyond the remit of the current report.

4.1.1 Towards a multi-tiered CBA

For the several types of infrastructure and sectors long lists of adaptation activities have emerged. Some of these adaptation activities are more crucial in terms of impact reduction and urgency when considering the return times of the addressed hazards. Other proposed interventions have an adaptation aspect, but also address the need to bring erosion and landslide risk management up to date regardless of climate change, as for example in the case for some of the coastal erosion interventions. In this CBA it was not possible to distinguish adaptation driven elements from otherwise motivated elements (e.g. maintenance backlogs).

The prioritization is based on a tentative review of identified measures by infrastructure component and sector presented in the preceding sections 3.1 – 3.10. For various infrastructure components and sectors the most crucial and/or urgent measures were identified. These measure propositions have been brought together in one map (Figure 4-1i below).

For some of the measures shown on the map, additional scrutiny and more detailed review is necessary before a classification decision and a CBA can be conducted. Furthermore, for some of the listed measures it seems highly unlikely that significant benefits are created, as seems the case for propositions no.1 and

54 https://www.theguardian.com/world/2022/nov/28/calls-for-crackdown-on-construction-in-italy-after-ischia-disaster

2 (see figure 4.1 and table 4.1. Hence a second filtering was applied as shown in Table 4-1. Only the projects which have the indication YES are included in the CBA. For some generic measures, often related to risk modelling, no CBA could be conducted. These are listed in Table 4-2. These tools seem nevertheless indispensable for adequate planning and management of risk reduction efforts and do constitute more than 1% to 1.5% of the total cost.

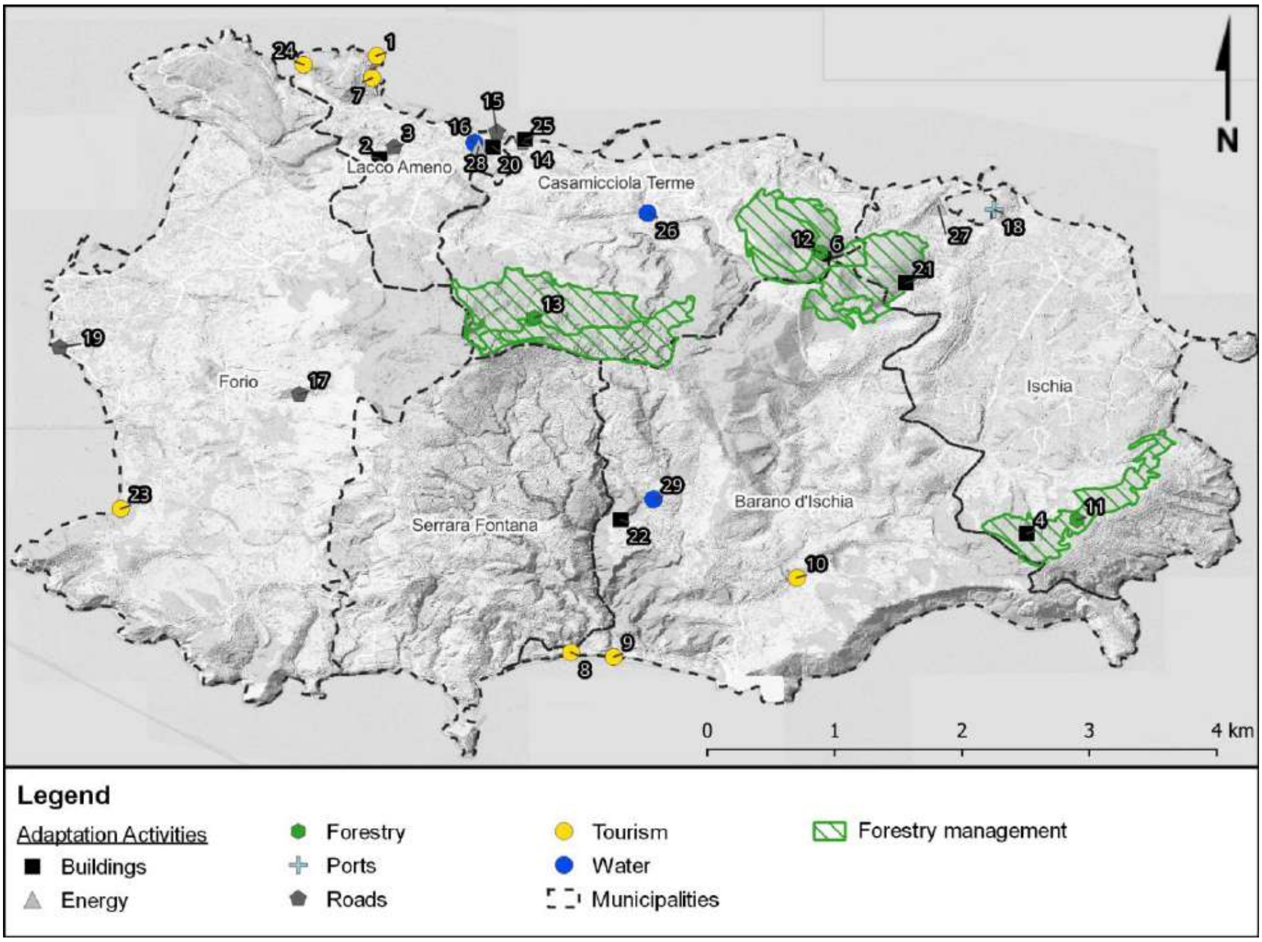


Figure 4-1. Combined hazard exposure and measure identification; investment objects numbered according to the list below

Table 4-1. Overview of proposed projects as part of CBA and indication of prioritization acceptance (YES/NO)

IN CBA?	ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Cost estimate [M€]	BCR	Comments
NO	1	Lacco Ameno	Tourism	Sea level	Completion of the safety and consolidation intervention on the eastern ridge of Montevico - northern ridge	2,00 M€		
NO	2	Lacco Ameno	Buildings	Landslide	Completion of the safety and consolidation work on the ridge behind the grandstand and the southern ridge of the municipal sports field	0,73 M€		

NO	3	Lacco Ameno	Roads	Landslide	Securing and consolidating the ridge overlooking via Cava Pannella	1,59 M€		
NO	4	Ischia	Buildings	Landslide	Various landslide and hydrology related works in the Monte Vezzi area. Cost estimation is based on the local data.	14,6 M€		Further studies are needed to determine exact adaptation activities
NO	5	Casamicciola Terme, Ischia, Barano d'Ischia	Common	Landslide	Various landslide and hydrology related works in the Cretaio area. Cost estimation is based on the approximate area cover compared to Vezzio investment estimation.	15 M€		Further studies are needed to determine exact adaptation activities
NO	6	Casamicciola Terme, Serrara Fontana, Forio	Common	Landslide	Various landslide and hydrology related works in the Forio area. Cost estimation is based on the approximate area cover compared to Vezzio investment estimation.	30 M€		Further studies are needed to determine exact adaptation activities
NO	7	Lacco Ameno	Tourism	Landslide	Safety and consolidation of the ridge overlooking Varulo beach	1,23 M€		
YES	8	Barano d'Ischia	Tourism	Landslide	Works to improve the safety of the Maronti beach ridges	4,47 M€	1,1	
YES	9	Barano d'Ischia	Tourism	Flooding	Extremely urgent works to make the ribs safe and restore the hydraulic functionality of the Alveo Cava Ponte/Nitrodi/Olmitello	6,08 M€	1,1	
YES	10	Barano d'Ischia (not urgent in water section)	Tourism	Flooding	Extremely urgent works to restore the hydraulic functionality of the Cava Rosato/Cavone Martoccio riverbed	1,60 M€	1,1	
YES	11	Ischia	Forestry	Landslide	Mont Vezzi forested area management	0,11 M€	2,0	
YES	12	Ischia, Barano d'Ischia	Forestry	Landslide	Cretao forested area management	0,14 M€	2,0	
YES	13	Casamicciola Terme, Barano d'Ischia	Forestry	Landslide	Casamicciola Terme Monte Epomeo forest management	0,41 M€	2,0	
YES	14	Casamicciola Terme	Roads	Landslide	Steel nets need to be replaced near the heliport, possible partially with retaining walls. Length 150m, height 15m. Hydraulic structures (drainage system) will be needed, if wall is chosen.	1 M€	3,4	
YES	15	Casamicciola Terme	Roads	Landslide	Steel nets need to be replaced, possible partially with retaining walls. Length 250m, height 10-15m. Hydraulic structures	1,5 M€	3,4	
YES	16	Casamicciola Terme	Water	Flooding	Drainage upgrading, mixed sewer into separate. Increased capacity for	1,00 M€	1,5	

					the storm water. Length at least 200m.			
YES	17	Forio	Roads	Landslide	Slope stability. Using Biotextile and steel nets in various location in the Forio mountain area.	0,50 M€	0,6	
YES	18	Ischia	Ports	Sea level	Raise of the quay level in Ischia Porto with a protective concrete wall along the edge of the actual quays on the restaurants section, with wooden deck on top.	3,00 M€	5,4	Pontoon quay
YES	19	Forio	Roads	Sea level	Stabilization of the cliff in Forio against coastal erosion with retaining wall coupled with the installation of natural rocks breakwater at the toe of the wall	15,0 M€	1,0	
YES	20	Casamicciola Terme	Buildings	Landslide	Several activities for the Ischia Hospital	6,50 M€	2,8	
YES	21	Ischia	Buildings	Wildfire	Vegetation control to create a buffer zone next to populated areas of Ischia	0,50 M€	15,5	
YES	22	Barano d'Ischia	Buildings	Wildfire	Vegetation control to create a buffer zone next to populated areas	0,50 M€	15,5	
YES	23	Forio	Tourism	Landslide	Poseidon hot spring resort site erosion protection	1,67 M€	4,5	
YES	24	Lacco Ameno	Tourism	Landslide	Negombo hot spring resort erosion protection	1,00 M€	7,5	
YES	25	Casamicciola Terme	Buildings	Sea level	Island heliport structures are crumbling (new info 30.11.2023). Coastal erosion protection as adaptation	5 M€	8,7	
YES	26	Casamicciola Terme	Water	Flooding	Redesign of a collector drain in Casamicciola Terme	0.43 M€	1,5	
NO	27	Ischia	Energy	Sea level	Possible Ischia electricity substation flood protection			Risk is not fully clear without further assessment
NO	28	Lacco Ameno	Energy	Flooding	Possible Lacco Ameno cable connection point flood protection			Risk is not fully clear without further assessment
YES	29	Barano d'Ischia	Water	Common	Combine existing water supply network to a circular network	0,31 M€	14,6	
YES	30	All	Water	Flooding	Enlarging the stormwater drainage system crossing areas prone to floods by 50 mm	11,9 M€	1,5	
YES	31	All	Water	Landslide	Rerouting drinking water pipelines from areas prone to landslides to areas with lower risk	3.78 M€	14,6	
YES	32	All	Water	Flooding	Connecting the two main drinking water network lines into one circular network	0.31 M€	14,6	

YES	33	All	Water	Landslide	Transforming mixed sewer system at high landslide risk into a separated sewer system	2.77 M€	**1,5**	
YES	34	All	Water	Landslide	Transforming mixed sewer system at medium landslide risk into a separated sewer system	1.45 M€	**1,5**	
NO	35	All	Water	Landslide	Transforming the mixed sewer system in areas with low or no landslide risks into a separated sewer system	5.53 M€		
YES	38	All	Common	Common	Natural Hazard Monitoring, Early Warning and Alarming system	2,8 M€	**4,2**	

Table 4-2. Common auxiliary efforts unfit for CBA

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Cost estimate [M€]
36	All	**Study**	Flood	Flood model	0,25 M€
37	All	**Study**	Landslide	Landslide assessment	0,25 M€
39	All	**Study**	Common	Digital elevation model	0,05 M€
40	All	**Study**	Sea level rise	Coastal model	0,2 M€
41	All	**Study**	Common	Natural Hazard Event Cadastre, Inventory and Documentation	0,3 M€
42	All	**Study**	Landslide	Feasibility studies for investments 4,5,6 (high risk landslide prone areas)	0,3 M€
43	All	**Study**	Common	Road inventory for condition and granular risk mapping. Should include the dimensions and traffic amounts of roads.	0,05 M€

Status of different sections within the CBA

The nature of this CBA is social cost benefit analysis, meaning that the net benefits for the Ischia island community as a whole are considered. However, for some adaptation activities such as for the energy sector and the Ischia port prevails a business model, where the costs are entirely covered by the revenues from the operations, incl. capital costs. On the other hand, there are projects, the modelling tools listed in Table 4-2, for which benefits cannot be quantified or at least not without major assessment efforts, extending well beyond the remit of this project.

1. Privately fundable investment efforts (port, energy)

For those projects a CBA can be conducted, but if it is done in the framework of a self-resourcing business model several assumptions may differ from what is usual in a social CBA. In a social CBA, there is the tendency to equate efficiency to minimal cost, whereas under market conditions efficient relates to best (long term) profit. If higher investments mean higher quality, revenues may increase just as well.

These considerations may be relevant for the investment in ports resilient to sea level rise, as well as in climate change resilient electricity distribution network. Given the significant number of travellers and port calls per year, a surcharge on ferry tickets and on port dues can be expected to cover the cost in a couple of years. Similarly, the protective investments in the electricity network can be captured from a small rise in the network charges (as part of the overall electricity price). On top of that there should be some leeway to co-fund more generic protective measures in locations where it is evidently beneficial for failure risk reduction of the electricity network. Eventually less failures in the electricity network means less repair and interruption cost, hence the investments most probably pay back for the power customers as well. All in all, this means the option could be considered to focus the CBA on investments which have a strong public goods character and hence cannot be recaptured by user charges, at least not to any significant extent.

2. Generic facilities without clearly attributable benefits (i.e. various models); initial prioritization

Facilities, for which it is hard to quantify benefits, may be better evaluated by means of multi-criteria analysis (MCA) rather than CBA. In the case of Ischia they are the activities listed in Table 4.2. For example, the evaluation of the acquisition of several risk assessment tools as listed in table 4.2, an MCA can be conducted through an expert elicitation process. In fact, the composition of the entire list of proposed adaptation activities and its initial prioritization would benefit from such an MCA process in order to obtain a consistent list of priority adaptation activities, which subsequently can be subject to a CBA.

3. Projects with a public goods or merit goods character and attributable benefits

Social CBA is in particular meant to assess investments in public goods and services, of which merit goods are a sub-category. In as far as the addressed effects on health and well-being, environment and safety can be addressed and quantified, there are several methods to attribute monetized values to such benefits, which often have the form of avoided costs. Most proposed projects fall in this category. Public goods are defined as goods that cannot be produced by the market for technical reasons or because it cannot be done profitably. Merit goods are defined as goods of which the use is lower than is optimal for society and the user. This is a fairly common feature for many safety measures for example.

The CBA conducted for this report is of necessity limited and indicative. Apart from the uncertainties regarding the costs and benefits of the infrastructure and sector specific packages (meaning related adaptation activities for a sector or area), it was not possible to carefully review synergistic effects across packages. More importantly, the conducted CBA remains close to the above-mentioned infrastructure / sector specific review rather than an overall integrated assessment aimed at the best result for the island as a whole.

Various stormwater and flood management measures in due course imply risk reduction for the road system and built-up areas, and in some cases may attenuate landslide risk (in terms of scale and impacts). Similarly soil and slope stabilization measures in the first place motivated for the road system reduces risks for the built-environment and the local sections of networks (drinking water pipes, sewers, power lines). Additionally, protection measures primarily motivated by building or tourism safety will provide risk reduction for other sectors as well.

4.2 General points of departure

To make investment packages comparable, both internally for their constituent parts and externally across packages for different infrastructures and sectors, the uniform project lifetime has to be agreed. From the point of view of accounting for effects of climate change, lifetimes of at least 40 to 50 years would be recommendable. However, such timespans increase the uncertainties of other dimensions. Furthermore, for most proposed investments a lifetime of approximately 25 years seems realistic. A part of the installations, contained in the adaptation activities, may be expected to have still significantly shorter lifetimes, necessitating reinvestment during the applied standardized project lifetime. Hence a project lifetime of 25 years is applied. For some elements, 12.5 years, 8.33 years, or other appropriate lifespans are applied. In addition, annual maintenance is applied for all elements, sometimes as composite outlay.

Key components and assumptions of the analysis are as follows:

- Project lifetime: 25 years
- Lifetime of components: 25, 12.5, and 8.33 years depending on the nature of the component
- Annual maintenance cost: usually around 1% of the investment sum
- Education and training (relevant for some of the investments): as annual cost, higher initially, recurring intermittently
- Value of statistical life (VoSL): ~3.6 mln.$ (Alberini (2007) in OECD 2012) which is converted into 3.5 million euro in this CBA; the GDP/capita in constant 2015 US dollars did not change much for Italy between 2007 and 2022 (World Bank on-line data); VoSL for injuries: € 45000 as occurrence weighed average of different injury levels (ISTAT / ACI 2022); for serious injuries (with long lasting impacts) ISTAT / ACI 2022 mentions € 450 000
- Expected number of fatalities: historical figures[55] indicate 4 to 5 every 4 to 5 years; fatality probability is indicated per project, if deemed relevant
- Expected number of seriously injured: historical figures indicate 9 to 11 every 4 to 5 years (see footnote); injury probability is indicated per project, if deemed relevant
- Smaller landslide and flooding events occur at a high frequency, annually or bi-annually (see section 2.4 of this report); larger scale events have an occurrence frequency of 5 to 7 years, but the frequency may increase up to every 4 to 5 years (section 2.4); these physical risks are however to be rated by investment location implying high uncertainty levels and fairly small figures at the level of specific locations of adaptation activities, i.e. applied annual occurrence probabilities are mostly between 1% ~ 3% annually, up to 10% in exceptional cases. An annual occurrence probability of 1% means the probability that the event occurs at least once in 25 years is about 22%. For a 3% annual occurrence probability the 25-year probability rises to 53%, and with a 5% annual occurrence probability the chances it occurs at least once in 25 years is 72%
- In order to represent the climate changed induced gradual increase of occurrence probabilities of landslide and (flash)flood related events, annual growth rates are added to the baseline occurrence probabilities (see also section 4.4.1)
- Discount rate: social discount rate of 4% as default level, with 3% or lower as alternatives in sensitivity analysis
- Value of (travel) time (VoT): 50% of median hourly wage rate (20 €). The average hourly wage in 2021 hovered around 15 €. Yet, tourists are mostly not from the lowest income deciles, whereas employers and (foreign) retired inhabitants may be expected to have effectively higher rates, hence a higher value has been applied.
- Socioeconomic development:
    - the resident population (~68000)[56] and the annual number of tourists (6 million overnight stays[57] and an estimated 150000 daytime visitors) is assumed constant over the entire 25-year period;
    - the gross regional income of the island population is 617 million euro (2020; ISTAT), whereas the regional product amounts to 455 million euro (2020; ISTAT). The difference is attributable to a large influx of domestic and foreign pensions. Tourism related economic activities are valued at 341 million euro (75% of the regional product), agriculture at about

55 Combined information from Iovino & Periello Zampelli (2007), Santo et al (2012) and fact finding of the study team.

56 According Energy Audit on Ischia (2015) there are 63740 Italian residents and 4000 foreign residents on the island

57 By combining information from https://www.wikiwand.com/en/Tourism_in_Italy with information from the local tourist organisation it gets clear the correct number is (approx.) 6 million overnight stays rather than 6 million tourists. 150000 day time visitors is a guestimate referring to the total number per year based on the ferry traffic, and includes also non-touristic visits.

45 million euro, and remaining private sector at about 41 million euro (guestimate) and the public sector at 27 million euro.
- the (inflation corrected) economic growth[58] of 1% per year is represented as equal growth figures for income and real estate prices (1% annually); in turn these assumptions affect the VoT and VoSL.

Landslides and non-coastal flooding are both closely related with extreme rainfall events, and indeed may both occur during the same extreme rainfall event. The aggregate amount of precipitation of all extreme rainfall events is not expected to grow that much in a changing climate (across different RCP levels, see chapter 2), but the growth is the strongest for highly extreme cases (over 80 mm/day). This is accounted for by assuming that rainfall induced floods and landslides cause at least fairly substantial water and mass movements. In some locations this may imply significant structural damage to buildings as well as fatality and injury risks, while in other location these effects are less substantial or absent, in which case loss of functionality and tourism deterrence are the main foci of risk reduction. Per case annual occurrence probabilities are assumed, based on the qualitative descriptions and urgency indications. These vary between 0.01 and 0.1 Furthermore, these annual probabilities can drift upward, with steps varying between 0.001 and 0.004, so as to represent effects of climate change depending on indications of deterioration from the hazard and case descriptions.

4.3 Summary results for the prioritized projects

The summary below provides results for the prioritized measures per infrastructure type or sector. The costs mostly concern the cost of realizing an adaptation activity, as well as monitoring and maintenance over the lifetime of these protective facilities. Benefits consist of (1) reduced physical damage and associated repair cost, (2) reduced costs of (temporary) limited functionality (of a home, hotel, transport infrastructure), (3) reduced or avoided deterrence effects to tourism, and (4) reduced numbers of casualties and fatalities.

The benefits of preventing casualties and fatalities are based on the estimated value of statistical life (VoSL) for Italy (Alberini 2007). VoSL does not mean a price for life as such, but reflects the apparent average realized willingness to pay for life saving protective measures in various sectors and/or regarding various hazards. The inclusion of VoSL (and related concepts) for investments with safety effects is a common practice in CBA. Similarly, a value for avoided injury is included as well, based on estimates of an ISTAT-ACI working Group (2022). Except for the 2022 events, the numbers of casualties and injuries have usually remained low (1 to 5 fatality and 4 to 40 injured per event). Such events have so far occurred every 4 to 5 years. Assumptions regarding possibly avoided casualties per project are often highly uncertain, whereas the VoSL of avoided casualties tends to affect the results appreciably.

Reduced costs of limited or disrupted access includes both avoided extra costs to households as well as avoided loss of business for tourism related firms. A part of the results includes upper and lower estimates. For investment costs, this is related to ranges indicated in the sectoral scans. For benefits, it relates to the uncertainty regarding the reduced number of casualties and fatalities. Also, the level of the discount rate affects the results significantly. 4% is here the default rate, but for some cases also the outcomes for 3% were explored, but eventually not shown in the presented results, as the largest uncertainties are at the benefit side (extent of avoided cost and avoided casualties). h.

It should be realized that the values indicated in the table represent both transaction-based benefits and monetized appraisals of welfare effects, such as VoSL and the value of travel time. Yet, monetized values may have less effect on the GDP of Ischia, at least in the short run.

58 Based on OECD DATA – Real GDP Long-term forecast – Italy (2023-2049), giving an annual growth rate of GDP of 1.08%. Assuming a constant population for Ischia, it translates into an income growth of 1%/year.

The indicators NPV and BCR stand for Net Present Value and Benefit-Cost Ratio respectively. The NPV is the balance of the sum of discounted benefits and discounted costs over the lifetime of the project (25 years). The BCR is obtained by dividing the sum of the (discounted) benefits by the sum of the (discounted) costs.

$$NPV\ (x) = \sum_{t=1}^{25} \frac{B_t - C_t}{(1+r)^t}$$

where Bt denotes benefits owing to project x occurring in year t, Ct denotes costs owing to project x occurring in year t, and r is the discount rate. Normally the NPV of project x should be larger than zero to be selected. However, due to budget constraints there may be competition among the projects with NPV > 0, in which case the NPV of project x should be larger than a predefined cut-off rate or at least be larger than various other considered projects in order to be chosen.

$$BCR(x) = \sum_{t=1}^{25} \frac{B_t}{(1+r)^t} \Bigg/ \sum_{t=1}^{25} \frac{C_t}{(1+r)^t}$$

The BCR should at least be larger than 1 to be selected. However, often a higher threshold is chosen to allow for uncertainty. The NPV is generally regarded as the superior indicator. On the other hand, the BCR allows for quick comparison of projects of different scales.

Table 4-3. Summary of CBA results per group of adaptation activities

Activity no.	Measures *	Investment in mln. €	Operational cost (25 year) mln.€	Benefits default (25 year) mln.€	BCR NPV (mln.€)
38	Multi-Hazard Early Warning & Observation System	3.8	3.2	16.4 ~ 29.6	BCR 2.3 ~ 4.2 NPV 9.44 ~22.61
11 12 13	Forest management / NbS	0.66	0.125	reduces residual risks of other measures / sustainability benefits (BCR >2)	
 29 32 16 26 30 31 33 34	Water management - Barano d'Ischia – interconnections - Casamicciola (2x) - All island rerouting and/or separating sewer & stormwater networks (4x)	21.95 0.62 1.43 19.9	5.48 0.155 0.357 4.975	48.4 10.5 2.6 35.8	 BCR:14.6 NPV: 9.8 BCR: 1.5 NPV: 0.9 BCR: 1.5 NPV:12.4
18	Port pontoon quay	3.0	0.75	20.2	BCR: 5.4 NPV:16.5
 14 15 17 19	Roads Casamicciola Forio cliff Forio inland	 2.5 10~15 0.5	 0.625 2.5 ~ 3.75 0.12	 9.96 11.55 0.38	 BCR: 3.4 NPV: 7.0 BCR 0.66 ~ 0.98; NPV -6.1 ~ -0.2 BCR: 0.6 NPV: -0.24;
 20 25 21 22	Buildings hospital heliport wildfire risk control in Ischia and Barano d'Ischia	 3.2 ~ 6.5 5.0 0.5 + 0.5	 0.8 ~ 1.6 1.25 0.250	 21.6 54.7 9.1	 BCR: 2.8 ~ 5.6; NPV: 13.6 ~ 17.5 BCR: 8.7 NPV: 48.4 BCR:15.5 NPV: 8.5
  10 9 8 23 24	Tourism Cava Rosato area Alveo Cava Maronti Beach# Poseidon Resort Negombo Resort§	 1.6 6.08 4.47 1.67 1.0	 0.4 1.52 1.18 0.42 0.25	 * Included in next. 13.9 8.8 8.8	 BCR: 1.05 NPV 0.7 BCR: 4.5 NPV 6.8 BCR: 7.5 NPV 7.6

expert suggestion	Vineyards – Adaptation pilots (4 years)	~0.1	~0.3	The benefits are created due to earlier uptake of adaptation activities; 1% less production loss equals 0.45 mln. € rescued income per year; the adaptation promotion can be expected to enable several million € of rescued value added

As a first overall impression many components seem to produce sufficient benefits to justify the investment and operational costs. Exceptions or at least yet not evident cases are a tourism related twin project at the southern coast (no.8+9), as well as two, quite different, road projects in Forio (no.17 and 19). The coastal road stretch on a cliff in Forio may only just pay off. However, in this case only the traffic related benefits are included, whereas the investment may also contribute to the safeguarding of a few buildings.

Even though results are shown by infrastructure type or sector it should be realized that there is significant interaction and synergy between the measures within and between different areas of the island of Ischia. Such effects could be accounted for only to a limited extent. From the point of view of proper use of CBA with the purpose of identifying the correctly sized budget and associated list of measures, it would be highly recommendable to better reflect these interactions in the analysis and revise the prioritized list of measures accordingly. Such list revision with respect to interaction effects could be conducted in the form of a group decision exercise applying MCA methods.

4.4 More detailed descriptions of the assessments per sector

4.4.1 Introduction

The generalized approach is to calculate the flows of costs and benefits over a 25-year period per project. Costs are composed of investment costs, all done in year 1, and operational costs, assumed to be an annual flow at a rate of 1% of the investment cost. Benefits accrue by avoiding different types of costs (losses) that would occur in the absence of the project. The annual flow of benefits represents expected values, with fairly high uncertainties and inter-annual variability.

The benefit types are: (1) reduced physical damage and associated repair cost, (2) reduced costs of (temporary) limited functionality (of a home, hotel, transport infrastructure), (3) reduced or avoided deterrence effects to tourism, and (4) reduced numbers of casualties and fatalities.

The entire approach can be formalized in the following equations:

$$B_t(i_x) = (1+g)^t . \frac{1}{(1+r)^t} . P_t\left(H_{j,x}\right) . ASC_x(i)$$

where g is the annual growth rate of income and r the social discount rate; $P_t(H_x)$ denotes the probability occurrence of hazard j for project x, and ASC the avoided structural damage cost for project x

$$B_t(i_x) = (1+g)^t . \frac{1}{(1+r)^t} . P_t(H_x) . AFC_x(i)$$

where AFC refers to the avoided cost of function loss for actors addressed by project x

$$B_t(i_x) = (1+g)^t . \frac{1}{(1+r)^t} . P_t(H_x) . ADC_x(i)$$

where ADC refers to the avoided cost of deterring tourists addressed by project x

$$B_t(i_x) = (1+g)^t . \frac{1}{(1+r)^t} . P_t(H_x) . ACC_x(i)$$

where AFC refers to the avoided cost of casualties (fatalities and injured) addressed by project x

$P_t(H_x) = P_0(H_x) + \Delta_{t,x} P_x(H_x)$

ASC can refer to repair costs of buildings and road sections, as well as to clearing costs of buildings, built-up areas, and roads, being a single figure or a typical unit cost times the number of units expected to be affected (homes, stretches of roads, etc.). Also, relocation of buildings or newly built substitutes belong to this group.

AFC refers the losses caused by temporary non-availability or non-accessibility, such as the estimated number of days of non-access times the average daily turnover of affected restaurants. Costs of temporary non-access to homes is represented by costs of alternative lodging and by costs of special delivery service for those stuck at home. It should be noted that decrease of turnover of tourism related services in one location will be partly compensated by more turnover elsewhere on the island. This effect is tentatively accounted for. Such compensation is hardly possible between mid-July and early September when the tourist services are working at or near their full capacity.

ADC denotes the avoided cost of deterrence of tourists coming to the island or at least to the area where project x is located. Very large extreme events can cause short spells of large reductions for the entire island, but mostly reductions will be more localized, meaning that at island level tourist expenditures diminish only by a few percent in the same or next year in most cases. The part of the GDP attributed to tourist services amounts to about 341 million euro. This means that even small percentual reductions in the number of overnights stays may entail many millions of income loss for the island. It should be noted that a decrease of tourism at Ischia may be partly compensated by increase in tourism elsewhere in Italy.

ACC are the avoided cost of casualties, being fatalities or injured. Landslides and floods can cause fatalities and injuries. In addition, limitations in the functioning of the hospital and/or the heliport may cause that injuries or illness become fatal in some cases or turn into injuries with more serious and lasting impacts, implying that the cost per injury rise significantly, e.g. tenfold the average of € 45000.

4.4.2 Multi-Hazard Early Warning System

This consists of an array of measures involving distributed in-situ observation capacity of soil and hydrological conditions and slope stability, a centralized data collection and processing system, analytical tools supporting warning creation, automated warning system. Several components of this system will have to be replaced several times during the 25 years project period. Also, regular upgrading and maintenance of the system and education and training of the staff has to be accounted for. For these reasons operational costs over the lifetime of the project are expected to amount to almost as much as the investment costs. Yet, it is worth it, as only a reliable Early Warning System will effectively save lives. The expected reduction in casualties and fatalities implies a significant positive NPV. Since the BCR and NPV are so strongly positive a sensitivity analysis does not affect the eventual judgement that this is a recommendable investment object.

In this case the estimation of the benefits is purely based on avoided fatalities and (heavy) injuries. If over a 25-year period, the EWS avoids 1 fatality in 5 years and 3 heavy injuries in 5 years the NPV of the benefits amount to 16.4 million euro. If the effectiveness would be 2 fatalities less per 5 years and 4 heavy injuries less per 5 years, the NPV of the benefits rises to 29.6 million euro. The estimation accounts for a 1% annual growth rate of income (and hence of VoSL) and a 4% discount rate (see §4.3 and §4.4.1 for explanations).

4.4.3 Forest management and water management

In the nature areas, mostly situated in the higher elevation areas of the island, the root systems of larger trees often do not help to stabilise soils on slopes. Hence the growth needs to be managed to achieve more dominance of shrubs, plants and small trees. This measure entails a larger effort in the first year(s), followed by annual maintenance. From experiences elsewhere and literature, it can be inferred that this measure will be effective regarding better retention of storm water, while making the managed areas and the immediate surroundings clearly less prone to landslides. The adaptation activity is specified for somewhat larger areas, which means that contributions to risk reduction of locations served by other projects cannot be quantified. Hence a specific cost-benefit analysis cannot be conducted. Considering the moderate costs it is highly likely that this measure pays off.

Water projects are decomposed in three subgroups, being:

(1) integration of drinking water networks to improve water supply resilience after landslides and floods (projects 29, 32)
(2) localized drainage solutions in Casamicciola Terme (projects 16, 26)
(3) a collection of measures entailing separation of storm water and sewer networks and rerouting of drinking water pipelines in many areas of the island. Benefits and costs were evaluated per grouping. (projects 30, 31, 33, 34)

For the third grouping, which encompasses many locations on the island, the occurrence probability is set higher (0.1 in year 1). From historical records and the risk analysis in the preceding chapter it can inferred that landslides and floods are the most risky events for the island, with on average more serious events once in every five years, involving significant physical damage and various casualties. To some extent casualties can be prevented thanks to the early warning system, but a residual risk will remain if no physical improvements are implemented in the water system. All water management projects seem to achieve positive net present values of the balance of costs and benefits, even though one of the Casamicciola Terme and one of the general water management projects may in fact not pass the NPV test.

The drinking water integration projects reach high scores, in particular, because it is assumed that significant limitations in drinking water availability will deter tourists more effectively either just through the media and/or because local authorities seek to put a temporary limit on the maximum number of people simultaneously residing on the island.

Table 4-4. Key data of included water management projects.

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Lat	Lon	inv.cost	OPEX
29	Barano d'Ischia	Water	Common	Combine existing water supply network to a circular network	40.71663884	13.91076533	310 000 €	77 500 €
32	All	Water	Flooding	Connecting the two main drinking water network lines into one circular network			310 000 €	77 500 €
16	Casamicciola Terme	Water (earlier roads)	Flooding	Drainage upgrading, mixed sewer into separate. Increased capacity for the storm water. Length at least 200m.	40.7506252	13.894145471	1 000 000 €	250 000 €
26	Casamicciola Terme	Water	Flooding	Redesign of a collector drain in Casamicciola Terme	40.74393352	13.910253859	430 000 €	107 500 €
30	All	Water	Flooding	Enlarging the stormwater drainage system crossing areas prone to floods by 50 mm			11 900 000 €	2 975 000 €
31	All	Water	Landslide	Rerouting drinking water pipelines from areas prone to landslides to areas with lower risk			3 780 000 €	945 000 €
33	All	Water	Landslide	Transforming mixed sewer system at high landslide risk into a separated sewer system			2 770 000 €	692 500 €
34	All	Water	Landslide	Transforming mixed sewer system at medium landslide risk into a separated sewer system			1 450 000 €	362 500 €

Table 4-5. Key assumptions per project specific CBA for water management

					buiding damage cost	direct cost of functionality loss	tourism deterrence effect	VoSL* 3.5 mln N fatality	VoSL* 0.045 mln N injured
project	**income growth**	**discount rate**	**specific event probability (SEP)**	**annual change in SEP**	**clearing cost; structural damage**	**cost of temporary substitutes**	341 000 000 €	3 500 000 €	45 000 €
29, 32	1	4	0,01	0,002		2 400 000 €	5,0 %	0	0
16, 26	1	4	0,01	0,002	500 000 €		0,5 %	0	0
31, 31, 33, 34	1	4	0,1	0,002	1 400 000 €	140000	3,0 %	1	2

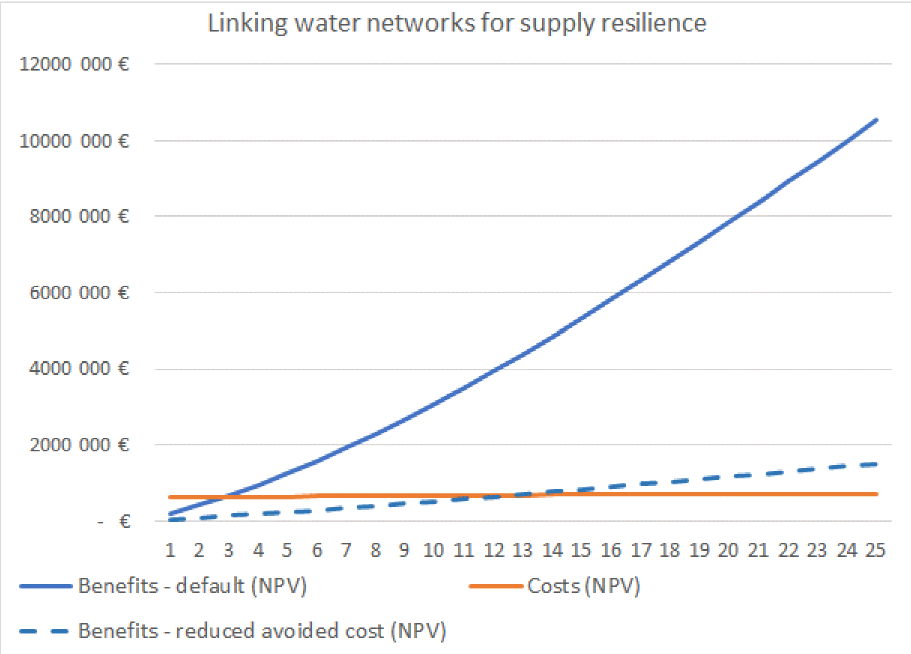


Figure 4-2. Benefits and costs over the lifetime for projects 29 and 32

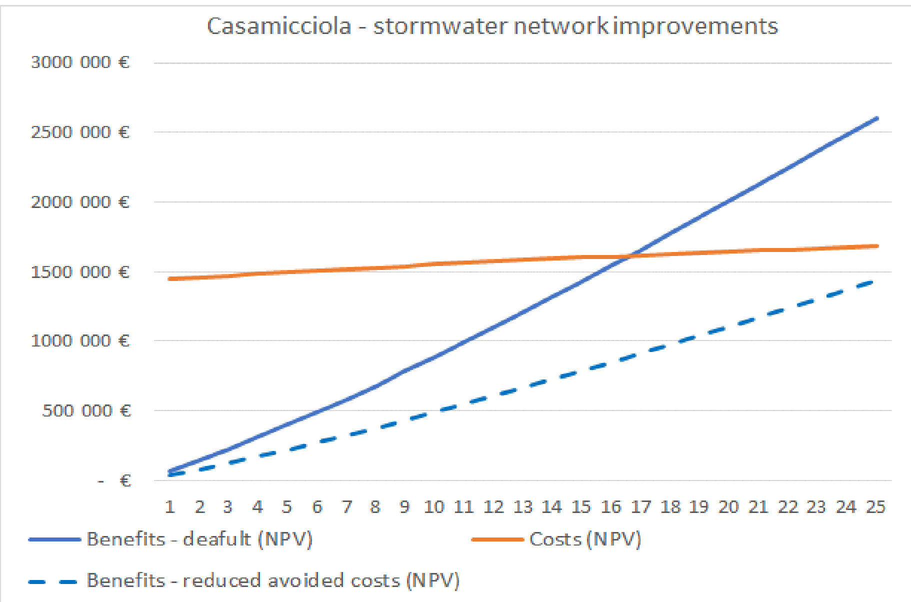


Figure 4-3. Benefits and costs over the lifetime for projects 16 and 26

Figures 4.2 – 4.4 show the cumulating costs and benefits of the projects over the 25 years lifetime of the projects. In the alternative valuation of the benefits named reduced avoided cost background assumptions per avoided cost category (see §4.4.1 and table 4.5) are on purpose lowered significantly (reduced by 50% or 2/3). There is usually not enough information to produce project-specific, properly underpinned, sensitivity intervals for key factors.

If the curve for the benefits using reduced avoided costs intersects the cost curve, it indicates that even with significantly moderated assumptions on avoidable cost the project is still expected to generate a net social benefit.

If the curve for the benefits using reduced avoided costs does not intersect the cost curve, but gets quite close to it, while the default benefit curve rises well beyond the cost curve, it indicates that there is still a good chance on positive social net benefit. Further analysis can clarify these chances better as well as identify options to reduce risks for net social losses.

Figures 4.3 and 4.4 are examples of such situations. The above explanations do also apply to similar graphs shown for the other projects.

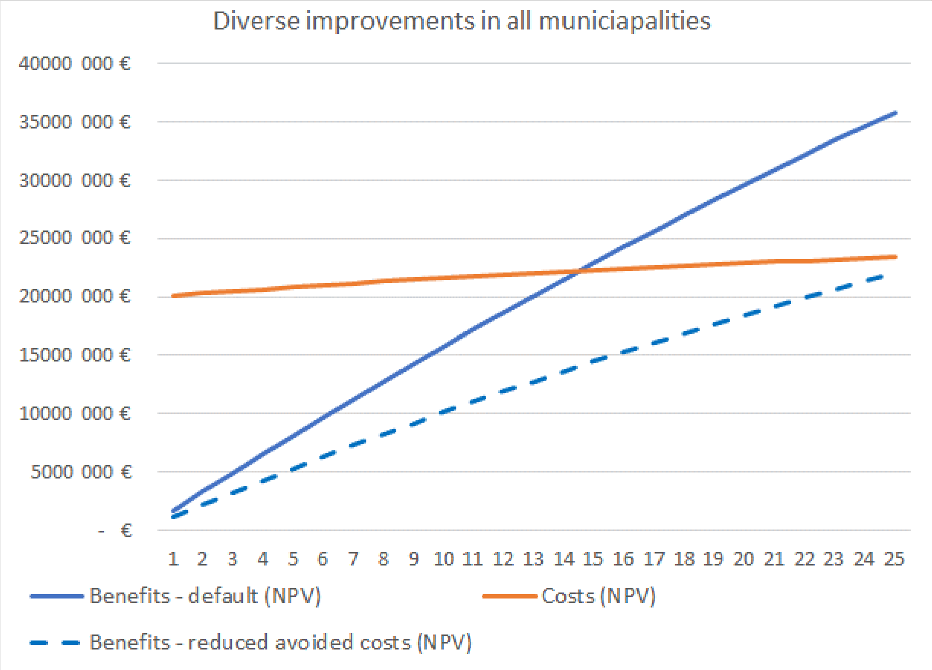


Figure 4-4. Benefits and costs over the lifetime for projects 30, 31, 33, and 34

4.4.4 Climate resilient port in Ischia

The effects of flooding of the port of Ischia are assessed on the basis of the expected number of days that disembarking from the ferries is not feasible due to high water. This is currently about 4 days per year, while it may rise to about 10 days during the next 25 years. By assuming that daily arrivals are halved and applying typical daily expenditures per visitor the value of lost days can be calculated. Obviously, tourists already on the island may have to stay longer, but on balance we expect it negatively affects the number of overnight stays on the island as tourists and authorities are expected to anticipate on the basis of weather forecasts. Furthermore, it means that the ferries to Ischia have less income, even though this may partly be compensated by more trips to other islands. The avoidance of ferry ticket sales losses and of tourist expenditure reductions explain most of the benefits. The benefit-cost ratio (5.39) is high for this case. So, it seems that making the port climate change resilient is an economically valid measure, even if benefits turn out to be significantly smaller than is assumed in the base case (default assumptions) the project will produce net social benefits. The investment and operation costs can probably be resourced from an extra levy on the ferry tickets.

Table 4-6. New kay (project 18) - avoided costs per component and NPV of the project

building damage cost	direct cost of functionality loss	tourism deterrence effect	VoSL* 3.5 mln / fatality 0.045 mln /	**Net NPV (B-C) mln. €**
clearing cost or area and restaurants	losses for ferriy companies; extra cost for ad-hoc solutions;	limited arrival capacity + deterrence effect	not relevant	**16 480 000 €**
686 433 €	6 167 796 €	13 373 442 €		**5,394**

Table 4-7. Key facts for project 18

ID	Municipality	Main Hazard	Adaptation activity description	inv.cost	OPEX
18	Ischia	Sea level	Raise of the quay level in Ischia Porto with a protective concrete wall along the edge of the actual quays on the restaurants section, with wooden deck on top.	3,00	0,75

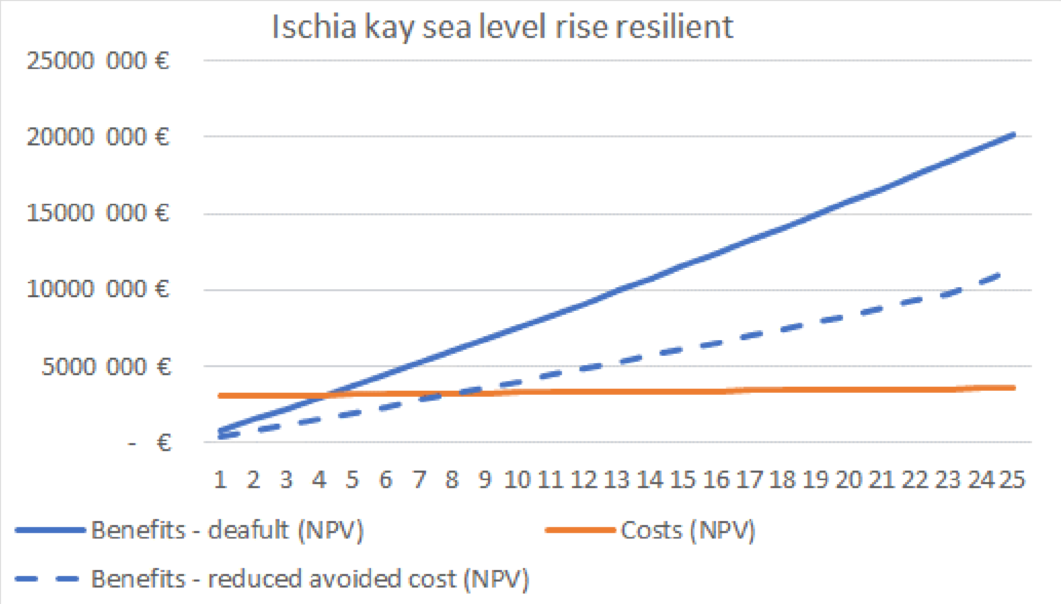


Figure 4-5. Benefits and costs over the lifetime of project 18

Ferry service background data

- Ferry tariff: 16 € per trip
- Round trips of tourists: 1.6 million producing 51.2 million euro ferry revenue
- Trips of residents (10x per year): producing 6.7 million euro ferry revenue
- Average ferry revenue per day: 158685 €
- Estimated maximum ferry revenue per day: 238027 €
- Estimated minimum ferry revenue per day: 95211 €

The lower end daily revenue is used in the calculations as the flooding risks are typically outside the holidays season. It is assumed that half of the daily arrivals can still be handled using other port facilities on the island.

4.4.5 Road projects

Three of the four road projects relate to risk reduction of obstructions and damage to the main circular road on the island. Two of those locations (no.14 and 15) are near to each other on the north side of the island, in proximity to the heliport. Landslide induced obstructions on those road sections hampers the accessibility of the heliport. Furthermore, it would create significant trip delays potentially lasting several weeks for many residents and visitors to the island. It may also create more overcrowded backstreets as smaller vehicles will seek alternative routes. The third location (no.19) is on the west coast in Forio, where is there is a risk for substantial direct damage due to collapse of coastal support, and thereby also of a road section. The reparation of that situation after collapse would take a long time, possibly up to a year. In this case there is alternative routing available, but collapse would still cause traffic delays.

The fourth project (no.17) concerns the only access road to a mountainous area with mixed residential and agricultural functions. Obstruction of the road can be expected to necessitate temporary alternative residences and operational restrictions and losses for the vineyards in the area.

Projects 14 and 15 seem solidly beneficial. The results for project 19 indicate that cost efficiency is very important to provide more certainty that the project is overall beneficial. Project 17 seems even more critical. Possibly, the actors involved will have to accept fairly simple measures to keep it socioeconomically sensible to do; implying that the location is economically less attractive due to the risks. Conversely, there may be avoided cost that could not be accounted for in this quick scan study.

Table 4-8. Key data of included road adaptation activities.

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Lat	Lon	inv. Cost	OPEX
14	Casamicciola Terme	Roads	Landslide	Steel nets need to be replaced near the heliport, possible partially with retaining walls. Length 150m, height 15m. Hydraulic structures (drainage system) will be needed, if wall is chosen.	40.75069102092889	13.898638733077789	1 000 000 €	250 000 €
15	Casamicciola Terme	Roads	Landslide	Steel nets need to be replaced, possible partially with retaining walls. Length 250m, height 10-15m. Hydraulic structures	40.75167852987871	13.896214016129749	1 500 000 €	375 000 €
17	Forio	Roads	Landslide	Slope stability. Using Biotextile and steel nets in various location in the Forio mountain area. Only access to various farms, lodges and houses	40.7266377	13.8778768	500 000 €	125 000 €
19	Forio	Roads	Sea level	Stabilization of the cliff in Forio against coastal erosion with retaining wall coupled with the installation of natural rocks breakwater at the toe of the wall	40.7311291	13.8555942	15 000 000 €	3 750 000 €

Table 4-9. Key assumptions per project specific CBA for road protection

				structural damage cost	direct cost of functionality loss	tourism deterrence effect	VoSL* 3.5 mln N fatality	VoSL* 0.045 mln N injured
income growth	discount rate	specific event probability (SEP)	annual change in SEP	road clearing and repair	cost of detours and congestion	341 000 000 €	3 500 000 €	45 000 €
1	4	0,13	0,001	2 500 000 €	2 600 000 €	0,25 %	0	0
1	4	0,13	0,001	2 500 000 €		0,25 %	0	0
1	4	0,05	0,001	220 000 €	135 000 €	0,00 %	0	0
1	4	0,05	0,001	1 050 000 €	2 600 000 €	2,00 %	0,1	1

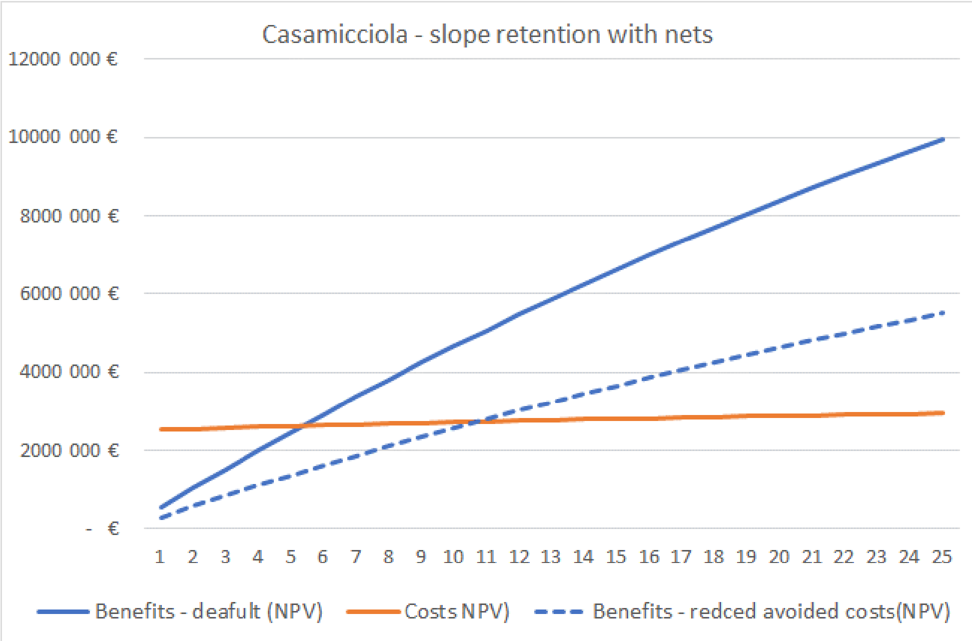


Figure 4-6. Benefits and costs over the lifetime of project 14 and 15

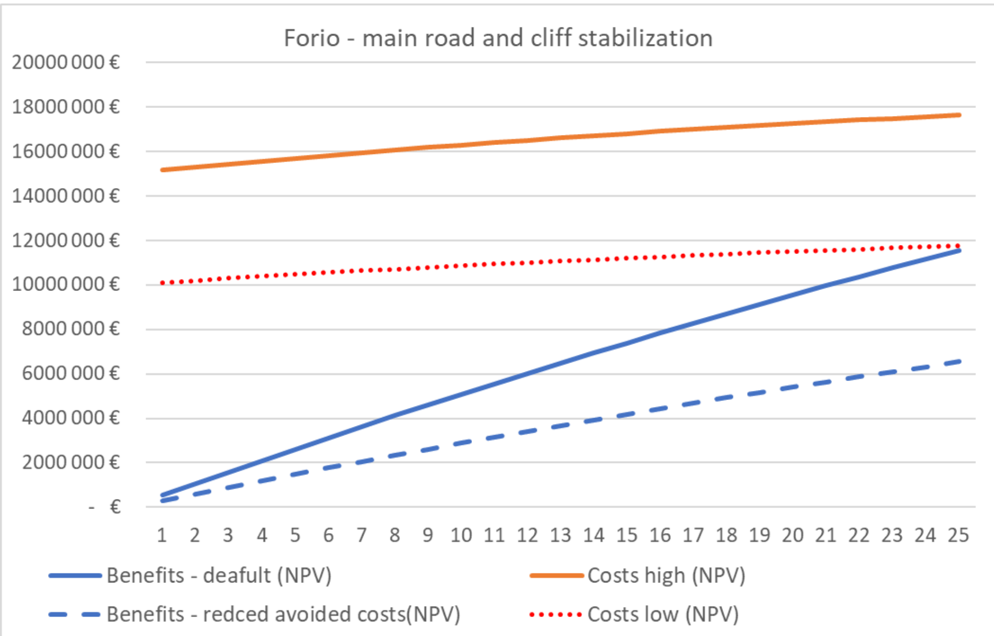


Figure 4-7. Benefits and costs over the lifetime of project 19

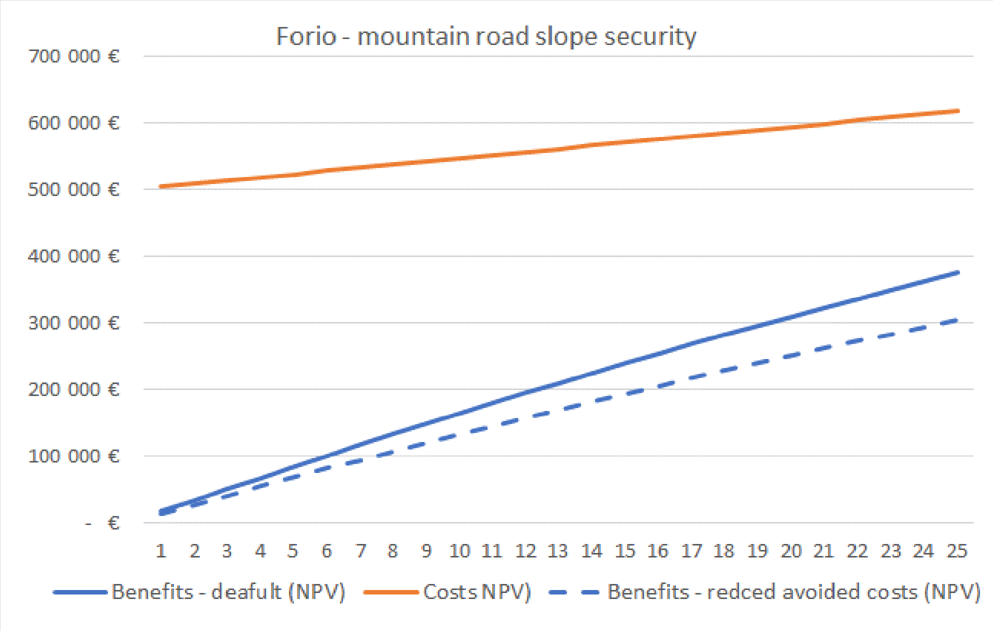


Figure 4-8. Benefits and costs over the lifetime of project 17

Detailed input data and calculation:

	length in km	% without redundancy	construction cost/km	new asphalt cost/km
main roads	30.5	50%	5.00 mln.€	2.00 mln.€
secondary roads	163.7	-	1.75 mln.€	1.00 mln.€
tertiary roads	148.6	-	0.88 mln.€	0.50 mln.€

	number in 2011
Population	68400*
registered number of passenger cars	36178
registered number of vans and trucks	19219
registered number of motor cycles and scooters	6823
estimated number of visiting cars / day	~300 (winter) – ~2000 (summer)

- Detour assumptions and calculations
- Assumed average wage rate: 20 € / hour (residents and tourists); 1% annual real growth rate
- Vehicle km cost: 0.60 € (same rate applied to cars, vans and trucks)

Note: The road package as such is not expected to save lives or injuries. These effects are contained in other measures (notably early warning systems).

4.4.6 Buildings projects

The crucial role of the heliport and the hospital in reducing mortality and morbidity risks, implies that even just temporary limitations on the functionality of these facilities creates high social cost. Especially, the availability of the heliport is essential to save lives, both of residents and tourists. Even if the potential benefits from casualty reduction and deterrence of tourists are halved or reduced even more, the net benefits remain substantial. The potential number of casualties is based on information about the frequency of helicopter flights, besides flights for wealthy visitors.

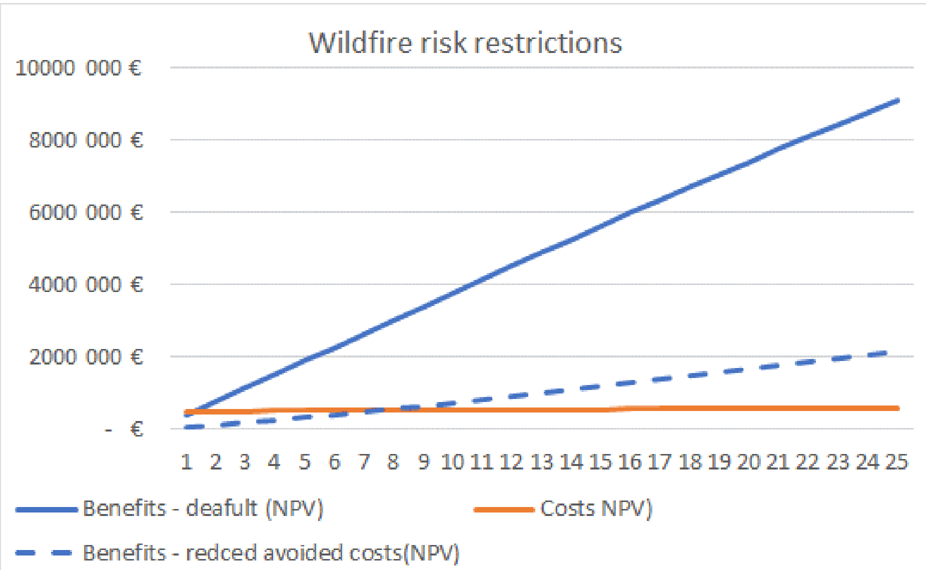
In the adaptation activities for the hospital, not necessarily all proposed measures are carried out, inter alia because most of the hospital buildings do not have a very long remaining lifetime. Therefore, there is a high and low level of investment cost distinguished (3.2 vs. 6.5 million euro) for this adaptation activity. Operational costs differ accordingly (1% of investment cost annually). It was not possible to assess to what extent avoided costs will diminish, if not all measures are carried out.

Table 4-10 Key data of included building protection projects

					buiding damage cost	direct cost of functionality loss	tourism deterrence effect	VoSL* 3.5 mln N fatality	VoSL* 0.045 mln N injured
ID	**income growth**	**discount rate**	**specific event probability (SEP)**	**annual change in SEP**		**cost of temporary substitutes**	341 000 000 €	3 500 000 €	45 000 €
20	1	4	0,01	0,002	500 000 €	600000	10 %	1	12
25	1	4	0,01	0,004		350000	10 %	6	24
21	1	4	0,03	0,001	1 600 000 €	140000	3 %	0	20
22	1	4	0,03	0,001					

Table 4-11. Key assumptions per project specific CBA for building protection

ID	**Municipality**	**Main sector**	**Main Hazard**	**Adaptation activity description**	**Lat**	**Lon**	**inv.cost min**	**OPEX min**	**inv. Cost max**	**OPEX max**
20	Casamicciol a Terme	Buildings	Landslide	Several activities for the Ischia Hospital	40.7502345	13.8958620	3,20	0,8	6,50	1,6
25	Casamicciol a Terme	Buildings	Sea level	Island heliport structures are crumbling (new info 30.11.2023). Coastal erosion protection as adaptation	40.7509654	13.8988124 2	5,00	1,25	5,00	1,25
21	Ischia	Buildings	Wildfire	Vegetation control to create a buffer zone next to populated areas of Ischia	40.7372875	13.9342380	0,50	0,125	0,50	0,125
22	Barano d'Ischia	Buildings	Wildfire	Vegetation control to create a buffer zone next to populated areas	40.7147082	13.9077062 18	0,50	0,125	0,50	0,125



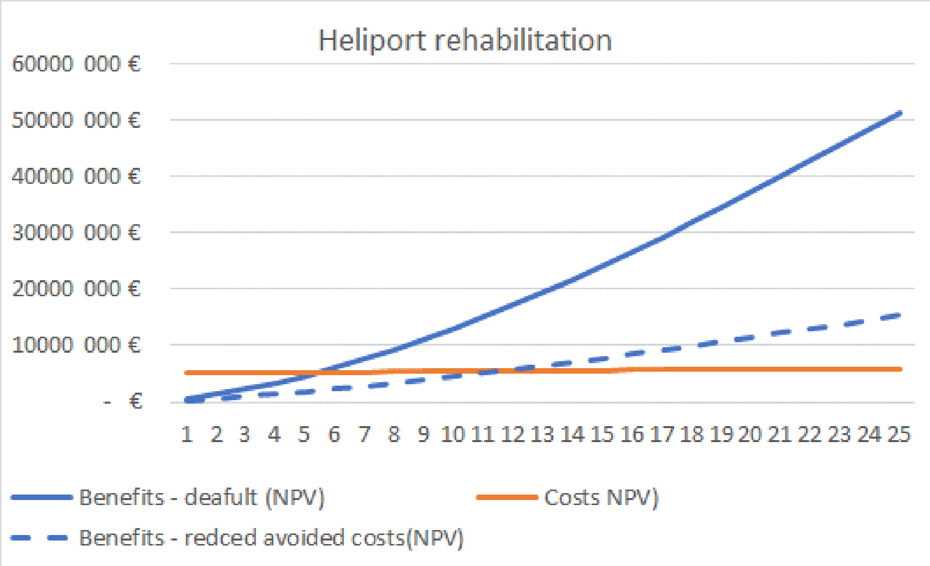


Figure 4-10. Benefits and costs over the lifetime of project 25

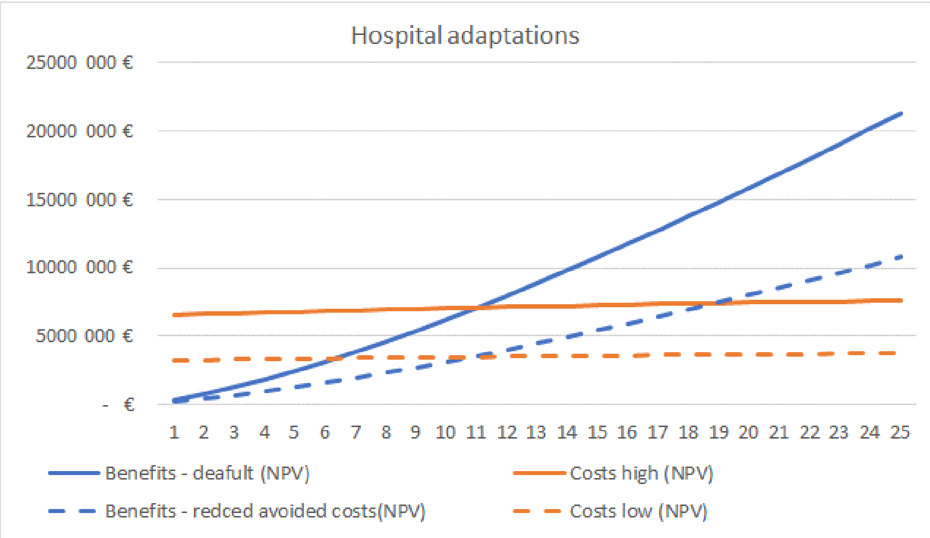


Figure 4-11. Benefits and costs over the lifetime of project 20

4.4.7 Tourism related projects

The investment projects for tourist locations have all to do with significant attractions or seaside hotel clusters all threatened by either landslides and rockfall or floods which possibly entail landslides as well. Project 10 could not be assessed owing to lack of information on impacts. Projects 8 and 9 are closely interrelated in terms of impacts and probably also occurrence (e.g. in relation to extreme rainfall). Projects 23 and 24 are very similar, concerning protection against rockfall and slope stability of coastal spa resorts surrounded by steep slopes and cliffs.

Both spa resorts attract quite large numbers of visitors, of whom many not only pay an entrance fee, but also use wellness services and restaurants or bars. Hence temporary closure amounts to significant losses of turnover, which will be only partly compensated by substitute tourist consumption. Due to the popularity of the spas the hazards may have also a relatively significant deterrence effect on tourism. Overall, the protection of these resorts seems to have a solid expectation on positive net social benefits.

The impact range for beach area and hotels to be protected through projects 8 and 9 is large, meaning that impacts could be dire with significant economic consequences, but threats may turn out to be less serious, causing significant repair cost and revenue losses due to temporary closure, but limited losses related to casualties and deterrence effects on tourism in general. This makes the outcome of the CBA for this (twin) project highly uncertain. In practice it means that it would be beneficial to assess carefully what needs to be done and how that can be done cost-efficiently.

Table 4-12. Key data of included tourist attraction protection projects

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Lat	Lon	inv.cost	OPEX
10	Barano d'Ischia (not urgent in water section)	Tourism	Flooding	Extremely urgent works to restore the hydraulic functionality of the Cava Rosato/Cavone Martoccio riverbed	40.709154	13.924109	1,60 M€	0,400
9	Barano d'Ischia	Tourism	Flooding	Extremely urgent works to make the ribs safe and restore the hydraulic functionality of the Alveo Cava Ponte/Nitrodi/Olmitello	40.701605	13.907080	6,08 M€	1,520
8	Barano d'Ischia	Tourism	Landslide	Works to improve the safety of the Maronti beach ridges	40.702045	13.903111	4,47 M€	1,118
23	Forio	Tourism	Landslide	Poseidon hot spring resort site erosion protection	40.7157454	13.86128035	1,67 M€	0,418
24	Lacco Ameno	Tourism	Landslide	Negombo hot spring resort erosion protection	40.7581041	13.8782674	1,00 M€	0,250

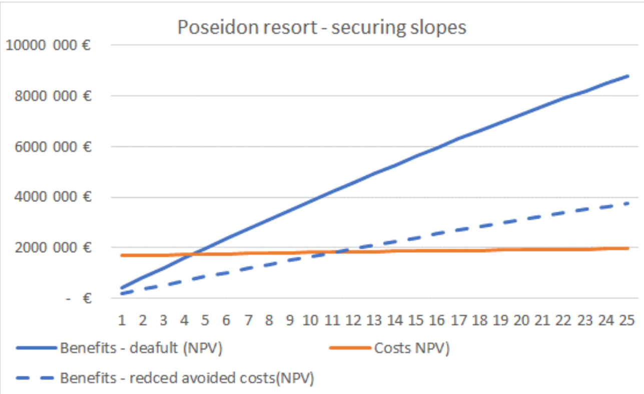


Figure 4-13. Benefits and costs over the lifetime of project 23

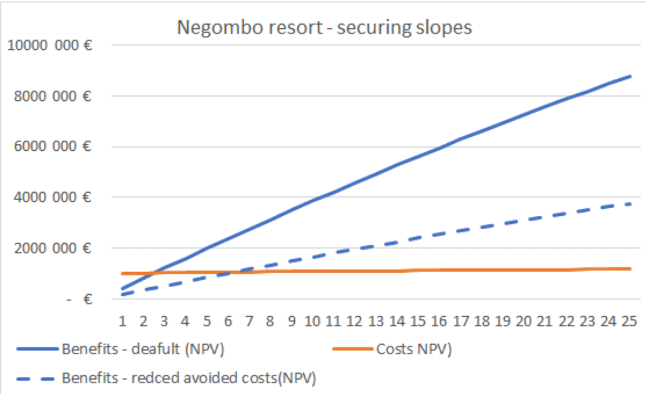


Figure 4-12. Benefits and costs over the lifetime of project 24

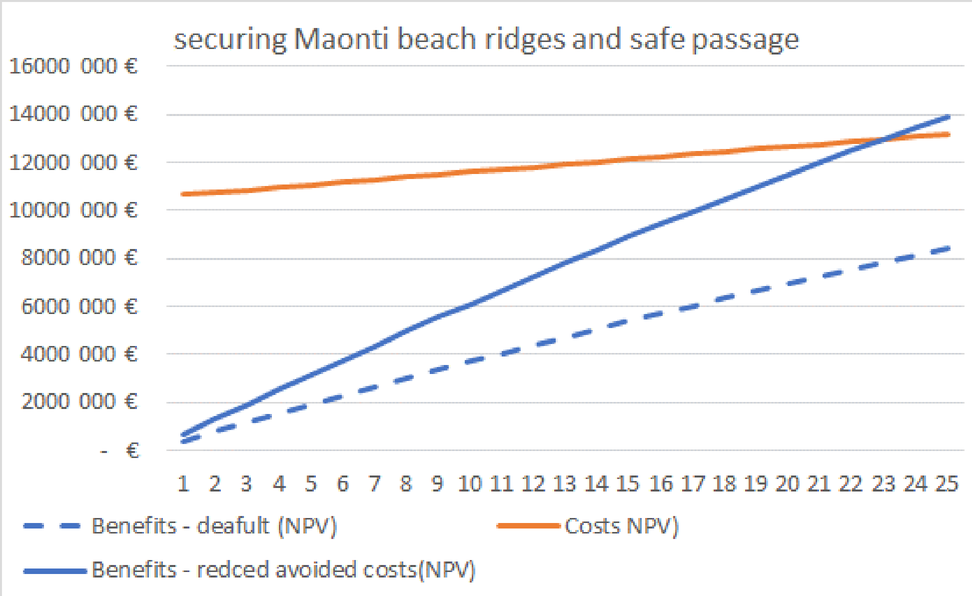


Figure 4-14. Benefits and costs over the lifetime of projects 8 and 9

4.5 Adaptation efforts to support the production of grapes and wine

Even though not proposed by the contact groups from Ischia, as experts we identified that supporting wine production to become climate resilient has significant positive economic effects on the island, also due to the link with tourism. Even though adaptation investments in this sector are private sector decisions, the risks regarding the selection of appropriate measures for this area (Ischia) are significant. From that point of view there is a public task to enhance the merit of better coping with climate change due to locally innovative adaptation.

Support for adaptation pilots, in this case of pilot patches of vineyards to test various adaptation solutions for a few years, could enhance timelier adaptation of the right selection of adaptation solutions for this region. Consequently, possible reduction in the production value of wine would be stopped or attenuated earlier. It should be noted that 1% improvement in grape output of all vineyards amounts to about 0.5 to 0.7 million euro of value added, annually[59]. The pilots should be a coordinated effort and the results and lessons should be available for the entire sector on the island (and beyond). Otherwise, public support is not justified.

59 The estimate of impact on aggregate value added for the sector on the island is based on reported wine production (1800 ton grapes = 10.2 million litres of wine = 13.6 bottles of wine), a wholesale price per bottle of 6 to 8 Euro, and a value added share of 65% for the producer.

5 Recommendations on Climate Change Adaptation Investment Options

The adaptation investment recommendations are presented in detail in chapter 3 of this report. Therefore, the recommended adaptation activity investments are described here only as a summary. They have been divided into two categories, short-term and long-term investments, based on the criticality assessment performed by the sectoral expert and the score from the cost and benefit analysis in Chapter 4.

The investment recommendations in this report focus on project schemes that are currently not being managed by the Struttura Comissariale. As mentioned above, it can be stated that, generally, the measures currently managed by the Strutture Comissariale are able to mitigate the natural hazard risk both under current conditions and under conditions of climate change in case they are properly designed. Therefore, only few adaptation activities are presented for Casamicciola Terme in this report in addition to the projects described by the Strutture Comissariale in the "Piano commissariale di interventi urgenti", but it is recommended to follow the proposed design criteria of Chapter 3.10 in the these projects. Some of the recommended investments were not included in the cost benefit analysis due to lack of information or otherwise not being suitable for the CBA, as is the case for the further studies that are required to gain additional information for more precise adaptation activity planning and the vineyards pilot projects.

Where the CBA scoring (BCR) resulted in a value of less than 2, expert judgement has also been used to determine whether the adaptation activity investments should be included in the short term or medium/long term investments. Expert judgement has also been used with the cases where the CBA was not carried out for an adaptation activity recommendation.

It should be noted that some of the investments can be combined to provide synergies, but possible synergies have not been considered in this study. For example, a road investment could provide synergy for other associated infrastructure like sewerage systems, proximal slopes, or coastal protection.

5.1 Short term investments

Short term investments are considered the most critical and beneficial for the island of Ischia based on the criticality assessment of each adaptation activity by the sectoral experts and the cost benefit analysis of the recommended adaptation activities. A large portion of the recommended adaptation activities are at the level of detail where their costs and some details and schemes are included in this report, but many sites still require further assessments in order to clarify the risks and to determine the exact adaptation activities required. The studies recommended for more precise, often local level risk assessments and adaptation activity planning and design are presented in Table 6-1 and should be performed with the highest priority to allow further identification of possible climate vulnerabilities and the detailed planning of recommended adaptation activities or other activities conducted by the Struttura Comissariale.

Table 5-1. Recommended further studies to provide information for more precise risk assessment and adaptation activity planning and design.

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Cost estimate [M€]	Comments
39	All	**Study**	Common	Digital elevation model	0,05 M€	Can reveal significant amount of adaptation needs especially on coastal areas once completed.
41	All	**Study**	Common	Natural Hazard Event Cadastre, Inventory and Documentation	0,3 M€	

36	All	**Study**	Flood	Flood model	0,25 M€	
37	All	**Study**	Landslide	Landslide assessment	0,25 M€	
40	All	**Study**	Sea level rise	Coastal model	0,2 M€	Cost estimation 50 k€/site, estimated 4 sites of interest. Can reveal significant amount of adaptation needs especially on coastal areas once completed.
42	All	**Study**	Landslide	Feasibility studies for investments 4,5,6 (high risk landslide prone areas)	0,3 M€	
43	All	**Study**	Common	Road inventory for condition and granular risk mapping. Should include the dimensions and traffic amounts of roads.	0,1 M€	

Table 5-2 presents all the recommended adaptation activities that should be considered for short term investments. Even though the Forio road adaptation (19) BCR score is low, it was still seen as a critical investment from the point of view of coastal protection and due to the fact that in case of a failure of this main road in the Forio coastal area, the alternative roads would not be able to convey the amount of traffic in the area. This would also heavily affect the resorts and hotels in the area.

Table 5-2. Recommended adaptation activities for short term investments sorted according to the CBA BCR with the largest number having the highest priority.

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Cost estimate [M€]	BCR	Prequisities
21	Ischia	Buildings	Wildfire	Vegetation control to create a buffer zone next to populated areas of Ischia	0,50 M€	**15,5**	
22	Barano d'Ischia	Buildings	Wildfire	Vegetation control to create a buffer zone next to populated areas	0,50 M€	**15,5**	
29	Barano d'Ischia	Water	Common	Combine existing water supply network to a circular network	0,31 M€	**14,6**	
32	All	Water	Flooding	Connecting the two main drinking water network lines into one circular network	0.31 M€	**14,6**	
31	All	Water	Landslide	Rerouting drinking water pipelines from areas prone to landslides to areas with lower risk	3.78 M€	**14,6**	36
25	Casamicciola Terme	Buildings	Sea level	Coastal erosion protection for Island heliport. Island heliport structures are reportedly crumbling.	5 M€	**8,7**	39, 40
24	Lacco Ameno	Tourism	Landslide	Negombo hot spring resort erosion protection	1,00 M€	**7,5**	
18	Ischia	Ports	Sea level	Raise of the quay level in Ischia Porto with a protective concrete wall along the edge of the actual quays on the restaurants section, with wooden deck on top.	3,00 M€	**5,4**	39, 40
23	Forio	Tourism	Landslide	Poseidon hot spring resort site erosion protection	1,67 M€	**4,5**	
38	All	Common	Common	Natural Hazard Monitoring, Early Warning and Alarming system	2,8 M€	**4,2**	

14	Casamicciola Terme	Roads	Landslide	Steel nets need to be replaced near the heliport, possible partially with retaining walls. Length 150m, height 15m. Hydraulic structures (drainage system) will be needed, if wall is chosen.	1 M€	**3,4**	
15	Casamicciola Terme	Roads	Landslide	Steel nets need to be replaced, possible partially with retaining walls. Length 250m, height 10-15m. Hydraulic structures	1,5 M€	**3,4**	
20	Casamicciola Terme	Buildings	Landslide	Several activities for the Ischia Hospital	6,50 M€	**2,8**	
11	Ischia	Forestry	Landslide	Monte Vezzi forested area management	0,11 M€	**2,0**	
12	Ischia, Barano d'Ischia	Forestry	Landslide	Cretao forested area management	0,14 M€	**2,0**	
13	Casamicciola Terme, Barano d'Ischia	Forestry	Landslide	Casamicciola Terme Monte Epomeo forest management	0,41 M€	**2,0**	
16	Casamicciola Terme	Water	Flooding	Drainage upgrading, mixed sewer into separate. Increased capacity for the storm water.	1,00 M€	**1,5**	36
26	Casamicciola Terme	Water	Flooding	Redesign of a collector drain in Casamicciola Terme	0.43 M€	**1,5**	36
30	All	Water	Flooding	Enlarging the stormwater drainage system crossing areas prone to floods by 50 mm	11,9 M€	**1,5**	36
33	All	Water	Landslide	Transforming mixed sewer system at high landslide risk into a separated sewer system	2.77 M€	**1,5**	36
34	All	Water	Landslide	Transforming mixed sewer system at medium landslide risk into a separated sewer system	1.45 M€	**1,5**	36
19	Forio	Roads	Sea level	Stabilization of the cliff in Forio against coastal erosion with retaining wall coupled with the installation of natural rocks breakwater at the toe of the wall	15,0 M€	**1,0**	40

5.2 Medium/long term investments

Even though the adaptation activity recommendations 4,5,6 (Table 5-3) are considered important, but as it is not possible to provide enough details for those within this study to confirm the exact adaptation activities, they are presented in the medium/long term investments. Further studies are nevertheless recommended as the corresponding areas are recognized, both by the locals and the GIS analyses of this study, as risk areas for landslides. The flood and sea level studies in this study were also not precise enough to fully confirm the need for further protection of the electricity stations on Ischia Island (investments 27 and 28).

Investments 1,3,7,8,9,17 and 35 were not considered critical and/or their BCR was low and are therefore recommended for long term investments with lower priority.

Table 5-3. Medium / long term investments for Ischia Island climate resilience

ID	Municipality	Main sector	Main Hazard	Adaptation activity description	Cost estimate [M€]	BCR	Prequisities

4	Ischia	Common	Landslide	Various landslide and hydrology related works in the Monte Vezzi area. Cost estimation is based on the local data.	14,6 M€	-	42
5	Casamicciola Terme, Ischia, Barano d'Ischia	Common	Landslide	Various landslide and hydrology related works in the Cretaio area. Cost estimation is based on the approximate area cover compared to Vezzio investment estimation.	15 M€	-	42
6	Casamicciola Terme, Serrara Fontana, Forio	Common	Landslide	Various landslide and hydrology related works in the Forio area. Cost estimation is based on the approximate area cover compared to Vezzio investment estimation.	30 M€	-	42
28	Lacco Ameno	Energy	Flooding	Possible Lacco Ameno cable connection point flood protection	Not defined	-	39, 40
27	Ischia	Energy	Sea level	Possible Ischia electricity substation flood protection	Not defined	-	36, 39
3	Lacco Ameno	Roads	Landslide	Securing and consolidating the ridge overlooking via Cava Pannella	1,59 M€	-	
7	Lacco Ameno	Tourism	Landslide	Safety and consolidation of the ridge overlooking Varulo beach	1,23 M€	-	
1	Lacco Ameno	Tourism	Sea level	Completion of the safety and consolidation intervention on the eastern ridge of Montevico - northern ridge	2,00 M€	-	
35	All	Water	Landslide	Transforming the mixed sewer system in areas with low or no landslide risks into a separated sewer system	5.53 M€	-	
17	Forio	Roads	Landslide	Slope stability. Using Biotextile and steel nets in various location in the Forio mountain area.	0,50 M€	**0,6**	
9	Barano d'Ischia	Tourism	Flooding	Extremely urgent works to make the ribs safe and restore the hydraulic functionality of the Alveo Cava Ponte/Nitrodi/Olmitello	6,08 M€	**1,1**	
10	Barano d'Ischia	Tourism	Flooding	Extremely urgent works to restore the hydraulic functionality of the Cava Rosato/Cavone Martoccio riverbed	1,60 M€	**1,1**	
8	Barano d'Ischia	Tourism	Landslide	Works to improve the safety of the Maronti beach ridges	4,47 M€	**1,1**	

6 Recommendations to strengthen project management

6.1 Struttura Commissariale team capacity

During the assignment, the consultants had several meetings with the Ischia Struttura Commissariale team of different configurations. During the meetings, it was observed that the Struttura Commissariale team is highly skilled in structural engineering related (buildings) matters (Table 7.1.) and is supported by the Università degli Studi di Napoli Federico II and the Università degli Studi del Sannio di Benevento related to geology, hydrology, hydraulics, landslides and nature-based solutions (forestry).

Table 6-1. Sectoral expertise included in the Struttura Commissariale staff.

Hydraulic Geotechnical Engineer
Environmental Expert
Construction Engineer
Structural Engineer
Civil Engineer
Structural Construction Engineer and project manager
Structural and civil Engineer
Structural Engineer

As this assessment has considered also other sectors outside the abovementioned ones, we have come to realize that the Struttura Commissariale team could be strengthened with experts having knowledge in water supply and wastewater treatment, coastal structures and with transportation (roads, ports) and energy networks.

The assignment team is aware of a Technical Assistance project, provided by the EIB, which already covers the capacity issues with procurement and tendering.

A technical climate adaptation expert could be also added to the Struttura Commissariale team or consultancy procured to make sure that all the investments follow the appropriate design criteria considering the future climate conditions and climate impacts on Ischia and to continue the work of identifying climate vulnerabilities on the Island of Ischia.

It is recommended that also possible future projects will be managed by the Struttura Commissariale, as they have the authority to perform the required tasks, while it seems difficult for the local stakeholders as the interventions require input and approvals from several sectors and levels of municipal and regional authorities. The Ischia Island is also divided into 6 municipalities, which provides another layer to the decision making, especially when the adaptation investments concern several municipalities.

A small group of people, preferably a technical unit, should be set up to direct the climate risk adaptation related investments. The unit could work directly under the special commissioner and the surveillance of the deputy commissioner.

6.2 Monitoring

The abovementioned technical unit should create a roadmap for the investments based on their priority, to enable implementation of the climate adaptation investments. This climate adaptation roadmap should also describe the responsible entities for implementation of investments with time horizons and describe the possible other parties involved in the conversations as well. It should also include clear responsibilities for single adaptation activities within the technical unit or the Struttura Commissariale.The team should also develop the objectives of a monitoring program and follow the progress of implementation based on proper indicators supporting the objectives. The indicators could include, for example, the amount of money invested, number of investments or the number of beneficiaries. Monitoring of the progress should also ensure that results of investigations carried out to provide better basis for the design of adaptation activities, as e.g. more detailed flood or landslide risk assessments, are indeed taken up in the process of technical design.

In addition to monitoring the progress of the implementation of adaptation activities, the technical unit should also monitor general developments in climate-risk related subjects, as e.g. new methods for climate risk mitigation, or new developments in climate modelling. In case it is concluded that such new methodologies could improve the knowledge on climate risk in Ischia or the design of climate adaptation activities, the technical unit should consider the update of this climate risk assessment or of more specific sector-specific or design-related climate risk assessments. For the monitoring of scientific activities, it is recommended to assign the responsibility to a specific person within the technical unit that maintains close contact with scientific institutions.

The monitoring program should also describe the frequency of data collection and to whom it will be communicated to. It is recommended to perform a review annually and depending on the duration of the investment program, a midterm review and a final review should be also performed. The results of the reviews should be used to steer the progress of the investments towards their set objectives.

APPENDICES

1 Observed extreme precipitation events on Ischia

1.1 Introduction

The use of very high-resolution climate models and reanalyses is expected to give relevant advantages in climatology, particularly concerning the understanding and therefore accurate reproduction of atmospherical patterns localized in time and space. Nowadays it also is expected that these models will improve the capability of the state of art numerical models (running at about 10 km) to reproduce climate features within geographically constrained and/or complex areas (such as urban areas having a microclimate affected by human activities). The main motivation for this it is related to 3 main factors:

- better representation of the complexity and heterogeneity of the interface soil-atmosphere;
- Less use of physical parameterization to emulate processes (such as convection precipitation) that are directly simulated by numerical model;
- the mere presence of higher resolution also allows for a better representation of extremes, limiting (but not entirely omitting) the underestimation effects of extreme phenomena, due to the averaging operation over a finite-resolution computational grid.

By doing so, they facilitate a deeper comprehension of regional climate systems and microclimatic influences, allowing for a more precise prediction of climate trends and their potential impacts.

Moreover, their ability to recreate extreme weather events, which are often localized, stands as a crucial breakthrough, enhancing ability to study the frequency, intensity, and spatial distribution of such events and their evolution due to climate change.

Based on this premise, it was decided to attempt to reproduce the spatial distribution of precipitation over the isle of Ischia using data recently generated by the CMCC Foundation at a resolution of 2km, specifically the reanalysis known as ERA5@2km[60].

Unfortunately, the local in situ weather stations (Figure 1-1) provided observations only over a limited period[61] (Figure 1-2). It is therefore not possible to evaluate the performance of ERA5@2km over this area and to assess local trend or to remove the model bias[62].

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[60] ERA5@2km is a new hourly high-resolution precipitation dataset, obtained by downscaling ERA5 reanalysis (provided by Copernicus (in this first version it doesn't include data assimilation process) including data assimilation process at very high resolution): https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview)
Data are available on the DSS of the CMCC for download: https://dds.cmcc.it/#/dataset/era5-downscaled-over-italy/hourly .The dataset covers the whole Italian territory so to provide a very detailed (in terms of space-time resolution) and comprehensive (in terms of meteorological fields) dataset of climatological data for at least the last 30 years (01/1989-10/2020).
[61] A correct assessment of average and extreme climate patterns requires a climate analysis spanning a minimum period of 30 years.
[62] systematic model errors or biases refers to systematic errors or inaccuracies in a numerical or computational model's representation of atmospheric conditions. Biases can arise from various sources, including imperfect data input, simplifications in model equations, or limitations in model resolution. Essentially, it signifies a consistent discrepancy between the model's predictions and the real-world atmospheric observations, which can affect the model's overall accuracy and reliability in simulating weather or climate phenomena. It may be assessed from systematic comparisons of model simulations with observations wherever available.

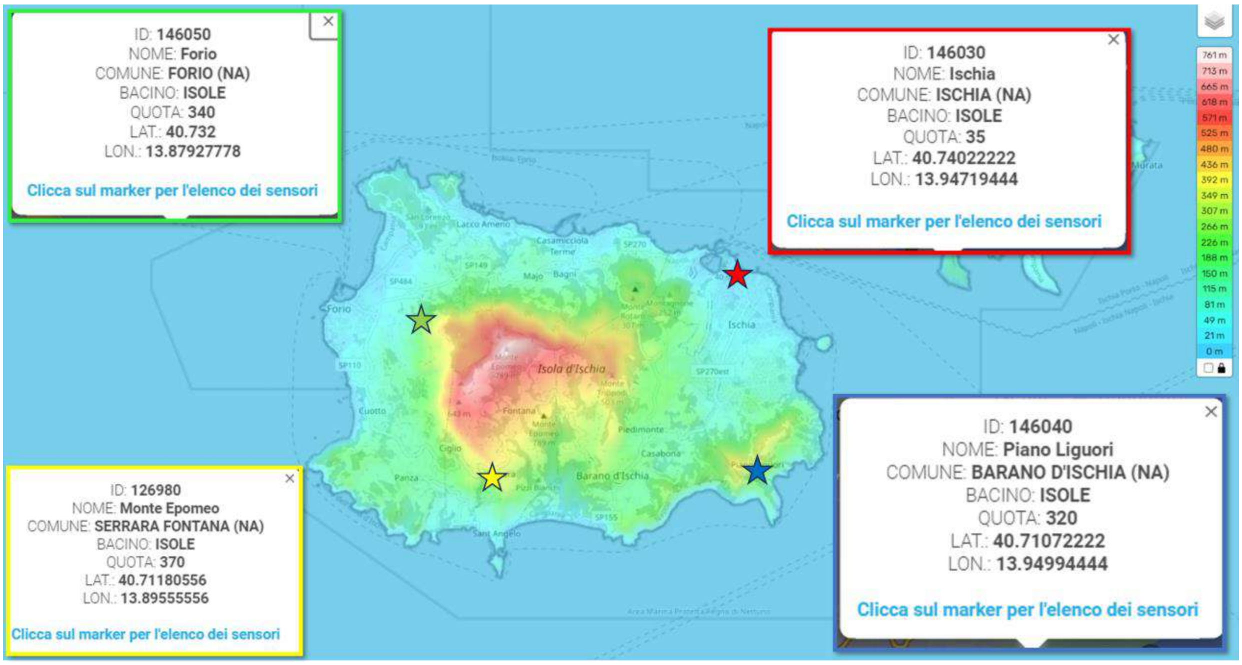


Figure 1-1: Orography of Ischia and location of the in situ precipitation station (source of the map: https://it-ch.topographic-map.com/map-4wg6nh/Ischia/?center=40.72723%2C13.91145)

Station	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Complete years (among the ones available)
FORIO							58	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	59	16/18
Monte Epomeo	80	100	1	0	0	0	0	0	1	0	0	4	1	0	0	0	0	2	6	0	0	0	0	59	21/24
Piano Liguori							41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59	16/18
Porto													0	0	0	0	0	0	0	0	0	0	0	59	11/12

Figure 1-2: analysis of the situ observations in terms of quality and completeness. In instances where the dataset contains more than 25% missing data (NaN) for a particular year, that specific year is marked as invalid and consequently it must be excluded from the analysis. These invalid years are visually highlighted in red for easy identification. This rigorous analysis serves to safeguard the integrity of statistical results by preventing any undue influence from incomplete or unreliable data. The applied analysis was proposed by Fioravanti et al. in 2016 (Fioravanti G., Fraschetti P., Perconti W., Piervitali E., Desiato F.: Controlli di qualità delle serie di temperatura e precipitazione, ISPRA, 2016)

Moreover, starting from the analysis of the ERA5@2km grid point model location and elevation (Figure 1-3, left) it appears that the numerical models still have an underestimation of the real orography of the isle. However, it is trivial to note that there is a significant added value in the representation of the orography compared to the re-analysis ERA5, Copernicus product, at a resolution of about 31 km (Figure 1-3, right).

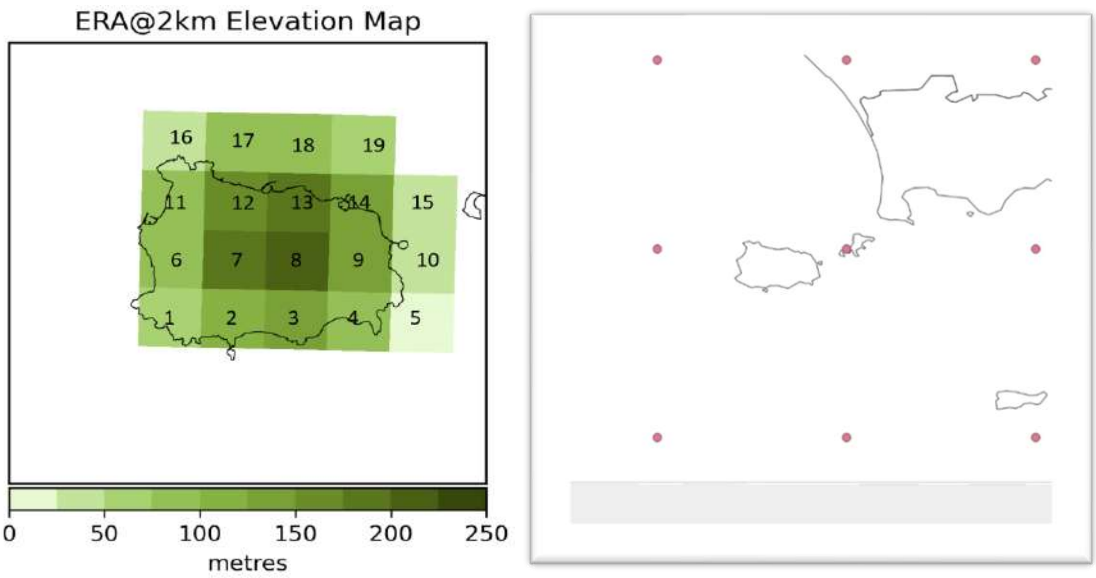


Figure 1-3: Elevation and colour-position association for the grid points ERA5@2km (left) and position of the grid points of ERA5 (right)

Based on all these existing limitations but wanting to determine if it is possible to use this product to gain a better understanding of the spatial distribution of precipitation during extreme events, a detailed analysis was conducted for two events considered extreme, in terms of their impacts, both occurring at the end of November.

1.2 Event of November 26th, 2022

The following graph reports the hourly precipitation observed during November 26th, 2022 by using:

- ERA5 reanalysis provided by Copernicus;
- ERA5@2 km re-analysis;
- Hourly precipitation by in situ station provided by Centro Funzionale Multirischi della Protezione Civile Regione Campania (localization reported in Figure 1-1).

Figure 1-4 illustrates a relevant underestimation in both re-analyses compared to the observed data. This underestimation is particularly surprising in the case of the 2 km re-analysis, which, in different geographical contexts[63] has demonstrated its added value, compared to lower-resolution re-analyses, such as ERA5, especially in identifying hourly precipitation maxima.

[63] Reder, A.; Raffa, M.; Padulano, R.; Rianna, G.; Mercogliano, P. (2022). Characterizing extreme values of precipitation at very high resolution: An experiment over twenty European cities. Weather and Climate Extremes, doi: 10.1016/j.wace.2022.100407

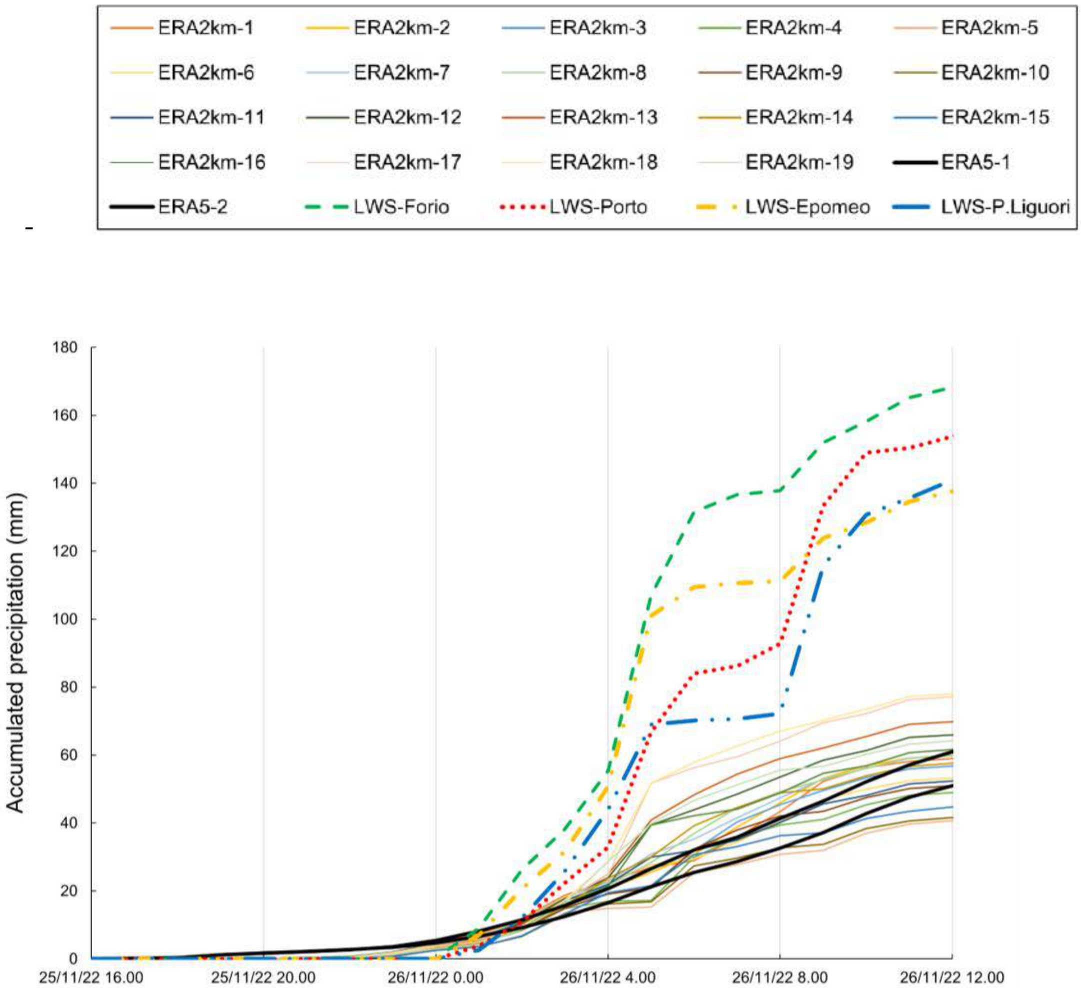


Figure 1-4: Hourly cumulated precipitation from ERA5@2km are represented by solid lines. Each grid point is numbered from 1 to 19, and a distinct colour is associated with each of them. The correspondence between the position and the number is displayed in Figure 1-3, right. In-situ precipitation stations are depicted using dashed lines, and the colour-position association can be found in Figure 2.1. ERA5 data is represented by black lines. Hourly precipitation data is reported up to 12 UTC to give more emphasis to the event happened in the morning.

For this event, which affects a particularly complex and spatially limited area like the Ischia Island, the re-analysis, however, struggles to accurately quantify rainfall amounts. The underestimation of the precipitation amounts can be explained by different factors:

- Exceptionality of the precipitation intensity compared to the area's climatology. Typically, models are not extensively calibrated and validated to reproduce these rare events; this may impact the model's ability to represent accurate quantities.
- The precipitation results generated by re-analysis data are averaged over 2 km x 2 km grid cells, this could lead to lowering the value of a highly localized peak.
- Due to the discrete resolution, the re-analysis struggles to faithfully replicate the actual orographic features of the region. This leads to a significant underestimation of the peaks of the mountain and, more in general, to an incorrect assessment of the orography and, consequently, of the orographic component of precipitation.

Despite this underestimation issue, it is important to note that, when comparing the value of the precipitation daily amount of ERA5@2km obtained for every grid point the day of the events, to their own climatology, the event appears extreme across the entire island.

The test to categorize this as an extreme event is based on the analysis that, on November 26th, the daily precipitation at all Ischia grid points of ERA5@2km exceeded the 99th percentile of the precipitation climatology for the period 1981-2010. Each grid point's value is compared to the climatology of the same grid point[64].

Additionally, the value of the hourly precipitation for ERA5@2km often exhibit higher values compared to the ERA5 reanalysis grid points. Finally in Figure 1-4, it is evident that most ERA5@2km points report precipitation values of greater magnitude compared to those of ERA5. This demonstrates that, therefore, some added value is generally present also in this extreme event.

Finally, there is a noticeable improvement in terms of spatial representation of precipitation pattern by comparing hourly precipitation maps of ERA5 reanalysis and ERA5@2km (Figure 1-5 and Figure 1-6, respectively) with the observation time pattern reported in Figure 1-4.

About this feature, it can be observed, looking at the maps in the Figure 1-5, that the model captures the timing of precipitation quite well placing the maximum precipitation in the Casamicciola area between 5 UTC and 6 UTC in the morning, where the greatest impacts were registered.

[64] for additional information, refer to: https://datastore.copernicus-climate.eu/documents/app-extreme-precipitation/C3S_D430.2.5.5_Catalogue_Past_Extreme_Precipitation_Events_User_Guide_v2-3.pdf

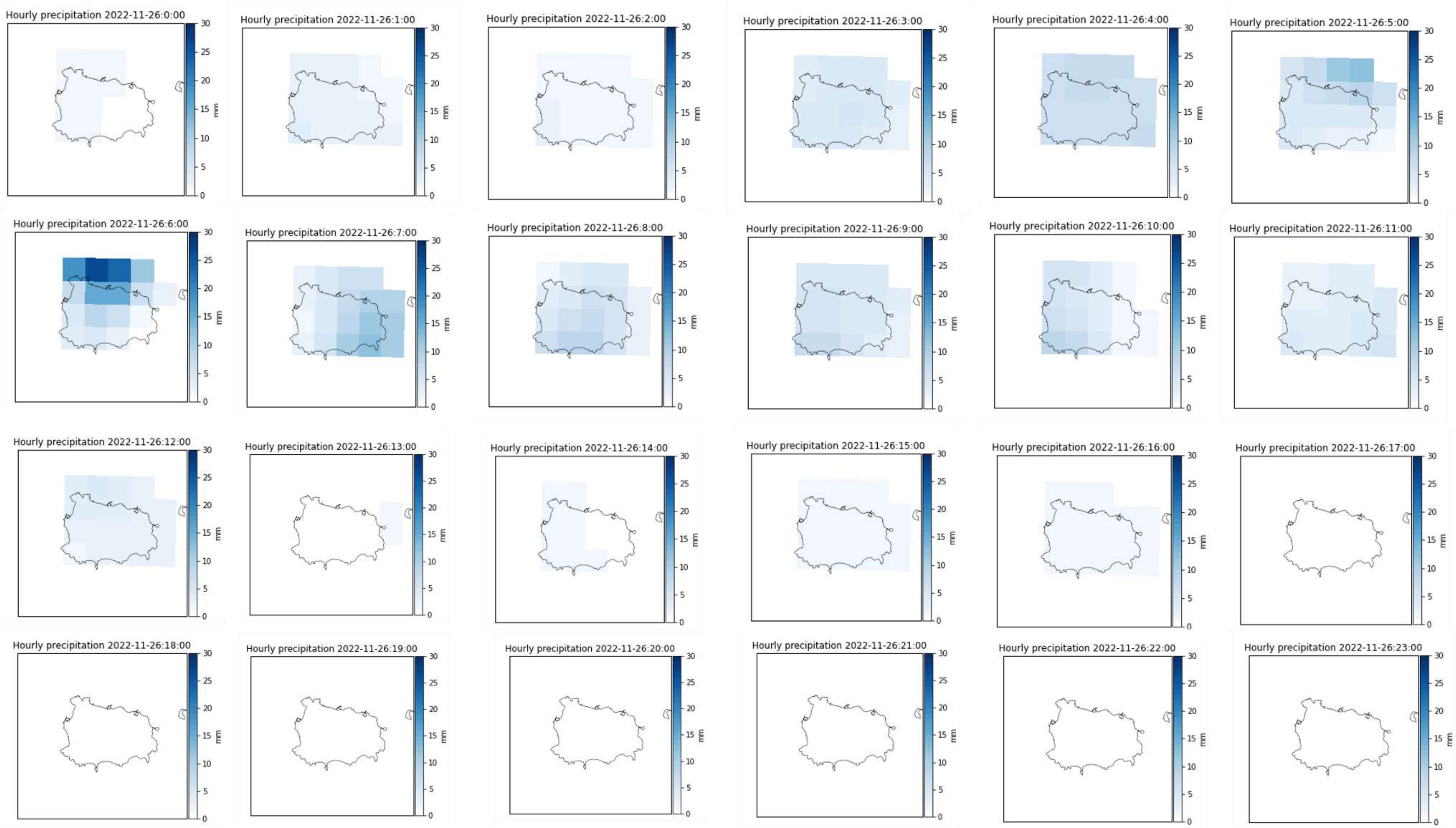


Figure 1-5: Map of the hourly cumulated precipitation with ERA5@2km-2022-11-26

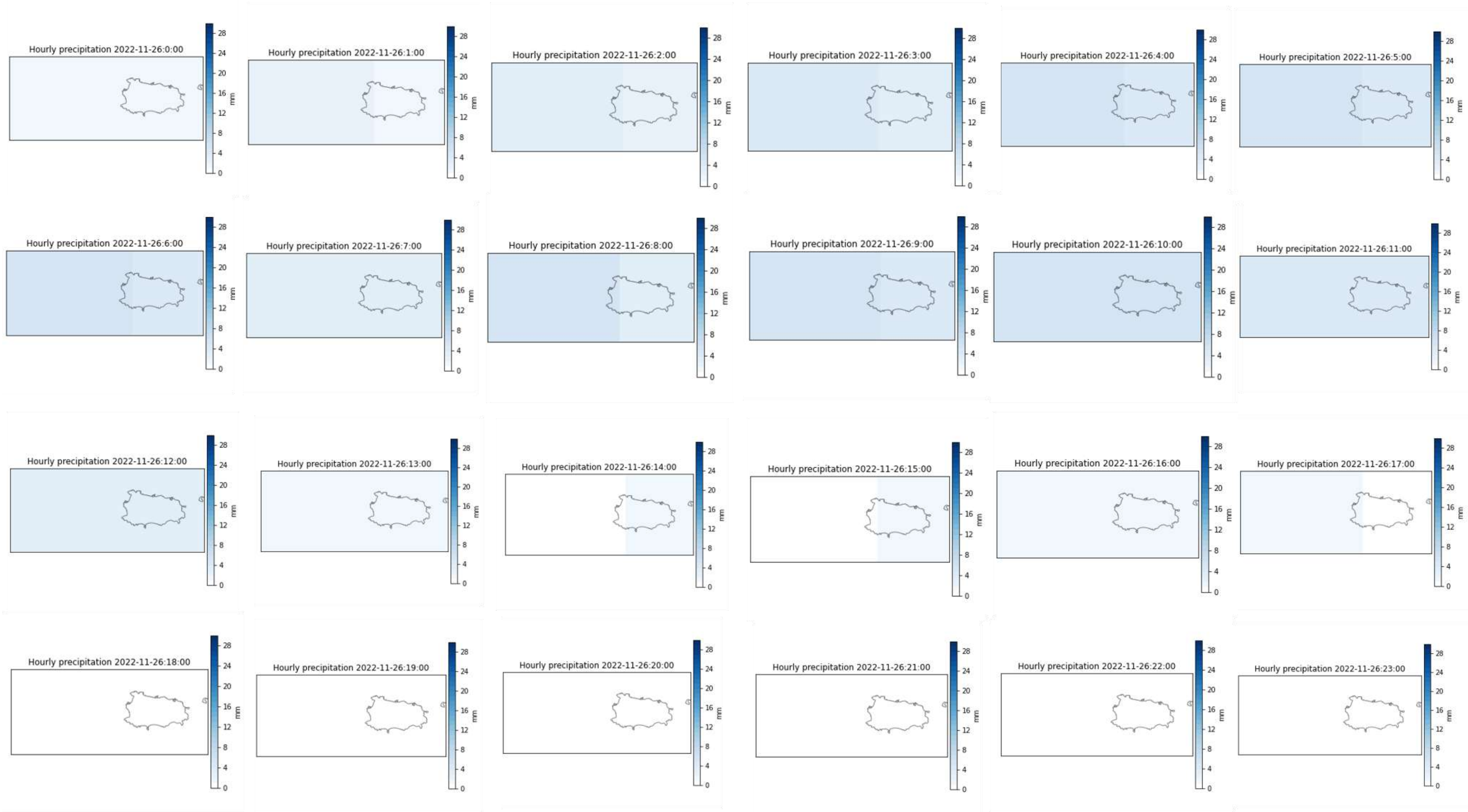


Figure 1-6: Map of the hourly cumulated precipitation with ERA5-2022-11-26

1.3 Event of November 25th, 2016

This second event caused significant damage and inconvenience on the island, through landslides, flooded roads, and disruptions to the residents. A yellow alert had been issued for this event. The most extensive damage was reported in Lacco Ameno and Forio d'Ischia.

The event of 25th November 2016, even if reporting hourly precipitation intensity was much less intense with respect to the first event, can be considered an extreme event for the climatology of ERA5@2km reanalysis because each grid point exceeded the 99th daily percentile of daily precipitation distribution over the period 1981-2010.

In this case the peak of precipitation and time are quite well represented in comparison with hourly patterns of the 4 in situ stations (*Figure* 1-7). The spatial distribution of hourly precipitation it is reported in the next figures (Figure 1-8 and Figure 1-9).

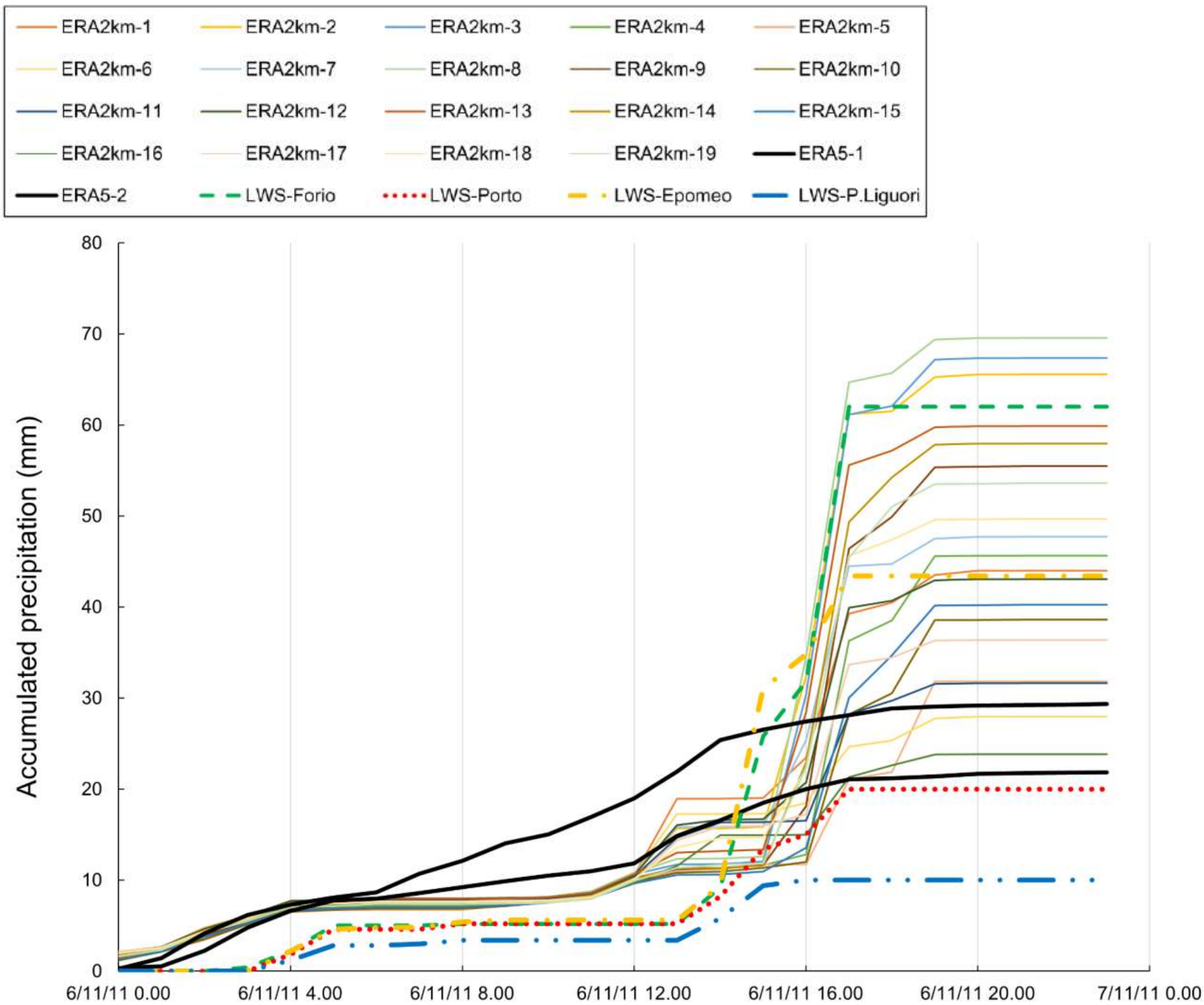


Figure 1-7: Hourly cumulated precipitation from ERA5@2km are represented by solid lines. Each grid point is numbered from 1 to 19, and a distinct colour is associated with each of them. The correspondence between the position and the number is displayed in Figure 3. In-situ precipitation stations are depicted using dashed lines, and the colour-position association can be found in Figure 2. ERA5 data is represented by black lines.

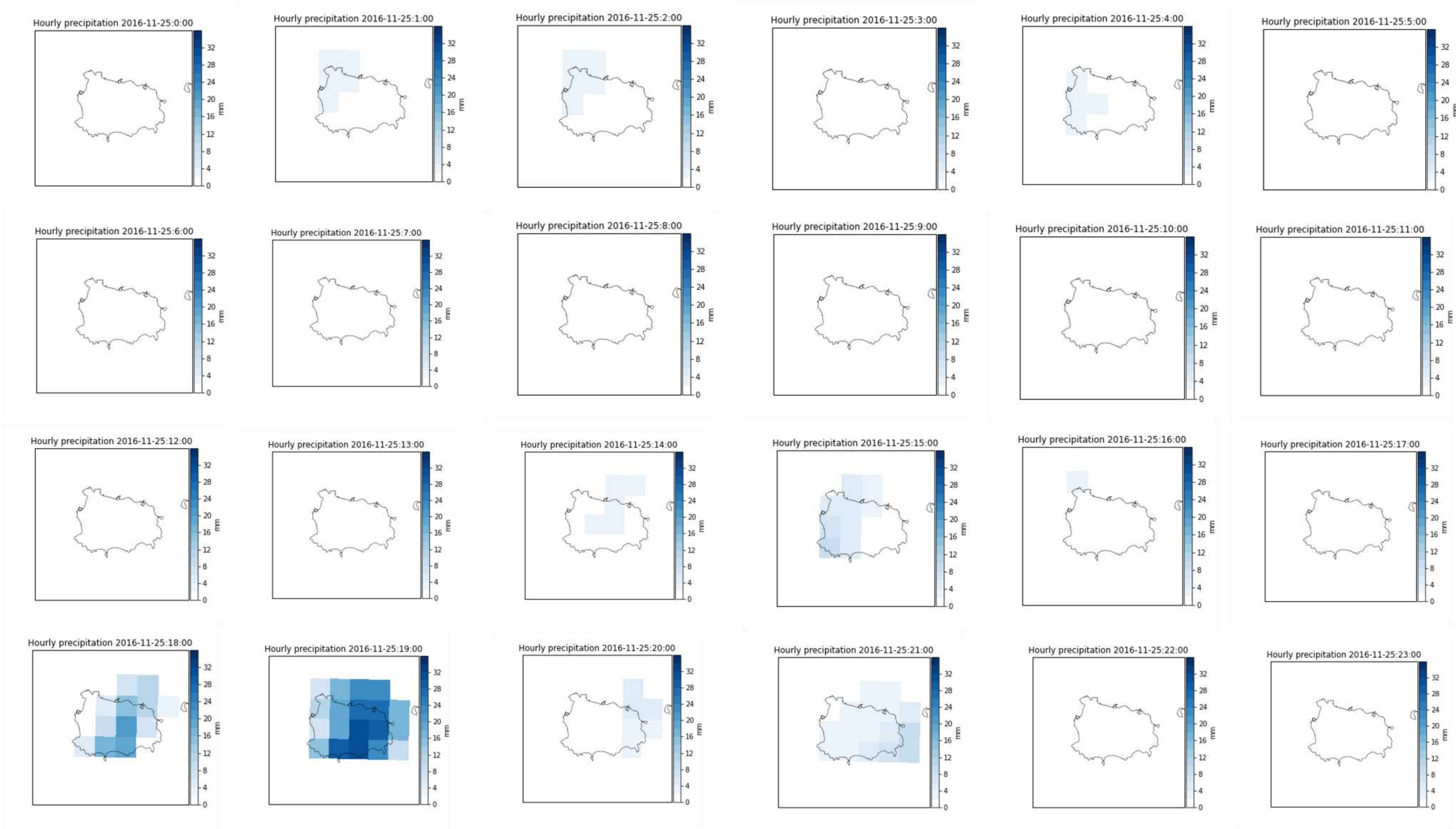


Figure 1-8: Hourly cumulated precipitation with ERA5@2km-2016-11-25

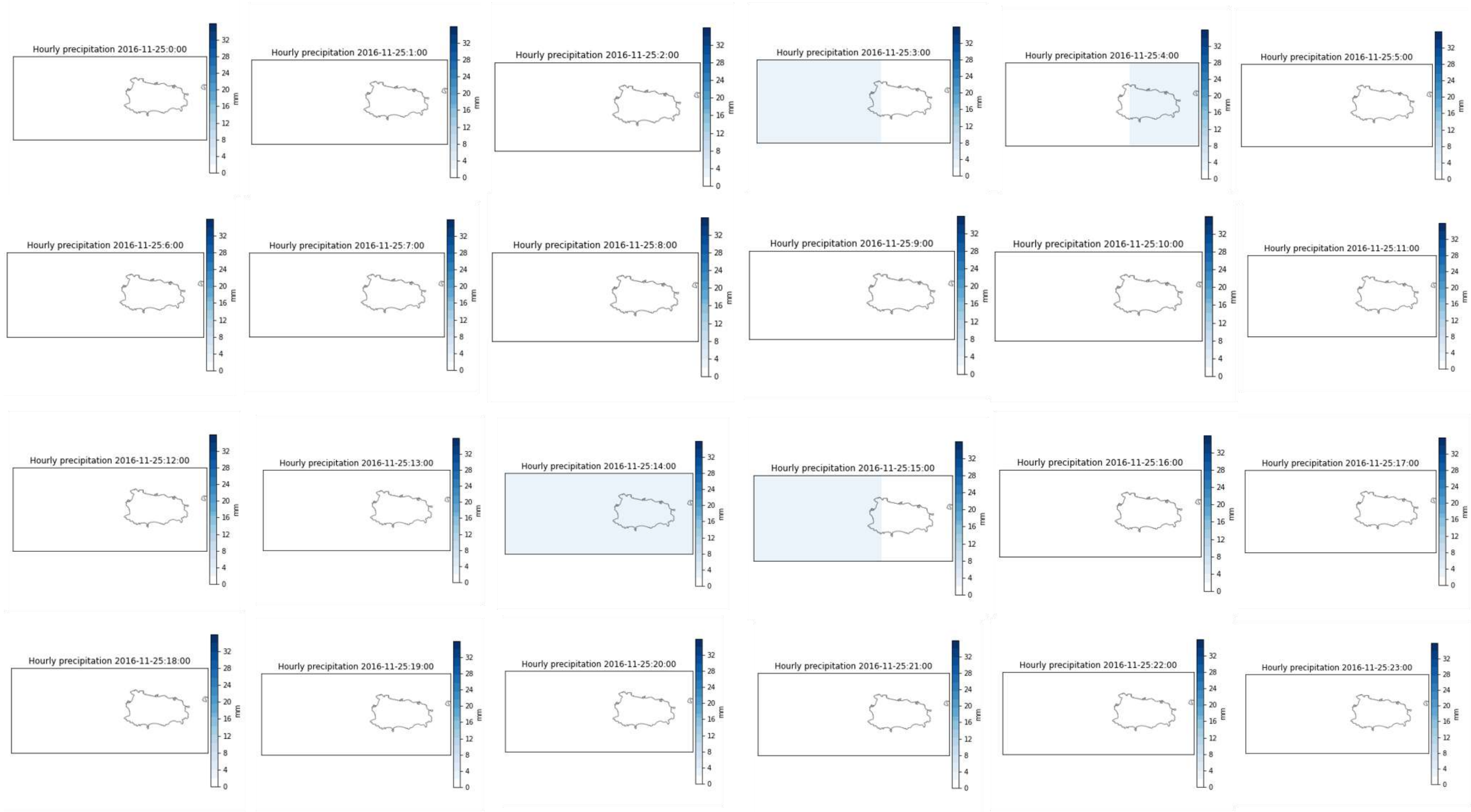


Figure 1-9: Hourly cumulated precipitation with ERA5-2011-11-25

1.4 Conclusion

In general, the analysis of these two events has underscored the difficult challenges in reproducing extreme precipitation events over Ischia Island. These difficulties persist even when employing innovative tools, such as very high-resolution re-analysis, which have demonstrated success in various contexts. This complexity can be largely attributed to the area's distinctive geographical characteristics.

Nonetheless, even within this complex region, enhancing the spatial resolution in reanalysis allows to better capture the dynamics of extreme events compared to other lower resolution reanalysis. However, this initial finding warrants further validation through a comprehensive analysis that encompasses various events.

Regarding the analysis of these two precipitation events, it is important to note that the study is significantly constrained by the limited availability of observations at different elevations and, especially in the first case, by a lack of data from the area most affected by heavy precipitation.

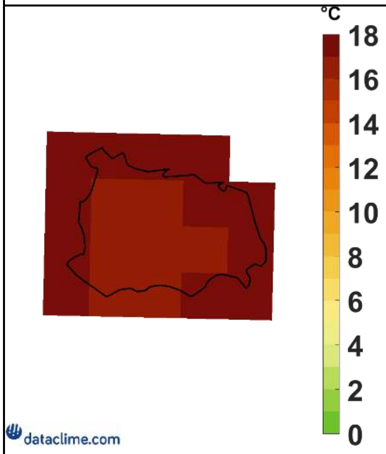
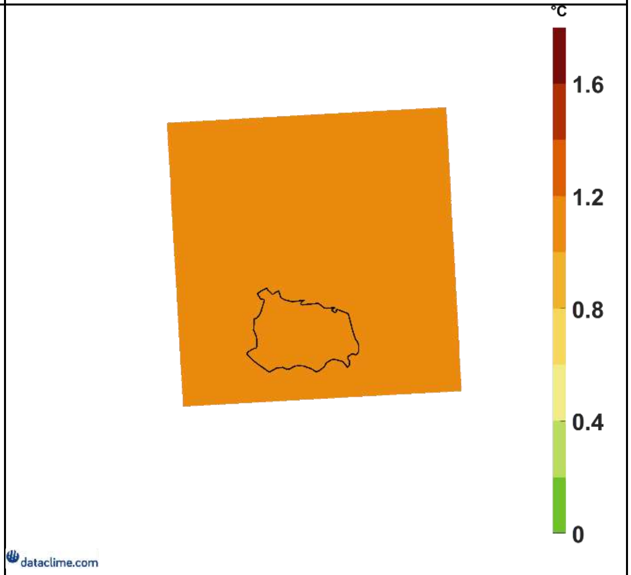
To enhance the performance of numerical models for reproducing precipitation spatial patterns, several potential improvements can be considered. First and foremost, expanding the availability of weather monitoring data is crucial. Such data can not only enhance current reanalyses through the assimilation of high-resolution data but also help reduce model biases. Additionally, the availability of data can have a positive impact on improving weather forecasting accuracy.

It is essential to emphasize that effective observations should be uniformly distributed spatially (comprising in-situ stations, satellite data, and radar data) and encompass monitoring of various atmospheric variables.

2 Climate Maps

2.1 Temperature

Mean temperature (°C)

<table>
<tr><td>Historical Period (absolute)</td><td>2050 RCP2.6 (projected change)</td></tr>
<tr><td>
</td><td>
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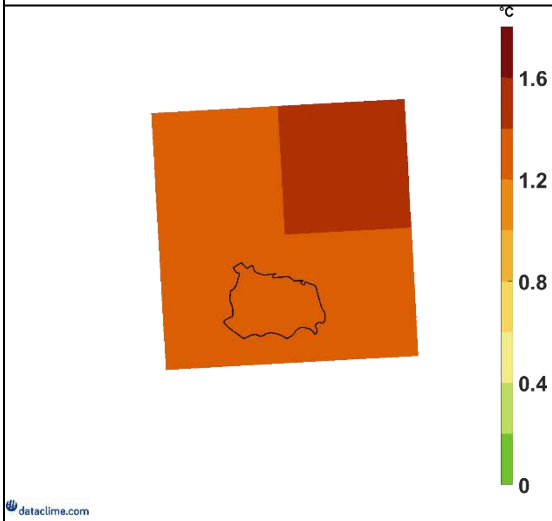
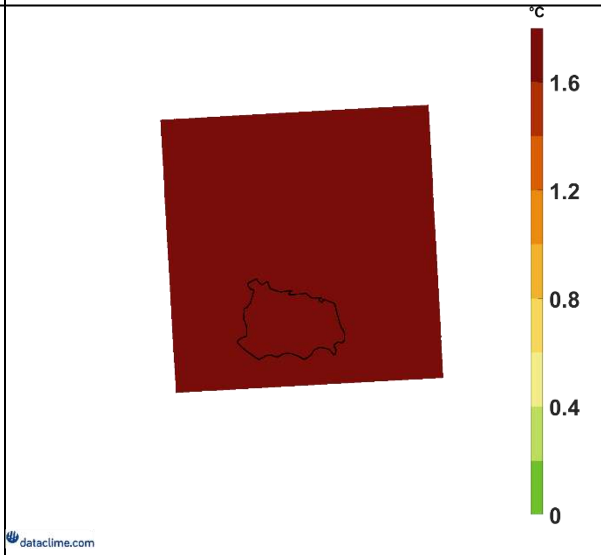
<tr><td>2050 RCP4.5 (projected change)</td><td>2050 RCP8.5 (projected change)</td></tr>
<tr><td>
</td><td>
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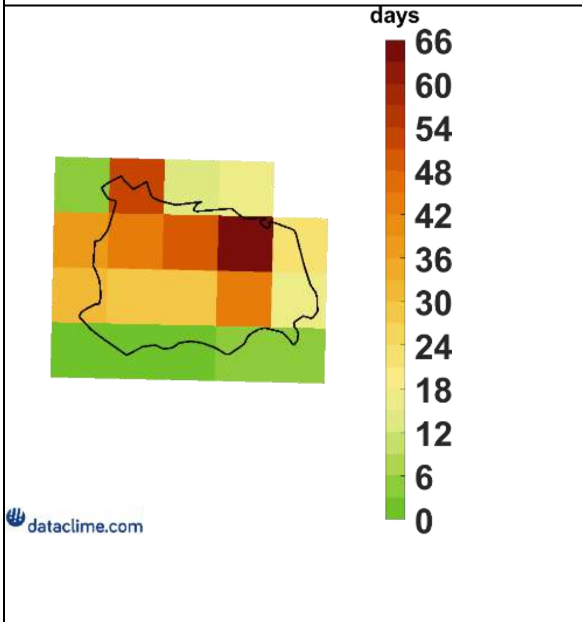
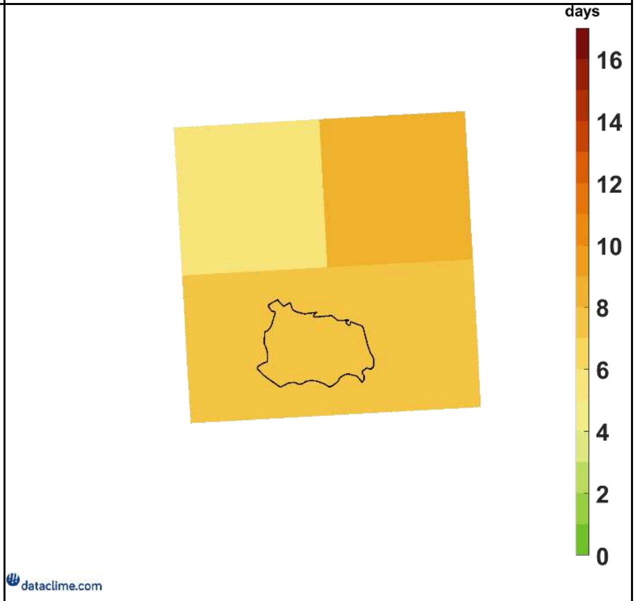
Summer days (days)

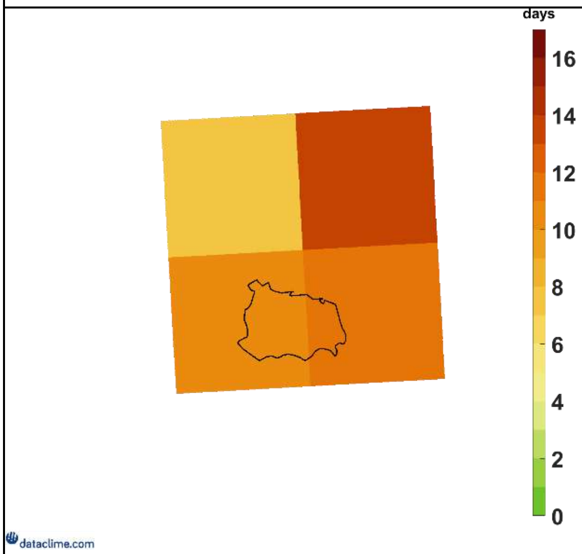
Historical Period (absolute)



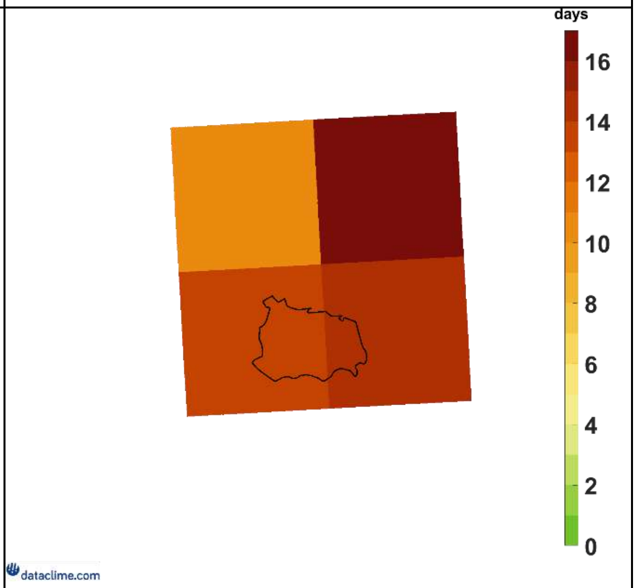
2050 RCP2.6 (projected change)



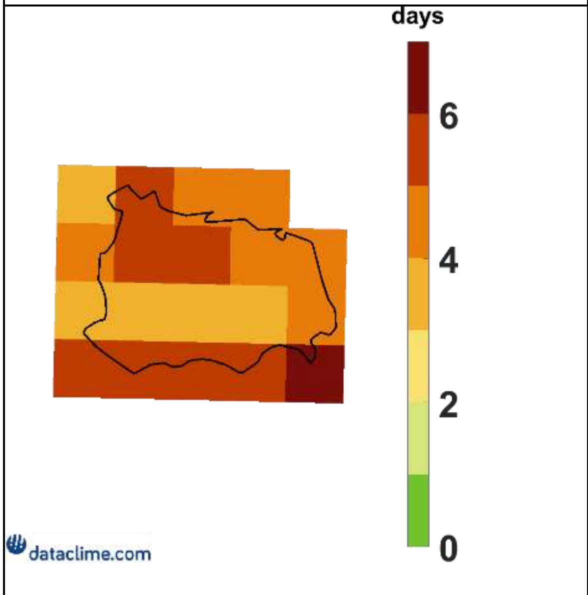
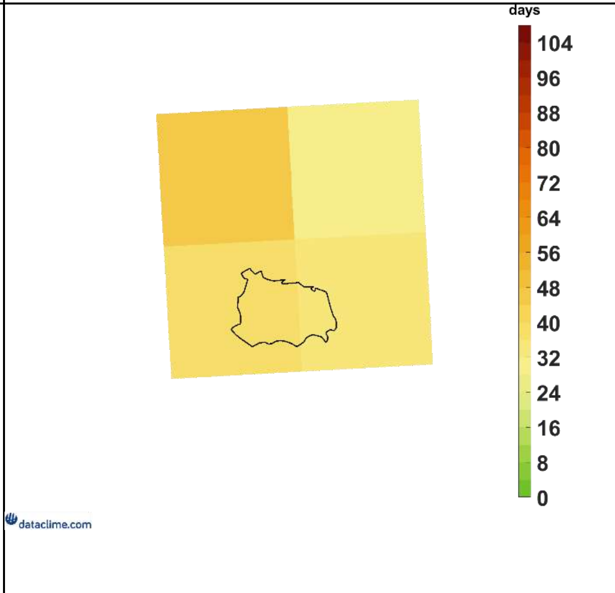
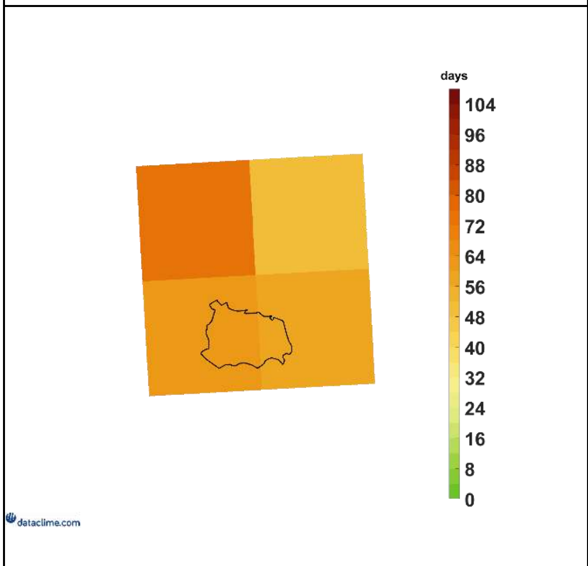
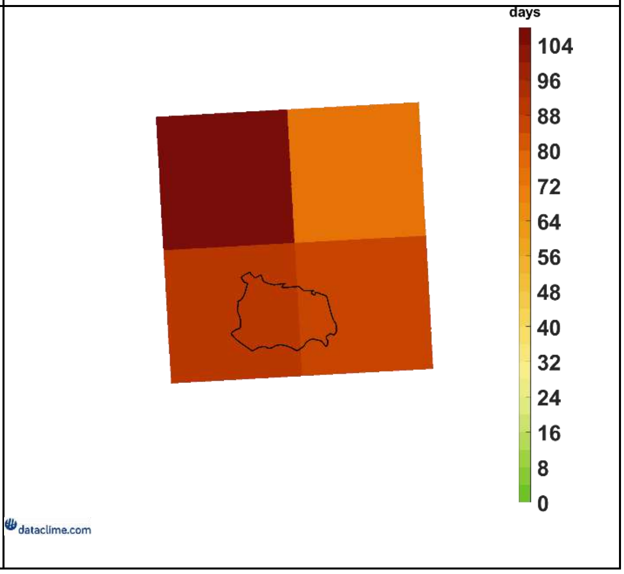
2050 RCP4.5 (projected change)



2050 RCP8.5 (projected change)

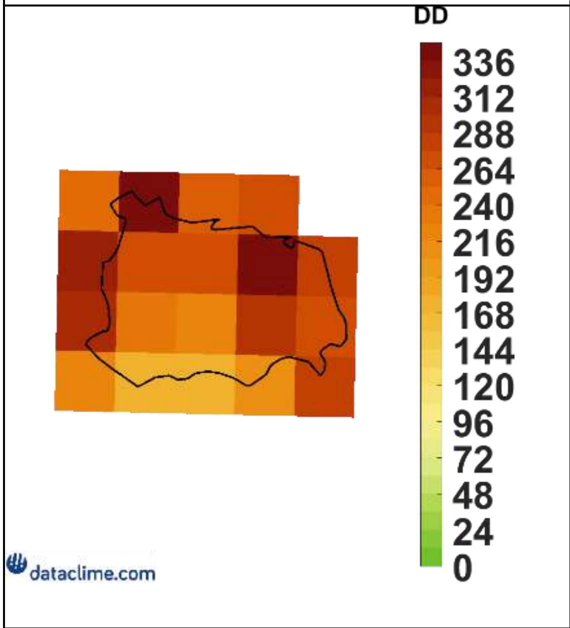


Warm spell duration index (days)

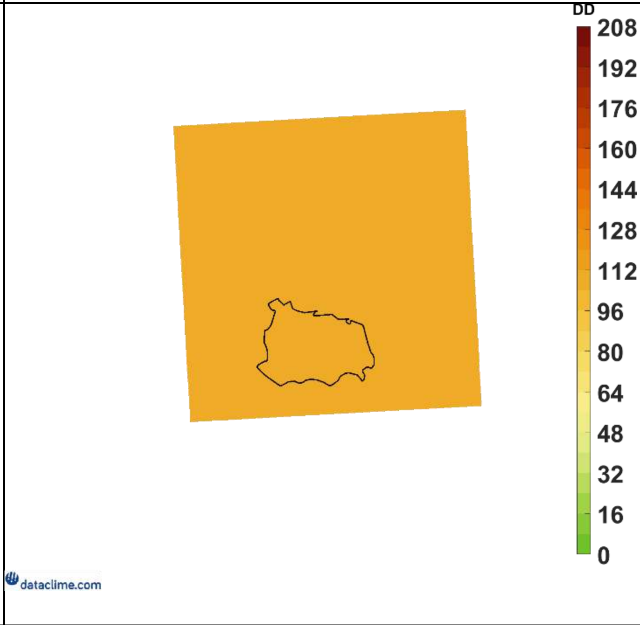
Historical Period (absolute)	2050 RCP2.6 (projected change)
	
2050 RCP4.5 (projected change)	2050 RCP8.5 (projected change)
	

Cooling degree days (DD)

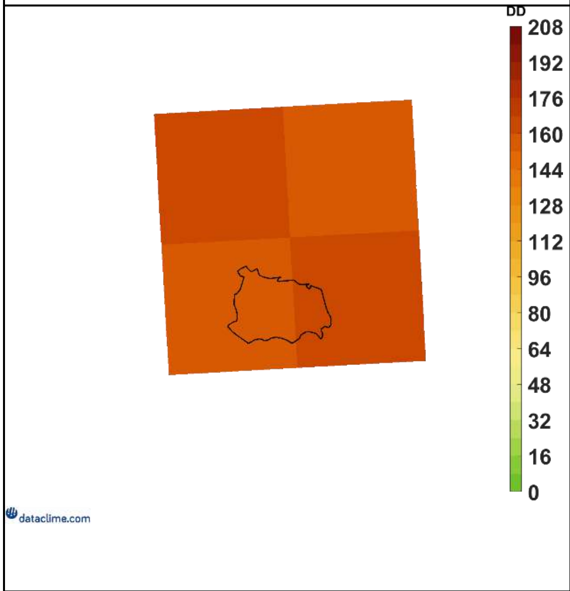
Historical Period (absolute)



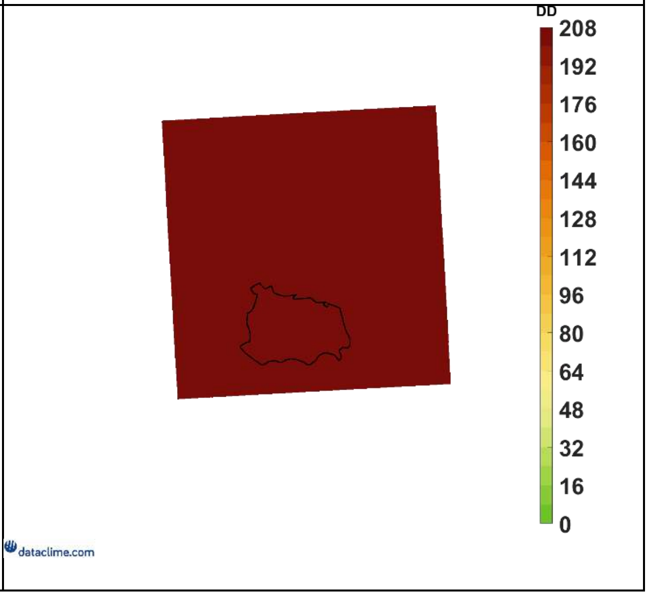
2050 RCP2.6 (projected change)



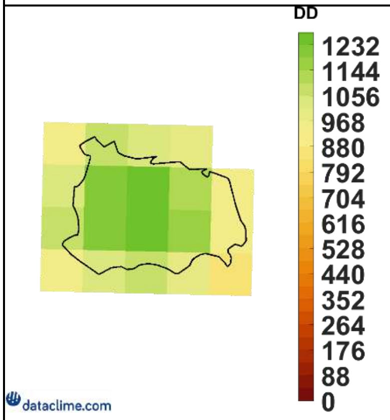
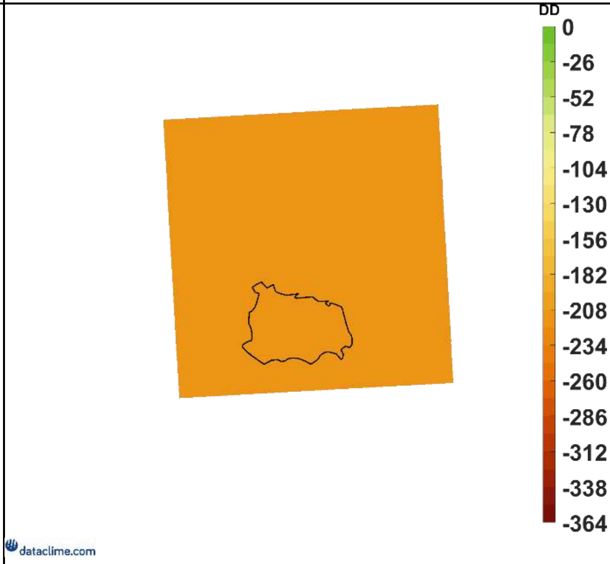
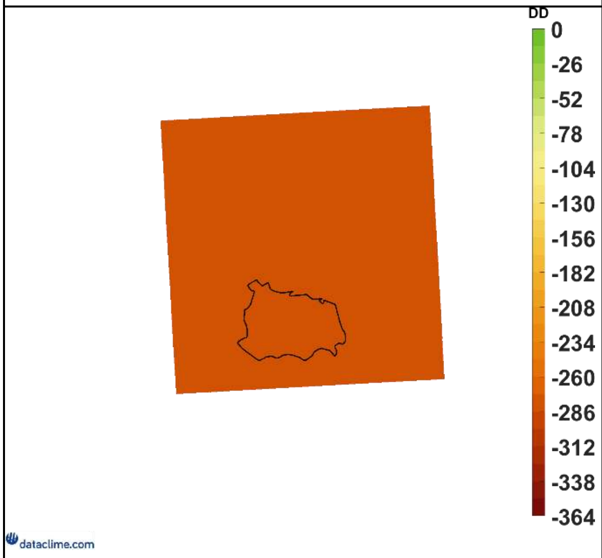
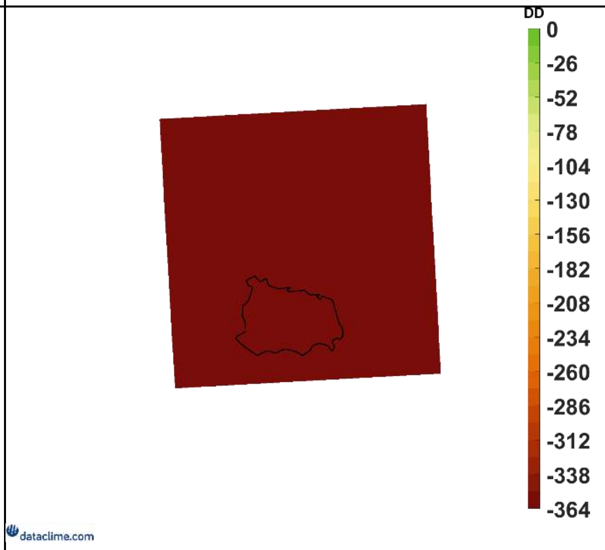
2050 RCP4.5 (projected change)



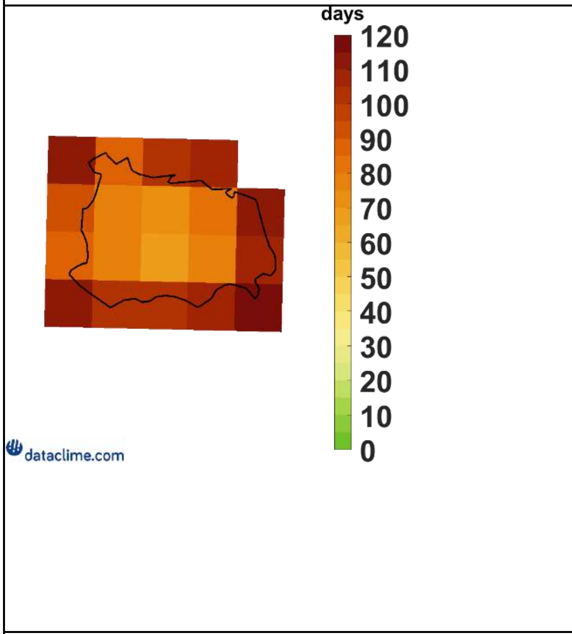
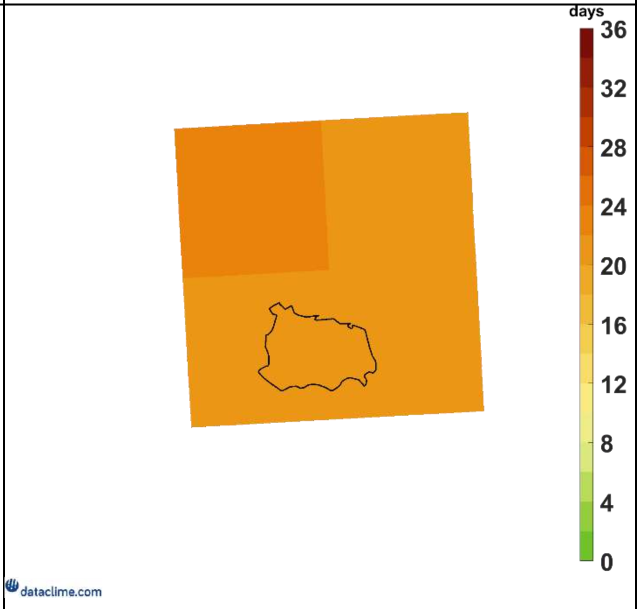
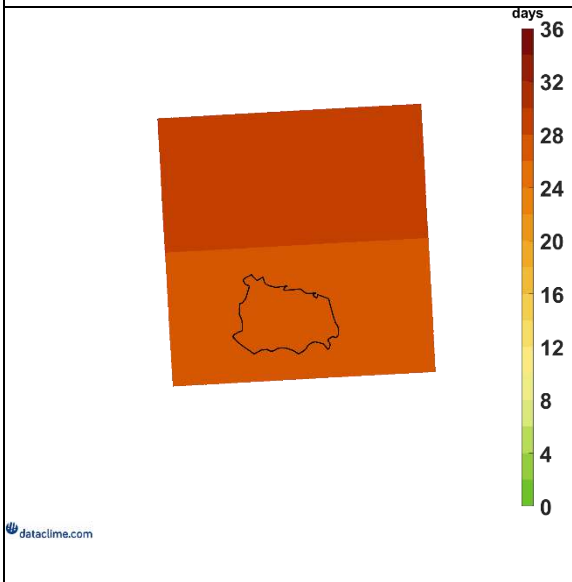
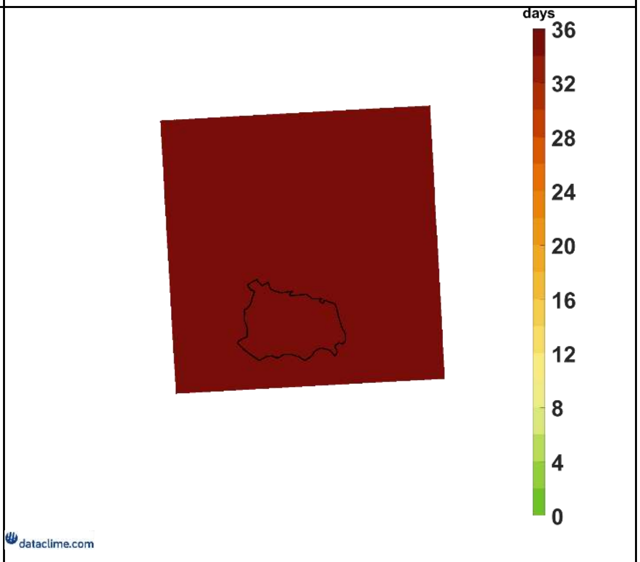
2050 RCP8.5 (projected change)



Heating degree days (DD)

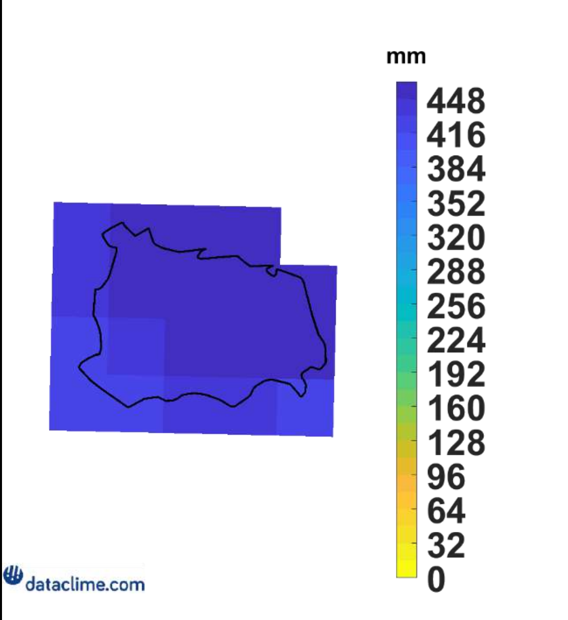
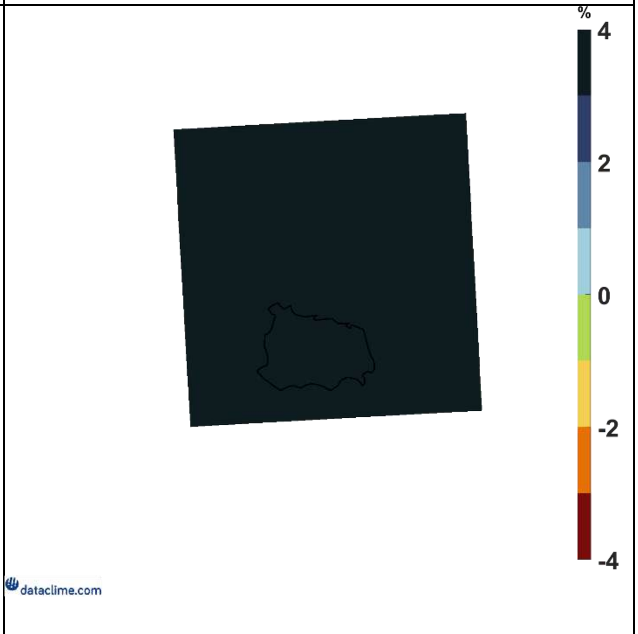
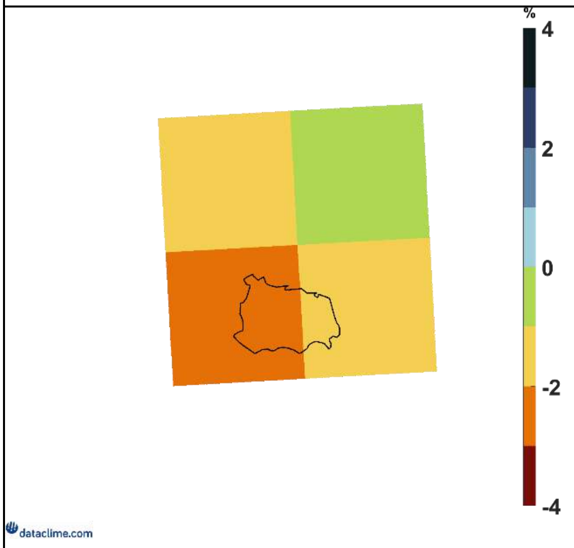
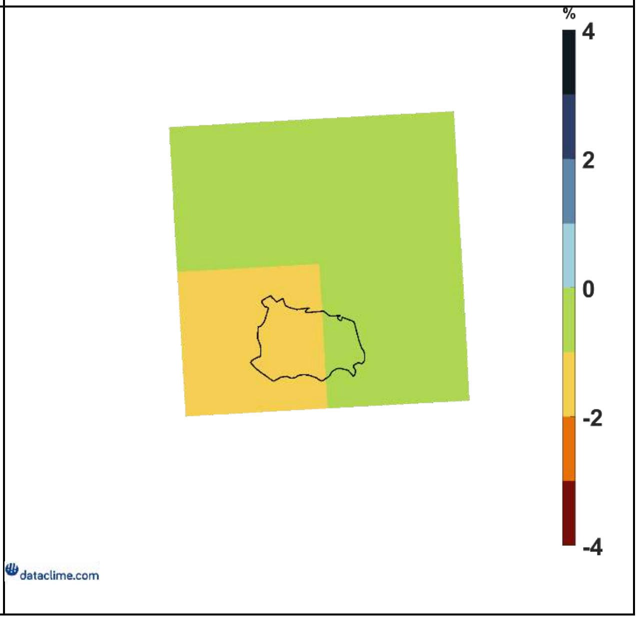
Historical Period (absolute)	2050 RCP2.6 (projected change)
	
2050 RCP4.5 (projected change)	2050 RCP8.5 (projected change)
	

Tropical nights (days)

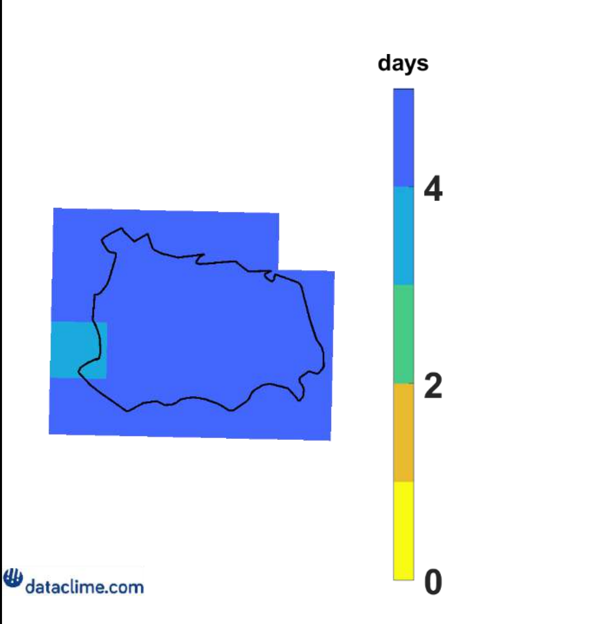
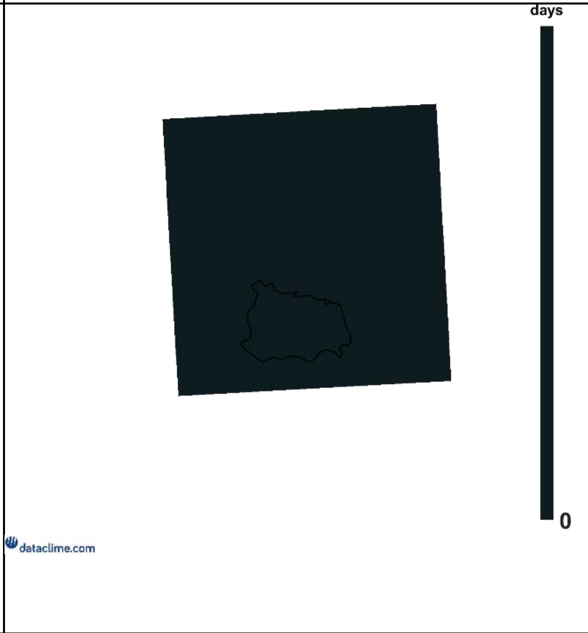
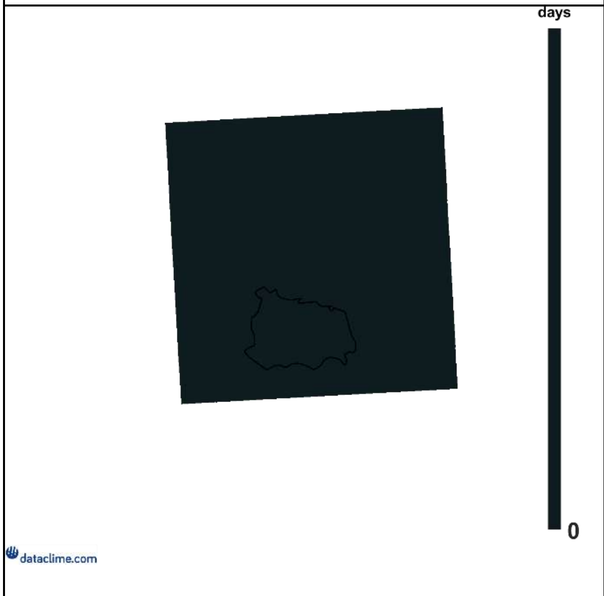
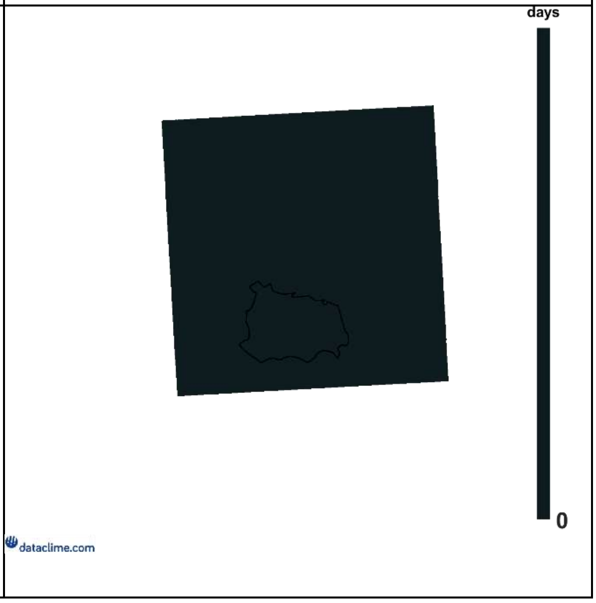
Historical Period (absolute)	2050 RCP2.6 (projected change)
	
2050 RCP4.5 (projected change)	2050 RCP8.5 (projected change)
	

2.2 Precipitation

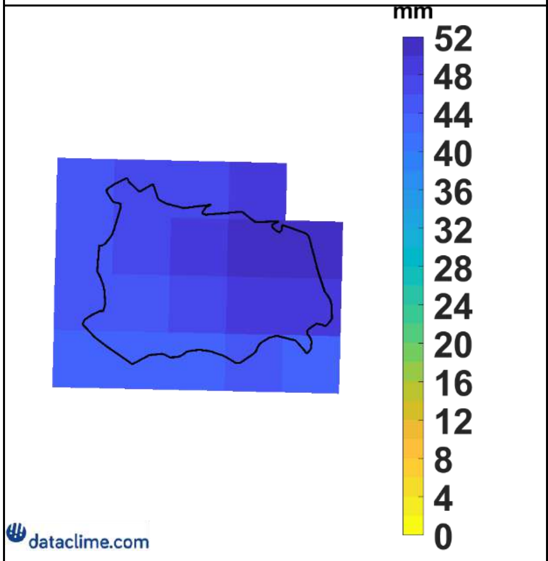
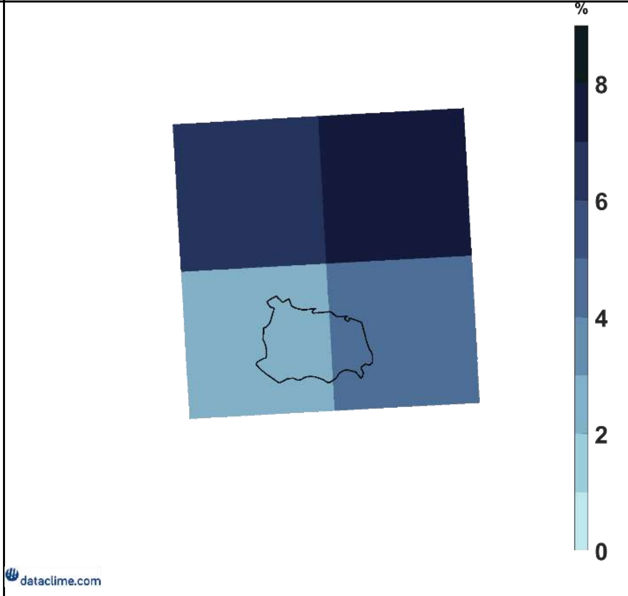
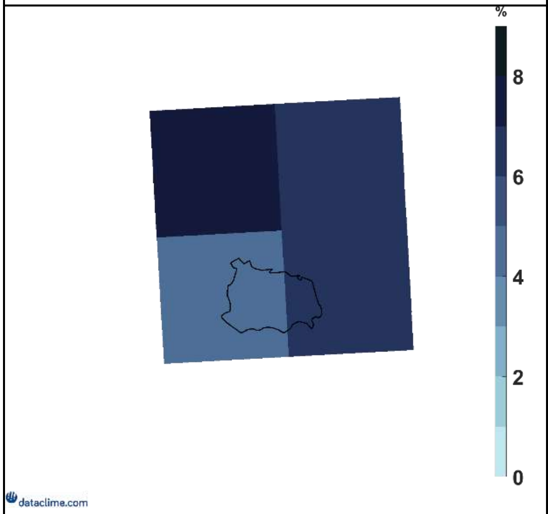
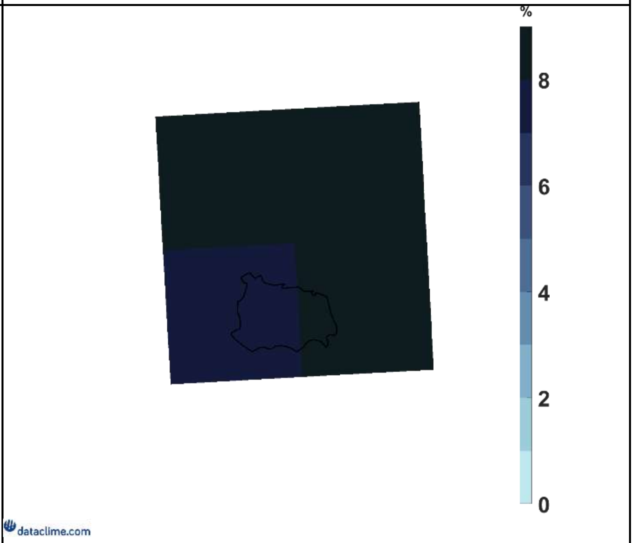
Average precipitation in wet days (mm)

Historical Period (absolute)	2050 RCP2.6 (projected change)
	
2050 RCP4.5 (projected change)	2050 RCP8.5 (projected change)
	

Very heavy precipitation days (days)

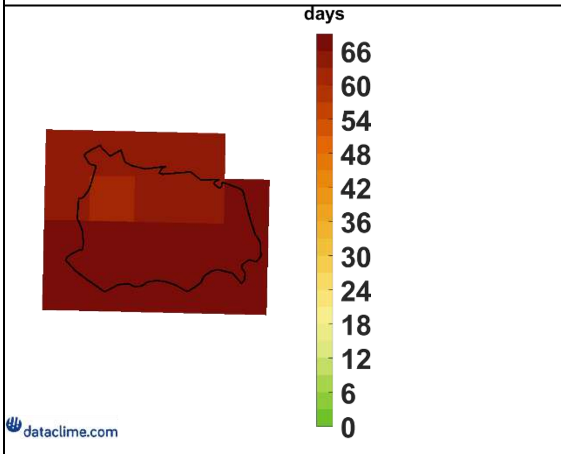
Historical Period (absolute)	2050 RCP2.6 (projected change)
	
2050 RCP4.5 (projected change)	2050 RCP8.5 (projected change)
	

Maximum 1-day precipitation (mm/day)

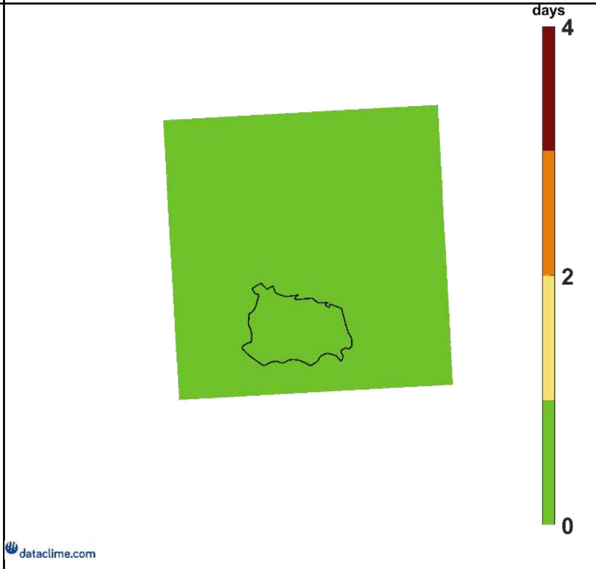
Historical Period (absolute)	2050 RCP2.6 (projected change)
	
2050 RCP4.5 (projected change)	2050 RCP8.5 (projected change)
	

Consecutive dry days (days)

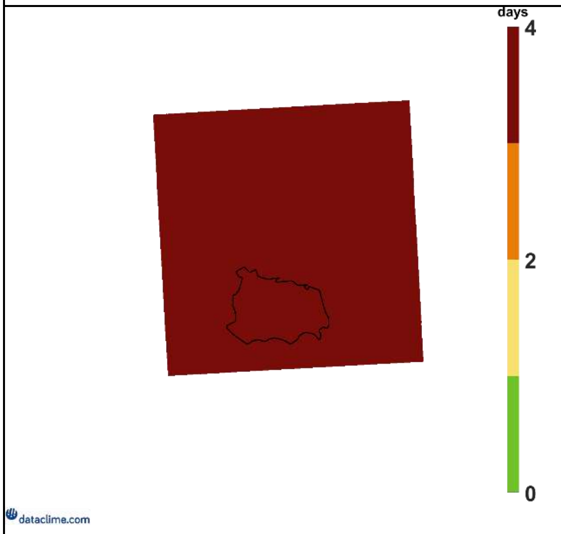
Historical Period (absolute)



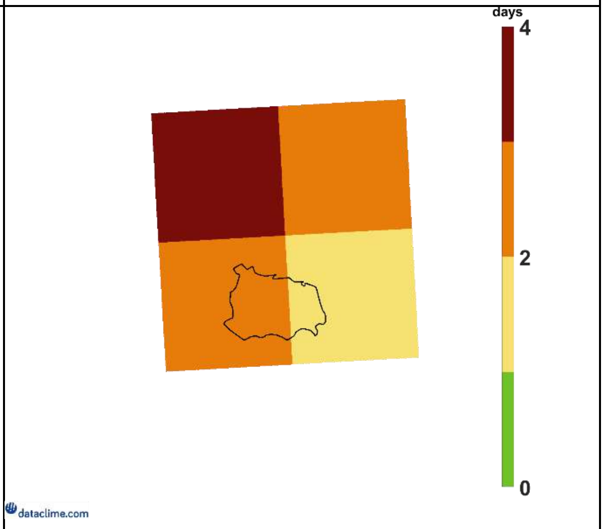
2050 RCP2.6 (projected change)



2050 RCP4.5 (projected change)



2050 RCP8.5 (projected change)



2.3 Wind

Extreme wind speed (m/s)

<table>
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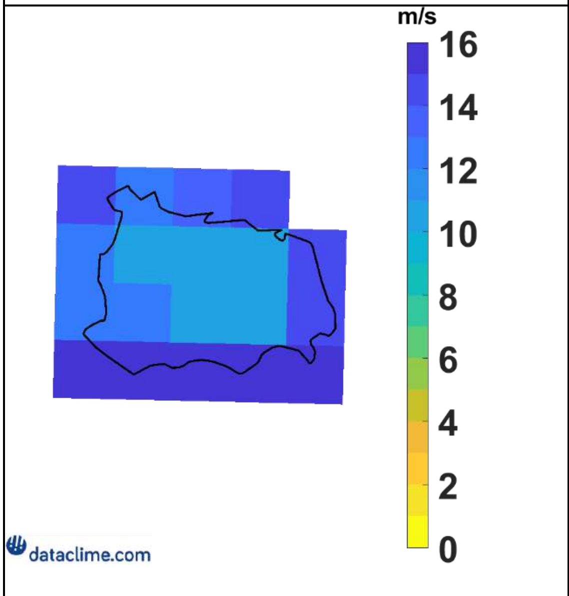
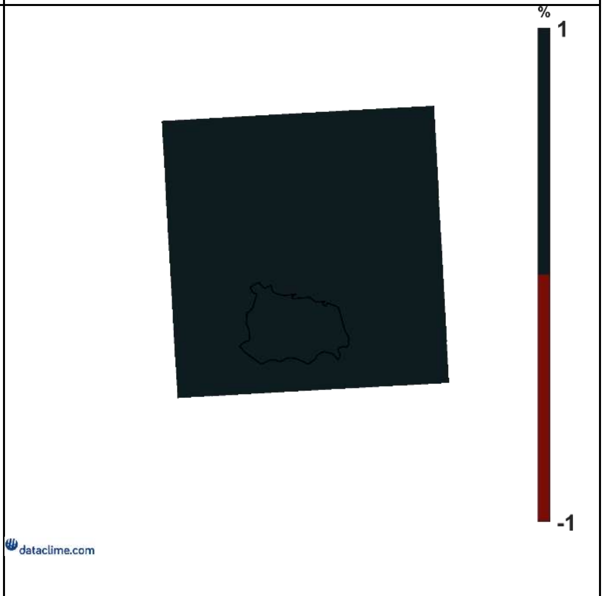
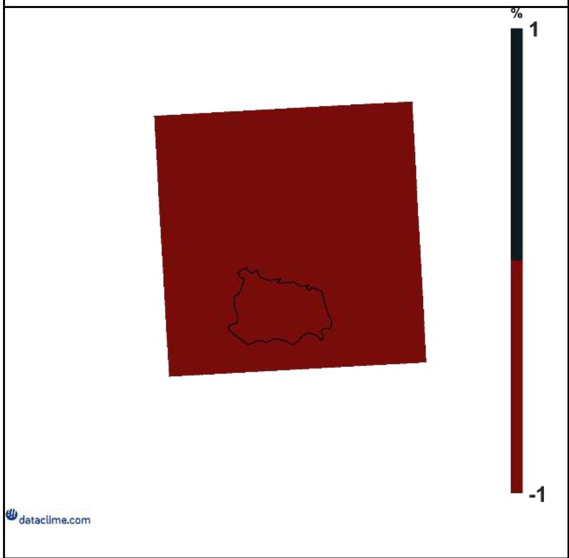
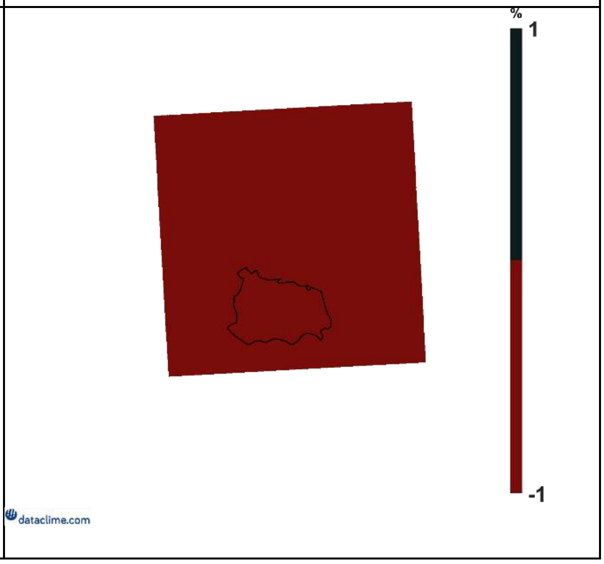
<tr><td>
</td><td>
</td></tr>
<tr><td>2050 RCP4.5 (projected change)</td><td>2050 RCP8.5 (projected change)</td></tr>
<tr><td>
</td><td>
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3 Appraisal of the disastrous event on November 26th 2022

During the first scope finding mission (3rd - 5th May, 2023), the Consultant had the opportunity to visit the area which was heavily affected by a disastrous event on November 20th 2022. This site visit gave important insights into the ongoing mechanism and characteristics of extreme landslide events in Ischia. In the following, the appraisal during and shortly after this site visit is documented in detail. However, it must be mentioned that in the meantime two scientific papers have been published, drawing a more detailed, yet, similar picture of the event.

3.1 Documentation

On November 26th, 2022, at approximately 05:00, a disastrous gravitational mass flow event (GMF) (i.e., combination of rock fall, landslide, and debris flows) occurred in the Municipality of Casamicciola on the Island of Ischia. Along its path, the event caused extensive damage to buildings, roads, cars, land and, unfortunately, the tragic demise of 12 people, including 4 children. On its way, the event hit homes located in Via Celario, continuing its course along Piazza Maio, Piazza Bagni and Via Monte della Misericordia, eventually reaching as far as the sea near the so-called "Anchor Monument" (Struttura Commissariale, 2023).

Extreme rainfall occurred on the Island of Ischia in the preceding hours of the event, leading to the detachment of several portions of ridges of Mount Epomeo (Strutt. Comm., 2023). Figure 3-1 gives an overview of several locations of GMFs and floods occurred during the extreme rainfall event. Several detachments happened, while one of these has fallen down several tens of meters and triggered a debris slide within the completely waterlogged pyroclastic soils located in the steep areas immediately below. This debris slide moved further down, eventually leading to the main disastrous event (Strutt. Comm., 2023). In total, approx. ~50.000 m³ of solid material has been mobilized.

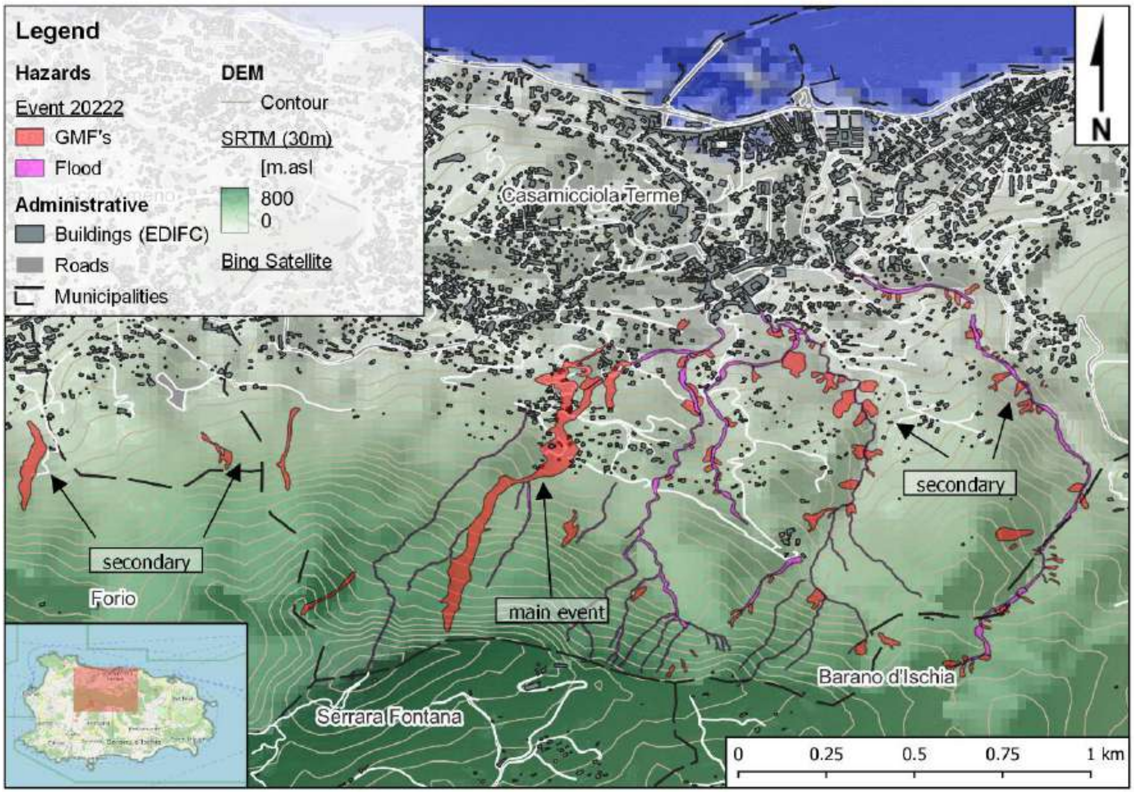


Figure 3-1 Overview map of the main disastrous and secondary events occurred on 26th Nov. 2022. (GIS-data sources of event mapping and infrastructures: Strutt. Comm., 2023)

Errore. L'origine riferimento non è stata trovata. shows two satellite images of Casamicciola prior (23rd Nov.) and after the disaster (1st Dec. 2022). Even in these low-resolution images, the main flow path of the main event can be seen (compare grey and red area). Furthermore, the water in the port is blurred by the sediment entring after the event (red rectangle). The satellite images have been obtained from Sentinelhub.

Figure 3-2 Sentinel-2 satellite images of Casamicciola taken on 23rd Nov. (left) and 1st Dec. 2022 (right); source: Sentinelhub

In summary, the main disastrous event was a cascading hydro-geological mass movement event comprising a rockfall/rockslide turning into a debris slide and debris flow, eventually, leading to a muddy torrential flood towards the city centre. Such complex events are mostly triggered by an extreme rainfall event, while the underlying drivers are of morphological, geological and seismic origin. The triggering conditions of these initial landslides appear to be attributable to phenomena of infiltration, sub-surface runoff (throughflow) and erosion occurring in the thin deposit of soil. Furthermore, antecedent rainfall plays an important role in the development of gravitational mass flows in pyroclastic soils (Uzielli et. al., 2018). The analysis of the actual precipitation is discussed in chapter 3.2 of this appendix. The morphological, geological and seismic background is described in the main report's chapter 1.4.

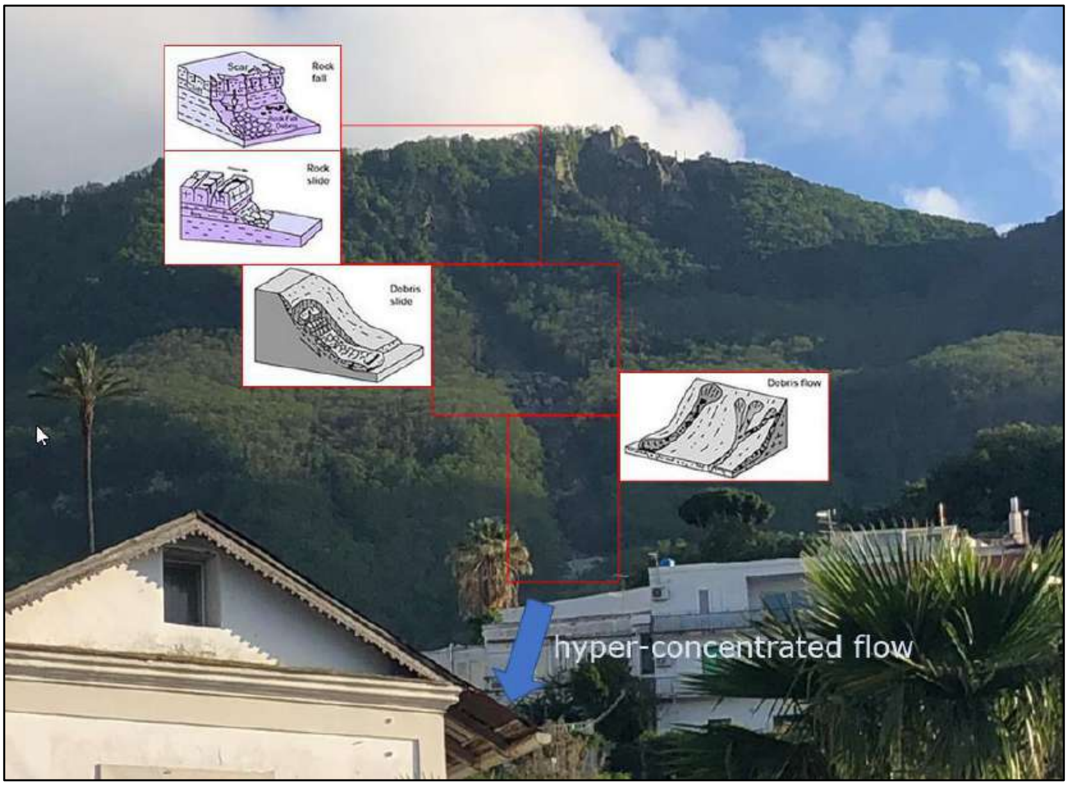


Figure 3-3 Mission documentation: analysis of processes related to the cascading event (date of photo: 05/12/2023)

In detail, a rockslide of solid materials with a thickness of a few tens of centimetres triggered massive amount of material. The debris slide detached from the mountain in a rapid flow (approx. 10 – 15 m³/s). It moved in the form of a veritable avalanche of sediment and trees in the upstream sections (Figure 3-4, Figure 3-5) turning into a debris flow in the existing flow channel. The rapid slide in the upstream section was slowed flow down by a small plane area with less slope. Approx. 40.000 m³ of material was deposited in this area, leading to massive damage of existing infrastructure. Eventually, the debris turned into a hyper-concentrated flow of water mixed with high concentrations of fine materials in the middle valleys and plains (Figure 3-6, Figure 3-7). The following pictures have been taken during the scope finding mission (10th to 12th May 2023).

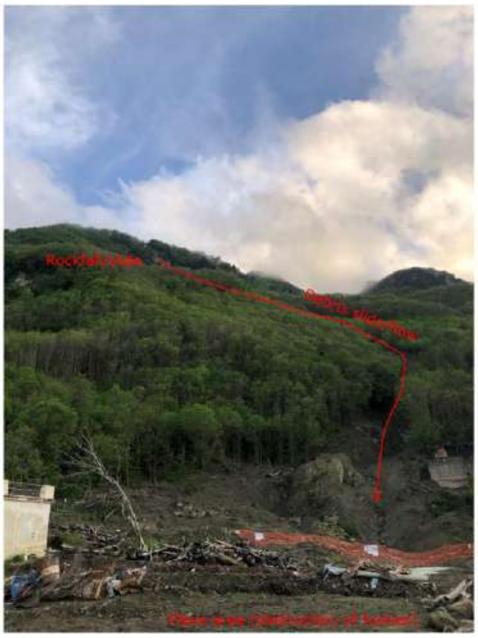


Figure 3-4 Mission documentation: upstream sections (date of photo: 05/10/2023)

Figure 3-5 Mission documentation: plain area – view downstream (date of photo: 05/10/2023)

Figure 3-6. Mission documentation: view upstream to plain area (date of photo: 05/10/2023).

Figure 3-7 Mission documentation: view downstream of hyper-concentrated flow path (date of photo: 05/10/2023)

3.2 Triggering precipitation event

Four precipitation stations (i.e., Monte Epomeo, Forio, Piano Liguori and Ischia) exist on the Island of Ischia. Detailed overview of the locations can be seen in Figure 1-15. The four stations have been in operation prior the event and the observations have been evaluated by (Strutt. Comm., 2023).

Figure 3-8 shows regional rainfall duration probability curves and the comparison of the observed sums of rainfall triggering the disastrous event. The regional rainfall probability curves are provided for different return periods (i.e., T=20, 50, 100, 200, 500 years). The figure shows that the station Forio received the highest amount of rainfall, while Piano Liguori received the lowest amount in total. The comparison shows that the shortest durations (1-2 hours) of rainfalls where in the range of a 20 to 50 years event depending on the station. Durations from 4 to 6 hours were of higher return periods, while the sums of 12-hours rainfall were clearly in the in the range of an extreme event with return periods between 200 – 500 years.

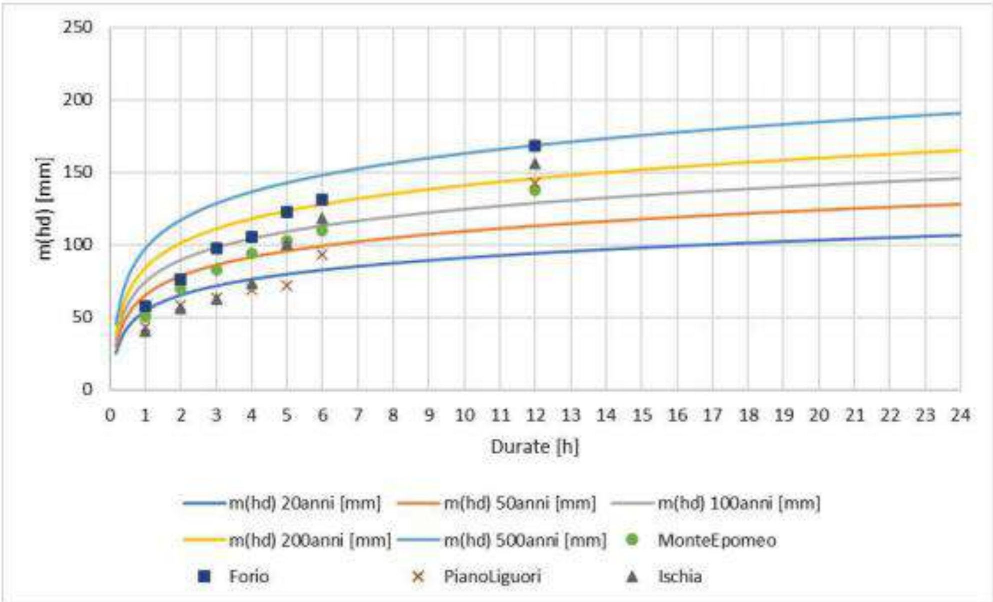


Figura 7 - Confronto tra la curva di probabilità pluviometrica regionale per la sola isola di Ischia al variare del periodo di ritorno e i massimi pluviometrici relativi all'evento del 26 novembre.

Figure 3-8 Rainfall duration curves for the Island of Ischia and observed station data (source: Piano commissariale di interventi urgenti)

The following figure shows a violine plot of daily rainfall events for the years 2000 – 2022 based on the Monte Epomeo gaging station. Rainfall events are defined as days, where the daily rainfall sum is larger than 1 mm/day. The plot shows, that the mean daily rainfall event is approx. 11 mm/day, and the 90-%-quantile is approx. 24 mm/day based on this data. The red dot in the figure marks the event recorded on November 26th, 2022, which was highest observed event, and thus an outstanding extreme rainfall event.

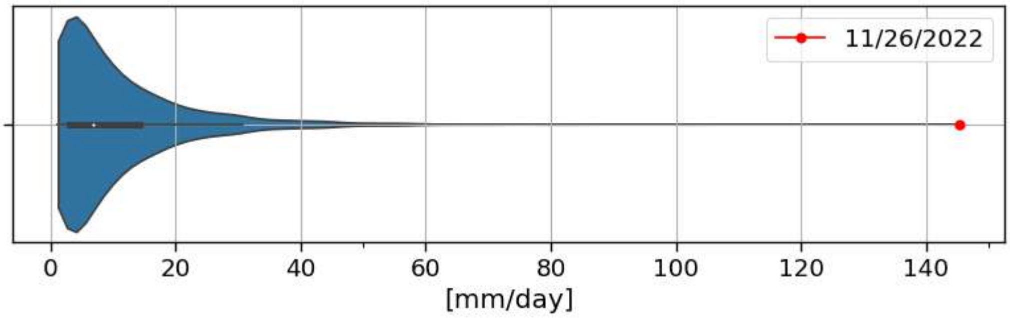


Figure 3-9 Violine plot showing the distribution of daily rainfall events (> 1 mm) from 2000 to 2022 based on Monte Epomeo station.

Berti et. al., 2012, Uzielli et. al., 2018 and references therein state that in pyroclastic soils the antecedent rainfall before a landslide plays a certain role in the triggering process. Figure 3-10 shows the antecedent rainfall sums of 30 days prior each rainfall event (> 1 mm) from 2000 to 2022 based on Monte Epomeo gauging station. It can be seen that the rainfall sum from 10/25 to 11/25/2022 (one day before the event) was 137 mm/30 days, which is in the range of the 75-%-quantile. Thus, the antecedent rainfall sum was high, but not very extreme in this case.

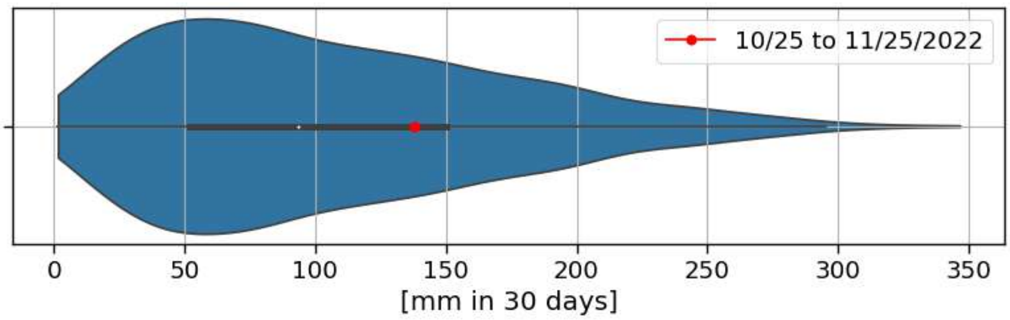


Figure 3-10 Violine plot showing the distribution of antecedent rainfall 30 days prior a rainfall event (> 1 mm) from 2000 to 2022 based on Monte Epomeo station.

3.3 Conclusions

The disastrous event occurred on 26th November 2022 was a very complex cascading event, starting with a rockfall, turning into a debris slide and flow and, eventually, leading to a hyper-concentrated flow with a runout into the port of Casamicciola.

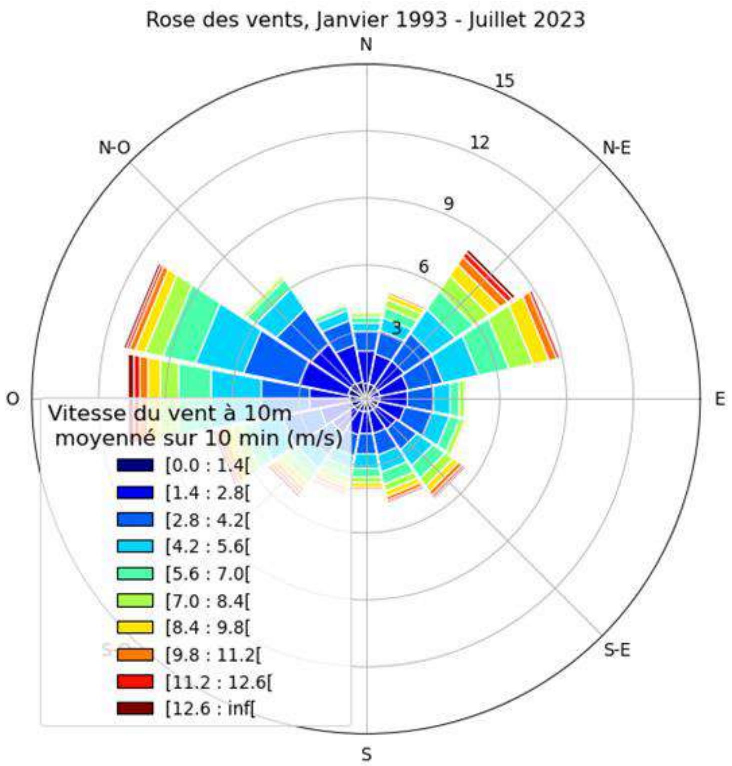
Such events have an enormous destructive potential due to the high flow velocities and material (rocks, sediments, mud) that are transported. The causes of such events are manifold and are a combination of morphological, geological, and seismic circumstances as well as extreme precipitation events. The actual triggering conditions are attributable to the processes of infiltration, sub-surface runoff and erosion occurring in the thin blanket of soil.

The occurrence of this specific event cannot be only attributed to actual climate change. In other words, the unfavourable geomorphological setting of the slopes at Mount Epomeo are susceptible to landslides and other mass movement in general, especially on the steeper mountain sides. Extreme rainfall events, accidentally for instance close in time to seismic activity, can always happen – independent of climate change. However, with respect to climate change, it can be stated that the likelihood of any landslide activation might increase in the future. Shifts in precipitation and temperature might also lead to greater erosion rates, increasing the potential mobilized amount of material.

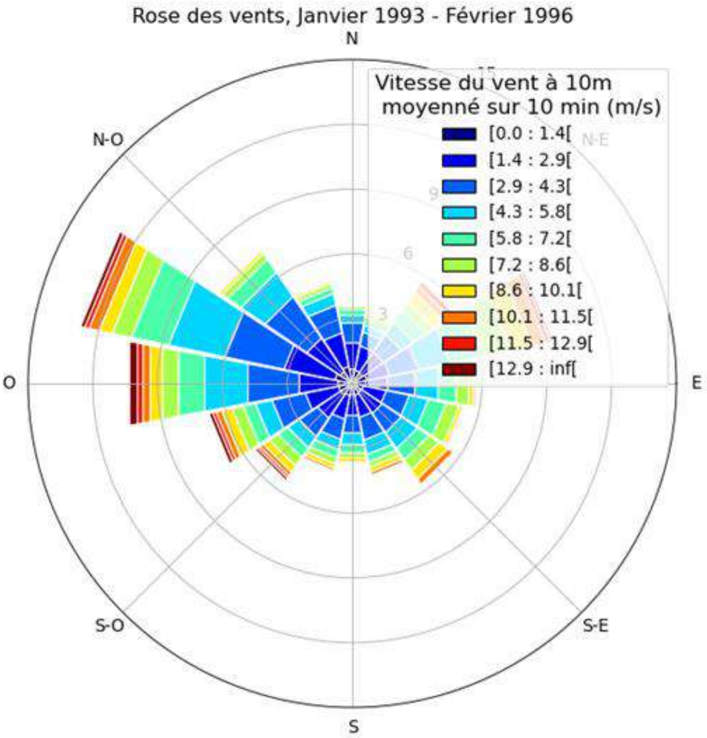
4 Additional information on Mediterranean Oceanography

This Appendix provides additional graphical information on wind and wave statistics and on artificial coastal defence structures in Ischia.

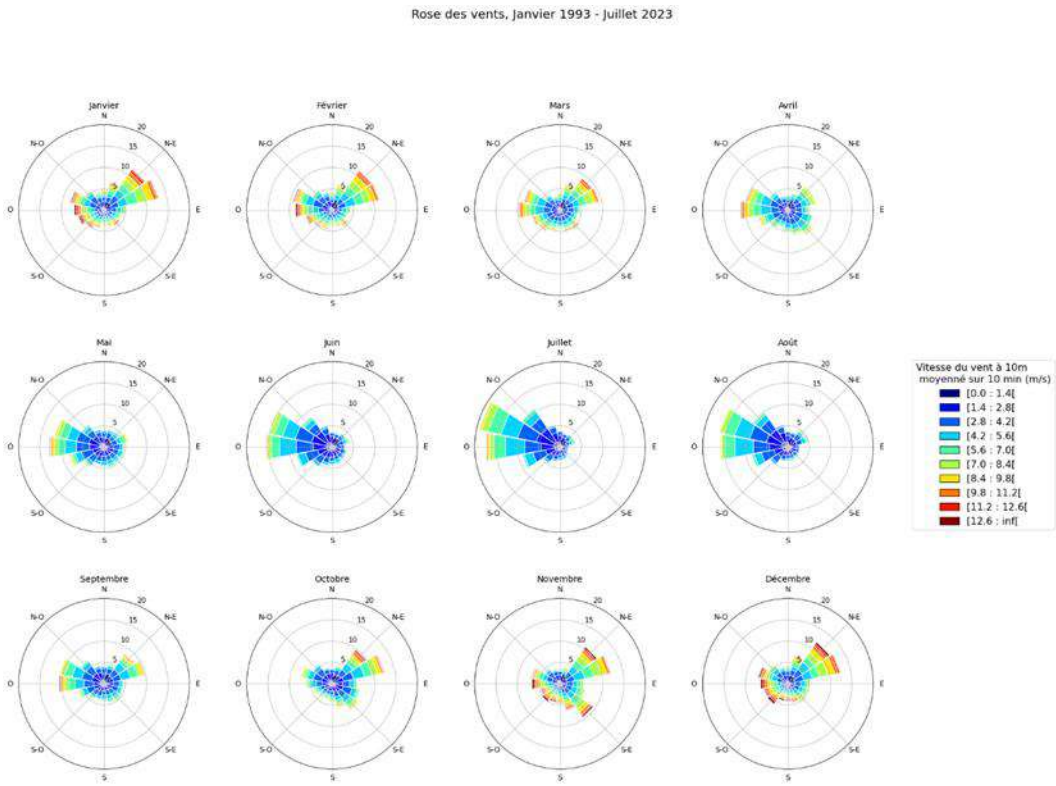
4.1 Wind statistics



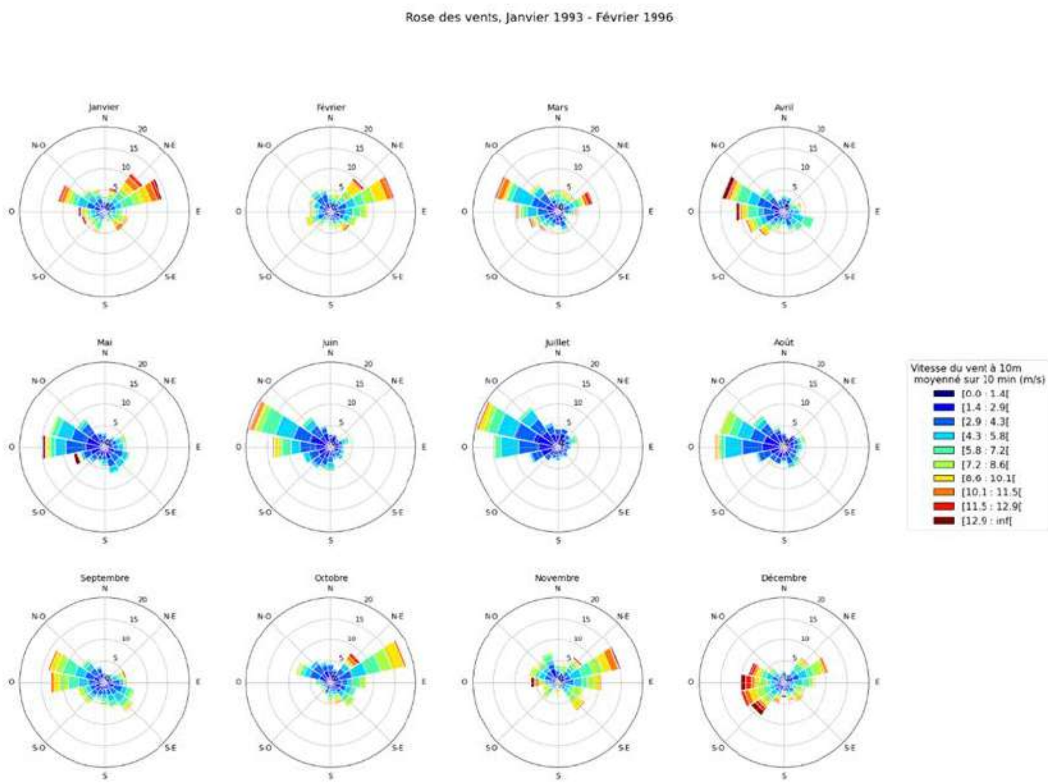
Wind rose at the East point



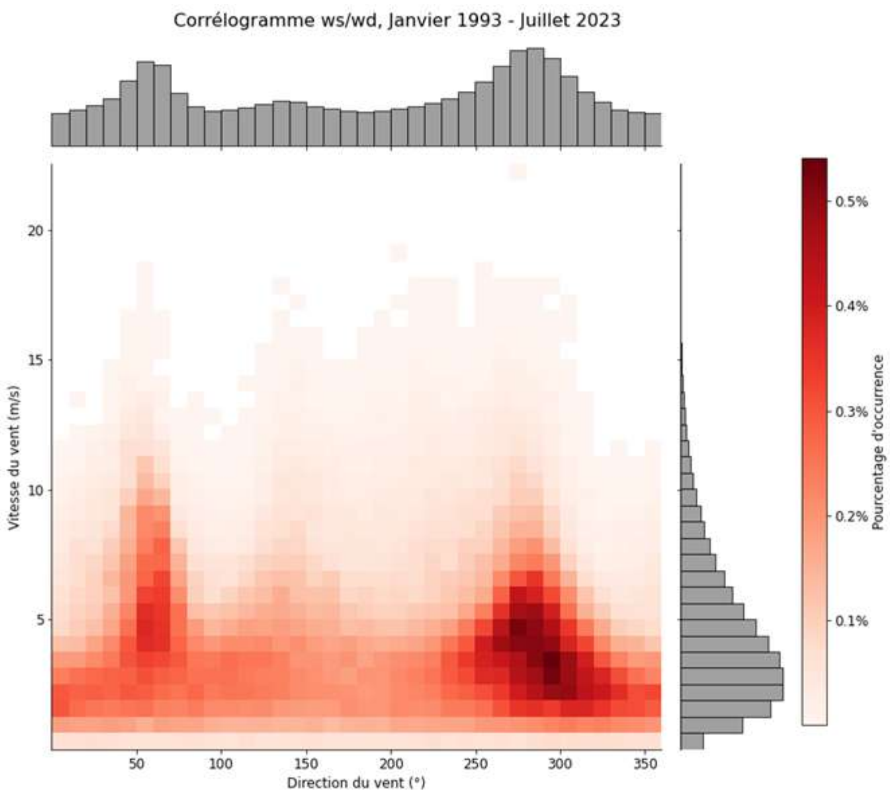
Wind rose at the West point



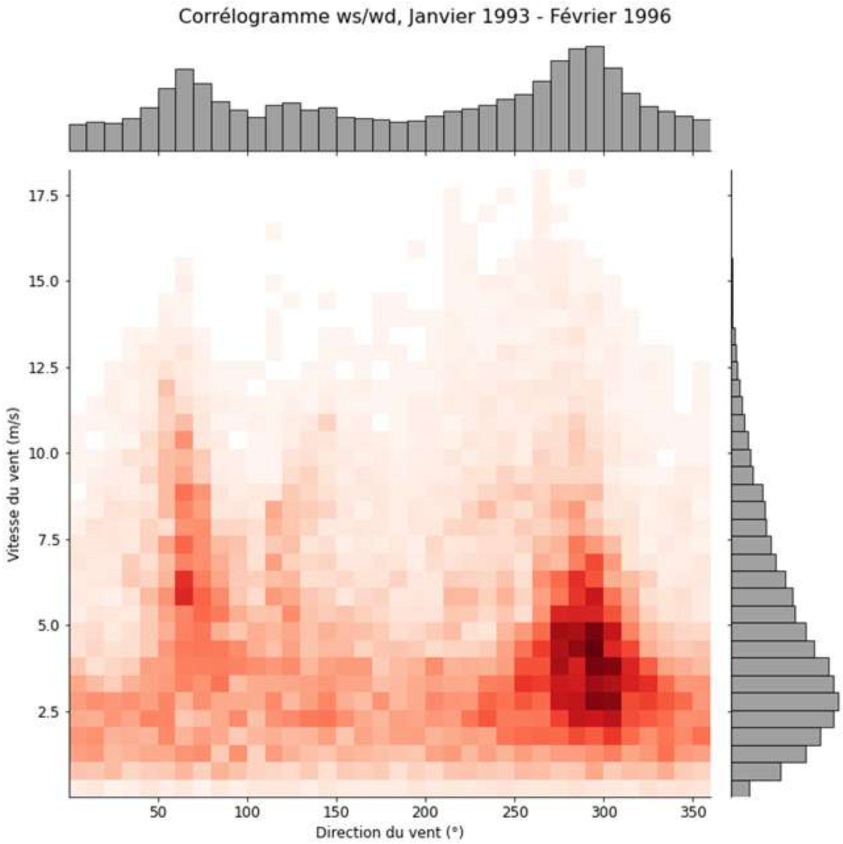
Monthly wind roses at the East point



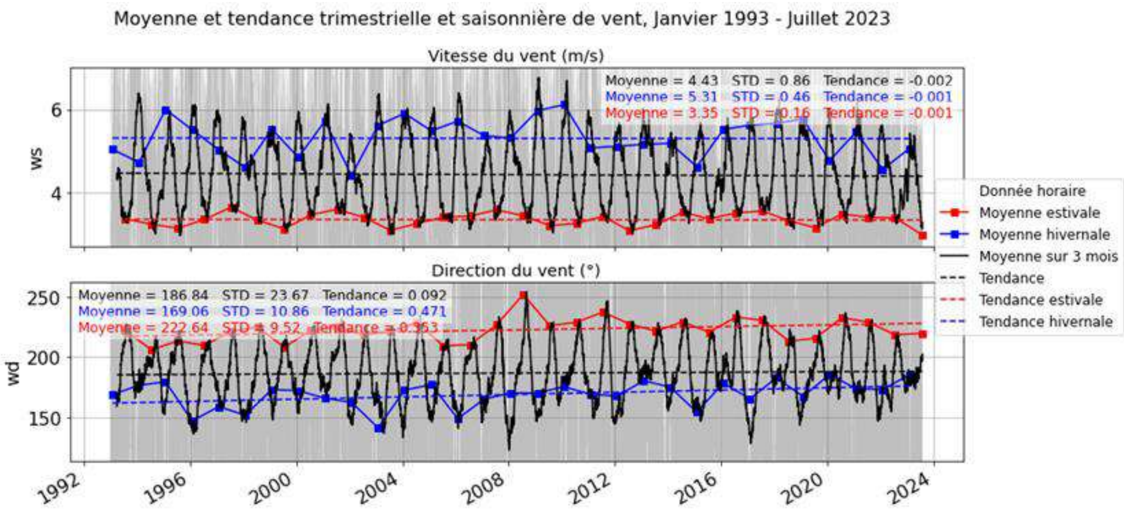
Monthly wind roses at the West point



Correlogram wind speed and direction at the East point

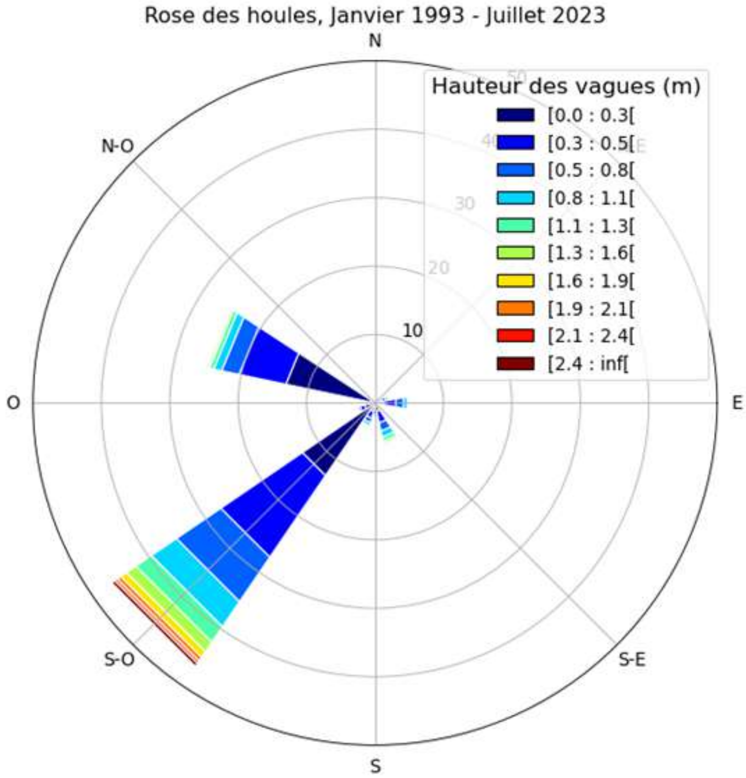


Correlogram wind speed and direction at the West point

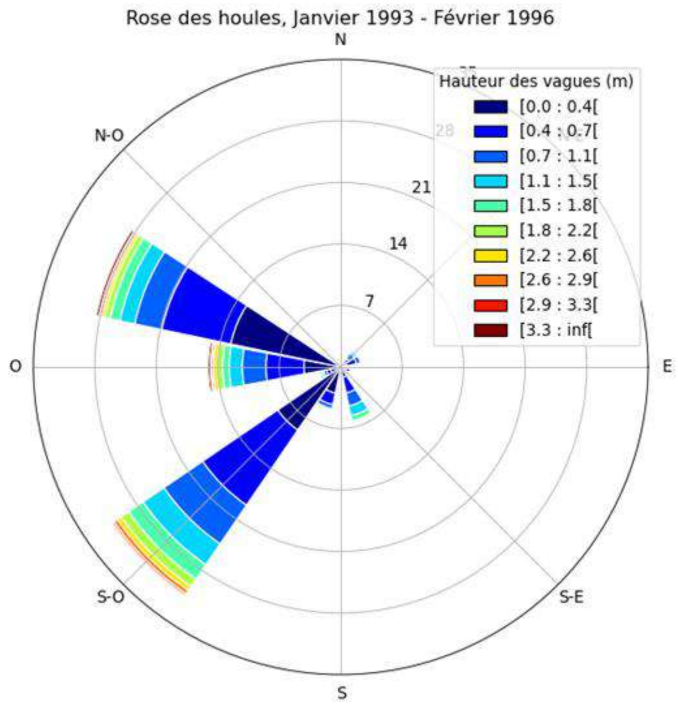


Wind trimestral average trends from 1993 to 2023

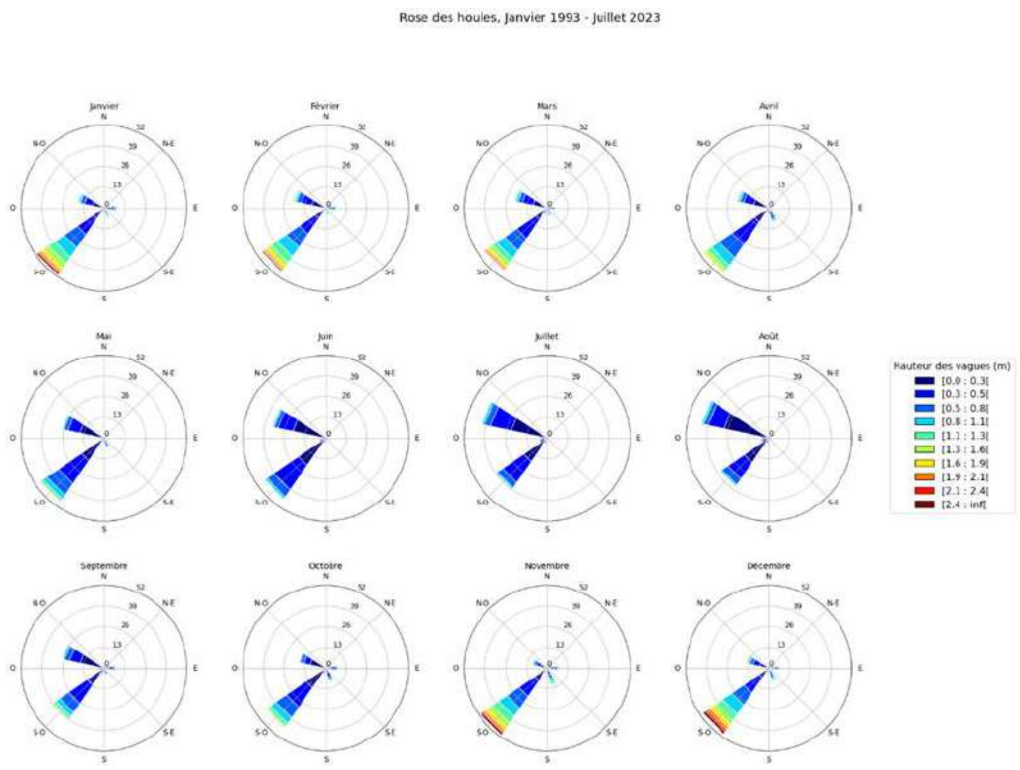
4.2 Wave statistics



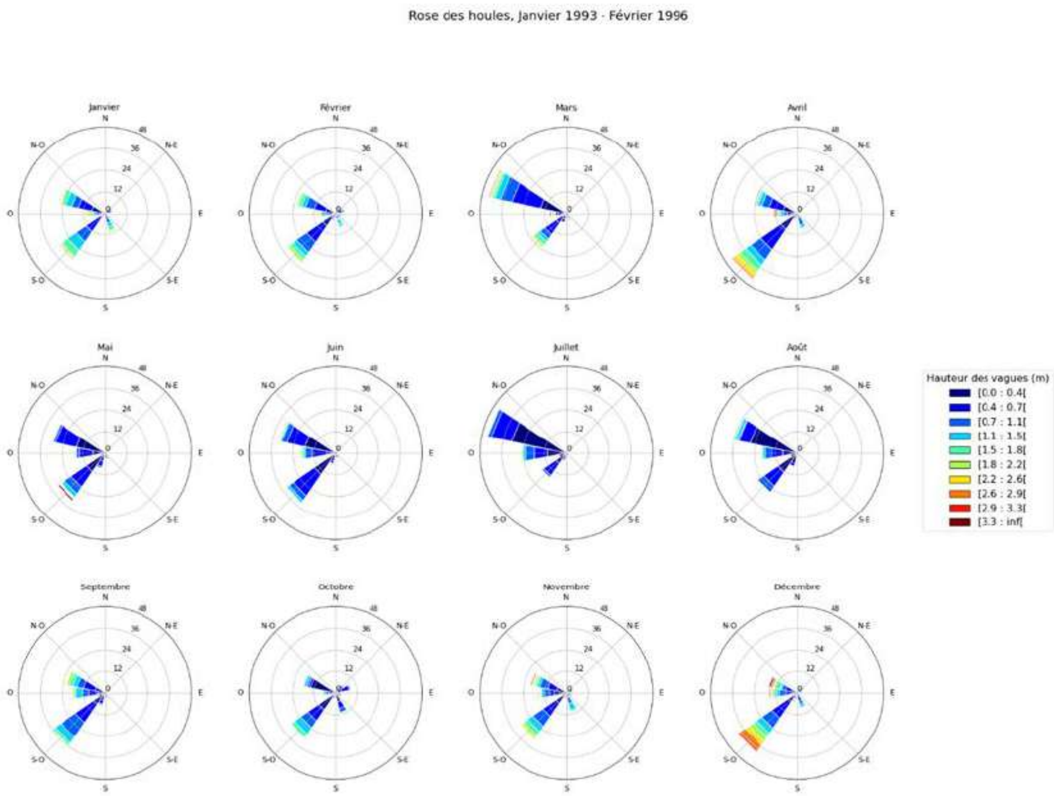
Wave rose at the East point



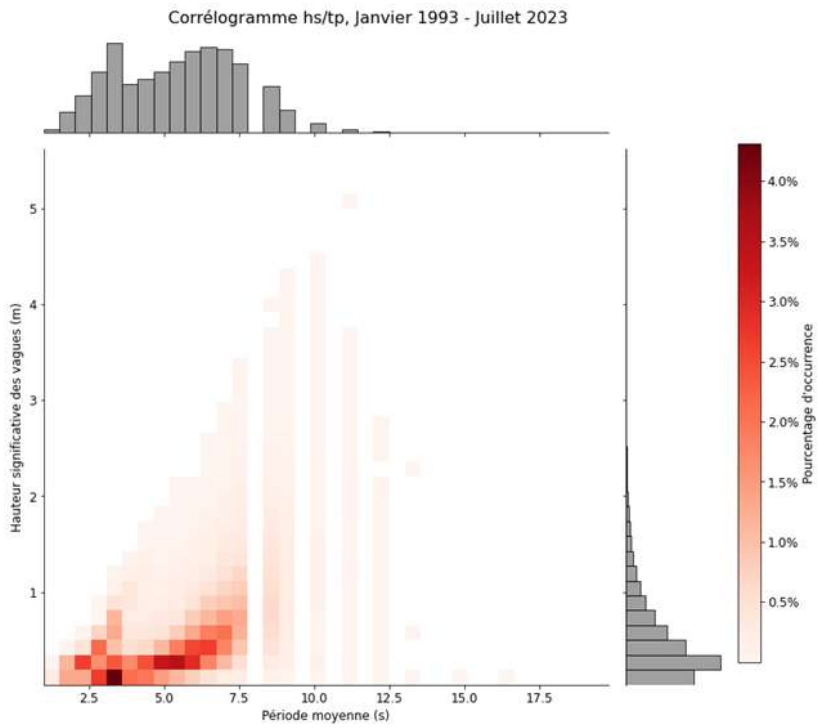
Wave rose at the West point



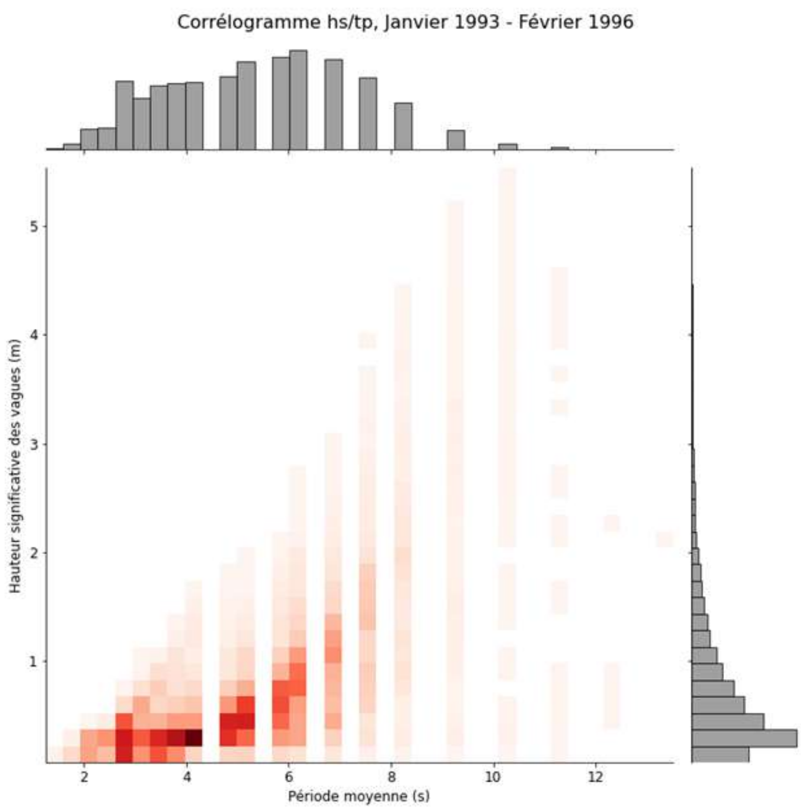
Monthly wave roses at the East point



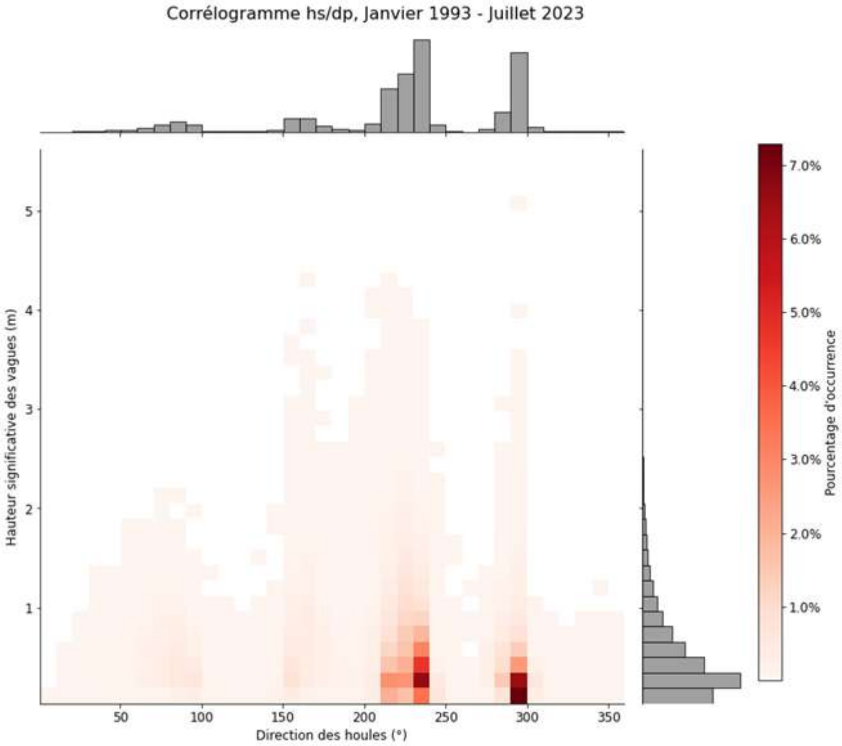
Monthly wave roses at the West point



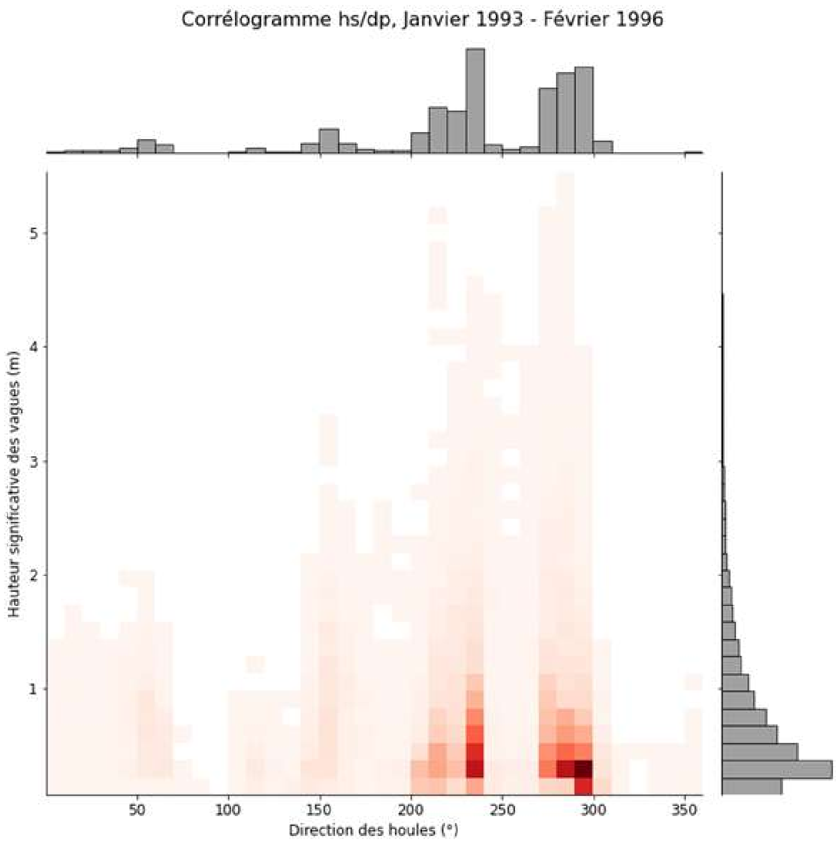
Correlogram wave height and period at the East point



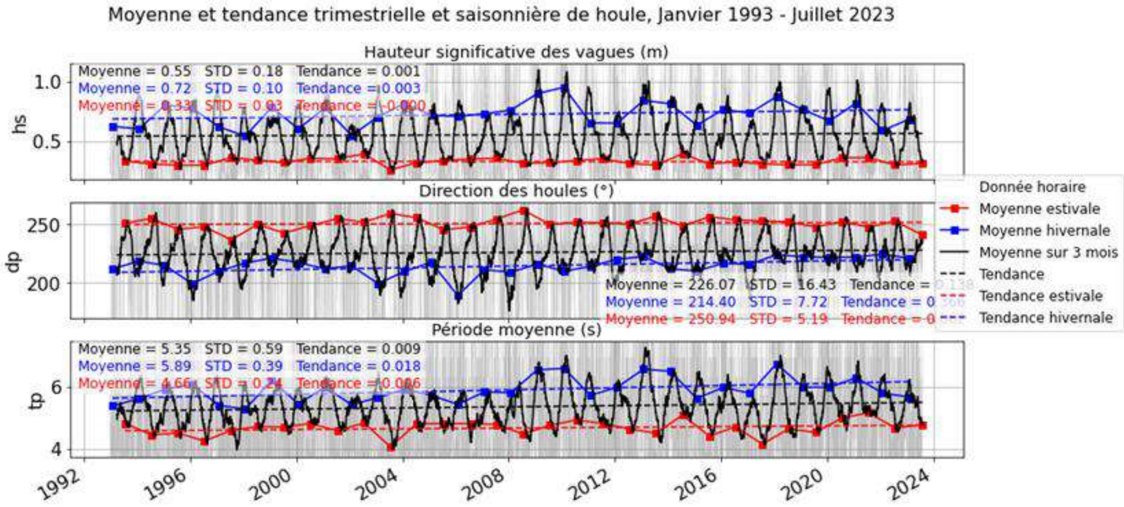
Correlogram wave height and period at the West point



Correlogram wave height and direction at the East point



Correlogram wave height and direction at the West point



Wave trimestral average trends from 1993 to 2023

4.3 Artificial coastal defence structures

In addition to the aerial photograph of all coastal defences on the island, as shown in Figure 3-21 in Chapter 3.3 and shown below, images of all single coastal defence structures are provided in this Chapter.

5 Detailed results for IDF curves under climate change

Table 5-1: CORDEX climate model runs (combination of GCM and RCM) used in the analysis of IDF curves

ID	modello GCM	modello RCM
1	CNRM-CERFACS-CNRM-CM5	r1i1p1_CNRM-ALADIN63_v2
2	CNRM-CERFACS-CNRM-CM5	r1i1p1_KNMI-RACMO22E_v2
3	ICHEC-EC-EARTH	r12i1p1_CLMcom-CCLM4-8-17_v1
4	ICHEC-EC-EARTH	r12i1p1_KNMI-RACMO22E_v1
5	ICHEC-EC-EARTH	r12i1p1_SMHI-RCA4_v1
6	ICHEC-EC-EARTH	r3i1p1_DMI-HIRHAM5_v2
7	MOHC-HadGEM2-ES	r1i1p1_DMI-HIRHAM5_v2
8	MOHC-HadGEM2-ES	r1i1p1_KNMI-RACMO22E_v2
9	MOHC-HadGEM2-ES	r1i1p1_SMHI-RCA4_v1
10	MPI-M-MPI-ESM-LR	r1i1p1_MPI-CSC-REMO2009_v1
11	MPI-M-MPI-ESM-LR	r1i1p1_SMHI-RCA4_v1a
12	MPI-M-MPI-ESM-LR	r2i1p1_MPI-CSC-REMO2009_v1
13	NCC-NorESM1-M	r1i1p1_GERICS-REMO2015_v1
14	NCC-NorESM1-M	r1i1p1_SMHI-RCA4_v1

Table 5-2: Detailed results (for different return periods and durations) for the 14 CORDEX climate model runs under RCP2.6

h_{BC} (d=1 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	46.7	42.9	42.7	39.1	43.4	42.3	47.8	37.5	38.2	37.1	39.6	48.4	42.7	42.8	42.2	3.7	0.1
10	55.8	60.4	49.5	44.6	50.2	49.7	54.5	46.3	47.6	42.9	47.3	59.5	48.9	49.8	50.5	5.2	0.1
20	65.6	89.9	56.0	50.2	56.7	56.8	61.0	57.1	59.2	48.6	56.2	72.2	54.8	56.5	60.1	10.4	0.2
50	79.8	162.6	64.4	58.1	65.1	65.9	69.4	75.8	79.2	55.9	70.6	92.1	62.5	65.3	76.2	26.6	0.3
100	91.9	263.6	70.8	64.5	71.4	72.8	75.6	94.3	99.0	61.4	84.1	110.0	68.3	71.8	92.8	51.2	0.6

h_{BC} (d=3 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	61.6	56.5	56.3	51.6	57.2	55.8	63.0	49.4	50.3	48.8	52.2	63.7	56.2	56.4	55.6	4.8	0.1
10	73.6	79.6	65.2	58.7	66.1	65.5	71.9	61.0	62.7	56.6	62.3	78.5	64.4	65.6	66.6	6.9	0.1
20	86.4	118.5	73.8	66.1	74.7	74.8	80.4	75.3	78.1	64.1	74.1	95.2	72.2	74.5	79.2	13.7	0.2
50	105.2	214.3	84.9	76.5	85.8	86.9	91.4	99.9	104.4	73.7	93.1	121.4	82.4	86.0	100.4	35.1	0.3
100	121.1	347.4	93.3	85.0	94.1	96.0	99.7	124.2	130.4	80.9	110.8	145.0	90.0	94.6	122.3	67.4	0.6

h_{BC} (d=6 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	71.0	65.1	64.8	59.4	65.9	64.3	72.6	57.0	58.0	56.3	60.2	73.4	64.8	65.0	64.1	5.5	0.1
10	84.8	91.7	75.2	67.7	76.2	75.5	82.8	70.3	72.3	65.2	71.8	90.4	74.2	75.6	76.7	8.0	0.1
20	99.6	136.5	85.1	76.2	86.1	86.2	92.6	86.7	90.0	73.8	85.4	109.7	83.3	85.9	91.2	15.8	0.2
50	121.2	247.0	97.9	88.2	98.9	100.2	105.3	115.1	120.3	84.9	107.3	139.9	95.0	99.1	115.7	40.5	0.4
100	139.5	400.3	107.5	97.9	108.4	110.6	114.9	143.1	150.3	93.3	127.7	167.1	103.7	109.1	141.0	77.7	0.6

h_{BC} (d=12 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	80.8	74.2	73.9	67.7	75.1	73.2	82.7	64.9	66.0	64.1	68.6	83.6	73.8	74.0	73.0	6.3	0.1
10	96.6	104.5	85.6	77.1	86.8	86.0	94.4	80.1	82.3	74.3	81.8	103.0	84.5	86.2	87.4	9.1	0.1
20	113.4	155.5	96.9	86.8	98.0	98.2	105.5	98.8	102.5	84.1	97.2	125.0	94.8	97.8	103.9	18.0	0.2
50	138.1	281.3	111.5	100.5	112.6	114.1	120.0	131.1	137.0	96.7	122.2	159.4	108.2	112.9	131.8	46.1	0.3
100	158.9	456.0	122.4	111.5	123.5	126.0	130.8	163.1	171.2	106.2	145.4	190.4	118.1	124.2	160.6	88.5	0.6

h_{BC} (d=24 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	91.5	84.0	83.6	76.6	85.0	82.9	93.6	73.5	74.7	72.6	77.6	94.7	83.6	83.8	82.7	7.2	0.1
10	109.4	118.3	96.9	87.3	98.3	97.4	106.8	90.6	93.2	84.1	92.6	116.6	95.7	97.6	98.9	10.3	0.1
20	128.4	176.1	109.7	98.3	111.0	111.2	119.5	111.9	116.0	95.2	110.1	141.5	107.4	110.8	117.6	20.3	0.2
50	156.3	318.5	126.2	113.7	127.5	129.2	135.9	148.4	155.2	109.5	138.3	180.4	122.5	127.8	149.3	52.2	0.3
100	179.9	516.3	138.6	126.3	139.9	142.6	148.1	184.6	193.8	120.3	164.7	215.5	133.8	140.7	181.8	100.2	0.6

Table 5-3: Detailed results (for different return periods and durations) for the 14 CORDEX climate model runs under RCP4.5

h_{BC} (d=1 hour) [mm]																
RT (years)	**ID1**	**ID2**	**ID3**	**ID4**	**ID5**	**ID6**	**ID7**	**ID8**	**ID9**	**ID10**	**ID11**	**ID12**	**ID13**	**ID14**	**EM**	**DS**	**CV**
5	47.7	36.0	41.7	45.8	39.3	43.9	48.6	35.9	36.1	37.0	51.1	42.5	41.2	39.1	41.8	5.0	0.1
10	65.3	45.5	49.6	52.3	45.1	51.2	56.5	42.0	42.0	42.9	59.7	49.0	52.2	45.1	49.9	7.0	0.1
20	94.2	61.0	57.8	58.7	50.6	58.1	64.0	48.6	48.5	48.5	68.0	55.3	66.5	50.9	59.3	12.0	0.2
50	163.8	97.8	69.3	66.9	57.9	67.1	73.8	58.6	58.3	55.9	78.6	63.3	92.5	58.5	75.9	28.4	0.4
100	258.4	147.1	78.7	73.1	63.2	73.9	81.1	67.1	66.7	61.4	86.7	69.4	119.8	64.1	93.6	53.2	0.6

h_{BC} (d=3 hour) [mm]																
RT (years)	**ID1**	**ID2**	**ID3**	**ID4**	**ID5**	**ID6**	**ID7**	**ID8**	**ID9**	**ID10**	**ID11**	**ID12**	**ID13**	**ID14**	**EM**	**DS**	**CV**
5	62.9	47.5	54.9	60.3	51.8	57.8	64.1	47.3	47.5	48.7	67.3	56.0	54.3	51.5	55.1	6.6	0.1
10	86.0	60.0	65.3	69.0	59.4	67.4	74.4	55.4	55.4	56.5	78.7	64.6	68.8	59.5	65.7	9.2	0.1
20	124.2	80.4	76.1	77.3	66.8	76.6	84.4	64.1	64.0	64.0	89.6	72.8	87.6	67.1	78.2	15.9	0.2
50	215.9	128.9	91.3	88.2	76.2	88.5	97.2	77.2	76.8	73.6	103.7	83.5	121.9	77.0	100.0	37.5	0.4
100	340.5	193.9	103.8	96.4	83.4	97.4	106.8	88.5	87.9	80.9	114.2	91.5	157.8	84.5	123.4	70.1	0.6

h_{BC} (d=6 hour) [mm]																
RT (years)	**ID1**	**ID2**	**ID3**	**ID4**	**ID5**	**ID6**	**ID7**	**ID8**	**ID9**	**ID10**	**ID11**	**ID12**	**ID13**	**ID14**	**EM**	**DS**	**CV**
5	72.5	54.7	63.3	69.5	59.7	66.7	73.8	54.6	54.8	56.2	77.6	64.6	62.6	59.3	63.6	7.6	0.1
10	99.1	69.1	75.3	79.5	68.5	77.7	85.8	63.8	63.8	65.1	90.7	74.5	79.3	68.5	75.8	10.6	0.1
20	143.1	92.7	87.7	89.1	76.9	88.3	97.2	73.9	73.7	73.7	103.2	83.9	100.9	77.4	90.1	18.3	0.2
50	248.8	148.6	105.3	101.6	87.9	102.0	112.0	88.9	88.5	84.8	119.5	96.2	140.5	88.8	115.2	43.2	0.4
100	392.4	223.4	119.6	111.1	96.1	112.2	123.1	101.9	101.3	93.2	131.6	105.4	181.9	97.3	142.2	80.8	0.6

h_{BC} (d=12 hour) [mm]																
RT (years)	**ID1**	**ID2**	**ID3**	**ID4**	**ID5**	**ID6**	**ID7**	**ID8**	**ID9**	**ID10**	**ID11**	**ID12**	**ID13**	**ID14**	**EM**	**DS**	**CV**
5	82.6	62.3	72.1	79.2	68.0	75.9	84.1	62.1	62.4	64.0	88.4	73.6	71.3	67.6	72.4	8.7	0.1
10	112.9	78.7	85.8	90.5	78.0	88.5	97.7	72.7	72.7	74.2	103.3	84.8	90.3	78.1	86.3	12.0	0.1
20	163.0	105.6	99.9	101.5	87.6	100.5	110.7	84.1	83.9	84.0	117.6	95.6	115.0	88.1	102.7	20.8	0.2
50	283.4	169.2	119.9	115.8	100.1	116.1	127.6	101.3	100.8	96.6	136.1	109.6	160.0	101.1	131.3	49.2	0.4
100	447.0	254.5	136.2	126.5	109.4	127.8	140.2	116.1	115.4	106.1	149.9	120.1	207.2	110.9	162.0	92.0	0.6

h_{BC} (d=24 hour) [mm]																
RT (years)	**ID1**	**ID2**	**ID3**	**ID4**	**ID5**	**ID6**	**ID7**	**ID8**	**ID9**	**ID10**	**ID11**	**ID12**	**ID13**	**ID14**	**EM**	**DS**	**CV**
5	93.5	70.5	81.6	89.7	77.0	86.0	95.2	70.4	70.6	72.4	100.1	83.3	80.7	76.5	82.0	9.8	0.1
10	127.9	89.2	97.1	102.5	88.3	100.2	110.6	82.3	82.3	84.0	117.0	96.0	102.2	88.4	97.7	13.6	0.1
20	184.6	119.6	113.1	114.9	99.2	113.8	125.4	95.3	95.0	95.1	133.1	108.3	130.2	99.8	116.2	23.6	0.2
50	320.9	191.6	135.8	131.1	113.3	131.5	144.5	114.7	114.1	109.4	154.1	124.1	181.2	114.5	148.6	55.7	0.4
100	506.1	288.1	154.2	143.3	123.9	144.7	158.8	131.5	130.7	120.2	169.7	135.9	234.6	125.5	183.4	104.2	0.6

Table 5-4: Detailed results (for different return periods and durations) for the 14 CORDEX climate model runs under RCP8.5

h_{BC} (d=1 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	46.4	44.4	41.9	41.9	46.6	40.5	49.1	38.7	39.0	37.9	48.0	49.3	43.4	43.3	43.6	3.9	0.1
10	57.5	52.1	47.7	47.2	54.4	46.8	57.0	45.4	45.5	43.1	59.1	60.4	50.7	50.2	51.2	5.6	0.1
20	71.3	60.0	53.3	53.1	61.9	52.9	64.6	52.8	52.0	48.0	71.8	73.5	57.7	56.7	59.2	8.3	0.1
50	95.2	71.0	60.4	61.9	71.5	60.8	74.4	64.0	60.7	54.4	91.5	94.8	66.7	65.3	70.9	13.5	0.2
100	119.2	79.8	65.8	69.6	78.7	66.7	81.7	74.0	67.6	59.2	109.3	114.8	73.4	71.7	80.8	19.3	0.2

h_{BC} (d=3 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	61.2	58.5	55.3	55.2	61.4	53.3	64.8	51.0	51.5	49.9	63.2	65.0	57.2	57.1	57.5	5.1	0.1
10	75.8	68.7	62.9	62.2	71.7	61.7	75.1	59.8	60.0	56.7	78.0	79.6	66.8	66.1	67.5	7.4	0.1
20	93.9	79.1	70.2	70.0	81.5	69.7	85.1	69.5	68.5	63.3	94.6	96.9	76.0	74.8	78.1	10.9	0.1
50	125.5	93.6	79.7	81.6	94.2	80.1	98.0	84.4	80.0	71.7	120.6	125.0	87.9	86.0	93.5	17.8	0.2
100	157.1	105.2	86.8	91.7	103.8	87.9	107.7	97.5	89.1	78.1	144.0	151.3	96.8	94.4	106.5	25.4	0.2

h_{BC} (d=6 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	70.5	67.4	63.7	63.6	70.8	61.4	74.6	58.7	59.3	57.5	72.9	74.9	65.9	65.8	66.2	5.9	0.1
10	87.3	79.1	72.5	71.7	82.6	71.1	86.6	68.9	69.2	65.4	89.8	91.8	77.0	76.2	77.8	8.6	0.1
20	108.3	91.2	80.9	80.6	93.9	80.3	98.1	80.1	79.0	72.9	109.1	111.6	87.6	86.2	90.0	12.5	0.1
50	144.6	107.8	91.8	94.0	108.6	92.3	112.9	97.3	92.2	82.6	139.0	144.0	101.3	99.1	107.7	20.5	0.2
100	181.0	121.2	100.0	105.7	119.6	101.3	124.1	112.3	102.6	89.9	166.0	174.4	111.5	108.8	122.8	29.3	0.2

h_{BC} (d=12 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	80.3	76.8	72.5	72.4	80.6	70.0	85.0	66.9	67.5	65.5	83.0	85.3	75.1	74.9	75.4	6.7	0.1
10	99.5	90.2	82.5	81.7	94.1	81.0	98.6	78.5	78.8	74.5	102.3	104.6	87.7	86.8	88.6	9.8	0.1
20	123.3	103.8	92.1	91.9	107.0	91.5	111.7	91.3	90.0	83.1	124.2	127.2	99.7	98.2	102.5	14.3	0.1
50	164.8	122.8	104.6	107.1	123.7	105.2	128.7	110.8	105.1	94.1	158.4	164.0	115.4	112.9	122.7	23.3	0.2
100	206.2	138.1	113.9	120.4	136.2	115.4	141.3	127.9	116.9	102.5	189.1	198.6	127.0	124.0	139.8	33.3	0.2

h_{BC} (d=24 hour) [mm]																	
RT (years)	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10	ID11	ID12	ID13	ID14	EM	DS	CV
5	90.9	86.9	82.1	82.0	91.3	79.2	96.2	75.7	76.5	74.2	94.0	96.6	85.1	84.8	85.4	7.6	0.1
10	112.6	102.1	93.5	92.5	106.5	91.7	111.7	88.8	89.2	84.3	115.9	118.4	99.3	98.3	100.3	11.1	0.1
20	139.6	117.6	104.3	104.0	121.2	103.6	126.5	103.3	101.9	94.0	140.6	144.0	112.9	111.2	116.1	16.2	0.1
50	186.6	139.1	118.4	121.3	140.1	119.1	145.7	125.4	119.0	106.6	179.3	185.7	130.6	127.8	138.9	26.4	0.2
100	233.4	156.3	128.9	136.3	154.2	130.7	160.0	144.9	132.4	116.0	214.1	224.9	143.8	140.4	158.3	37.7	0.2

6 Detailed cost estimations for proposed adaptation activities for the water supply and sewerage network

This chapter provides more details on a first cost estimation for recommended adaptation activities proposed for the Island's water supply and sewerage network in chapter 3.4.8.

6.1 Cost estimations for implementing redundant systems for supply network in areas of risks for landslides

Costs have been estimated for rerouting drinking water pipelines from areas prone to landslides to areas with lower risk and for connecting the two main network lines into one circular network. The implementation/relocation of (new) buffer tanks is not considered in this cost estimation due to insufficient information.

Costs for installing water pipelines can vary widely depending on various factors, including the location, project size, local regulations, materials used, and further site-specific conditions. Many of these parameters are unknown to the authors and exceed the scope of this report, which is why a general formula provided by the OECD is used for rough cost estimations[65]. Since this formula is from the year 2005, it has been further adjusted for this study considering the inflation rate in Italy, which was 36.51% in 2022 compared to 2005[66].

$$Costs = (0.0009dia^2 + 0.2884dia) \cdot pipeline\ length \cdot 1.365 \qquad (1)$$

This formula is applicable to both supply system and sewer system, including pipeline, excavation, laying, and backfilling, plus an additional 15% for fittings, etc.

For the installation of the pipelines next to roads, additional costs for road reconstruction of 300 EUR/m were assumed and integrated in an adapted formula 2.

$$Costs^* = \left((0.0009dia^2 + 0.2884dia) \cdot pipeline\ length \cdot 1.365\right) + pipeline\ length\ next\ to\ road \cdot 300EUR \qquad (2)$$

with Dia= diameter of pipe in mm

Using formula 2, the total cost amounts to **4,091,063 EUR**, including **3,783,929 EUR** for rerouting drinking water pipeline sections prone to landslide risks to more secure areas where possible and **307,134 EUR** for connecting the two main drinking water network lines into **one** circular network. More detailed information for each pipeline size and risk category can be found in Table 6-1 and Table 6-2.

[65] https://www.oecd.org/env/outreach/36228967.pdf
[66] https://www.worlddata.info/europe/italy/inflation-rates.php

Table 6-1 Cost estimation for rerouting drinking water pipeline sections prone to landslide risks to more secure areas where possible

Pipe diameter [mm]	Potential rerouted pipeline [m]	New pipeline next to road [m]	Estimated costs [EUR]
60	649	150	63,200.95 €
80	822	0	32,352.74 €
100	566	100	59,236.95 €
150	739	400	184,069.45 €
275	673	673	337,292.93 €
300	715	0	163,507.31 €
350	4628	4000	2,534,231.43 €
500	635	300	410,036.77 €
TOTAL	**9427**	**5623**	**3,783,928.54 €**

Table 6-2 Cost estimation for connecting the two main drinking water network lines into one circular network

Pipe diameter [mm]	Potential new pipeline [m]	New pipeline next to road [m]	Estimated costs [EUR]
125	2297	500	307,134.49 €
TOTAL	**2297**	**500**	**307,134.49 €**

6.2 Cost estimations for transforming mixed sewer system at risk into a separated sewer system

Costs have been estimated for transforming the mixed sewer system in landslide-prone areas into a separated system. This includes installing additional stormwater pipelines along the existing network, assuming that the existing pipelines, which are currently still used for both, will be used exclusively for transporting the wastewater afterwards.

Using formula 1 presented in the prior subchapter, the total cost amounts to **4,219,586 EUR**. Please note, in this case, the costs for road reconstruction were not considered due to a lack of information about the length of the existing mixed sewer system installed under and next to roads. More detailed information on costs for each pipeline size and risk category can be found in Table 6-3.

Table 6-3 Cost estimation for the transformation of the mixed sewer system into a separate sewer system in areas prone to landslides.

Pipe type	Diameter [mm]	Length at high risk [m]	Cost estimation
PVC DN160	160	139	13,127.59 €
PVC DN200	200	66	8,440.25 €
CV DN300	300	493	112,740.01 €
PVC DN300	300		- €
PVC DN315	315	472	116,074.58 €
PVC DN400	400	1894	670,575.12 €
CV DN400	400	660	233,674.54 €
PVC DN500	500		- €
CV DN800	800	67	73,783.98 €
CAV DN1500	1500	263	882,330.75 €
UNKNOWN	450	1549	659,799.88 €
TOTAL		**5603**	2,770,546.70 €

Pipe type	Diameter [mm]	Pipe length at medium risk [m]	Cost estimation
PVC DN160	160		- €
PVC DN200	200	699	89,389.92 €
CV DN300	300		- €
PVC DN300	300	143	32,701.46 €
PVC DN315	315		- €
PVC DN400	400	2220	785,996.19 €
CV DN400	400		- €
PVC DN500	500	975	491,395.05 €
CV DN800	800	45	49,556.41 €
CAV DN1500	1500		- €
UNKNOWN			
TOTAL		**4082**	1,449,039.02 €
Total Mixed Pipeline at Risk		**9685**	**4,219,585.72 €**

6.3 Cost estimations for transforming the mixed sewer system in areas with low or no landslide risks into a separated sewer system

This chapter provides a preliminary cost estimate for transforming the mixed sewer system in areas with low or no landslide risks (remaining mixed sewer system that has not been considered in the previous subchapter) into a separated sewer system. This includes, as described above, installing additional stormwater pipelines along the existing network, assuming that the existing pipelines, currently used for both, will be used exclusively for transporting wastewater afterwards.

Using formula 1, the total cost amounts to **5,527,745.33 EUR**. Please note, in this case, the costs for road reconstruction were not considered due to a lack of information about the length of the existing mixed sewer system installed under and next to roads. More detailed information on costs for each pipeline size can be found in Table 6-4.

Table 6-4 Cost estimation for transforming of the mixed sewer system into a separate sewer system in areas prone to landslides

Pipe Type	Diameter [mm]	Pipeline length in low risk – no risk areas [m]	Cost estimation
PVC DN160	160	444	41,932.73 €
PVC DN200	200	369	47,188.67 €
CV DN300	250	1884	330,096.74 €
PVC DN300	300	368	84,154.81 €
PVC DN315	315	1676	412,163.12 €
PVC DN400	350	228	65,731.37 €
CV DN400	400	5774	2,044,298.19 €
PVC DN500	500	3053	1,538,696.49 €
CV DN600	600	1420	963,483.21 €
CAV DN1500	1500		
UNKNOWN	450		
TOTAL		**15216**	**5,527,745.33 €**

6.4 Cost estimations for improving stormwater drainage infrastructure

This chapter provides a preliminary cost estimate for enlarging the stormwater drainage infrastructure of Ischia in flood prone areas. This study assumes that increasing the diameter by 50 mm of stormwater drainage pipelines crossing flood-prone areas is sufficient to significantly reduce the flood risk for surrounding settlements. It should be noted that for this rough cost estimation, local parameters such as the exact rainwater volumes, etc. have not been considered. Hence, a more comprehensive study is necessary before implementing the proposed adaptation activity. To estimate the costs, formula (1) from the previous subchapter was used, with a small modification:

$$Costs^* = ((0.0009dia + 50\ mm)^2 + 0.2884dia + 50\ mm) \cdot pipeline\ length \cdot 1.365 \qquad (3)$$

This equation includes the costs for the pipeline, excavation, laying, and backfilling, plus an additional 15% for fittings, etc. Please note, in this case, the costs for road reconstruction were not considered due to a lack of information about the length of the existing stormwater drainage infrastructure installed under and next to roads.

The total estimated cost amounts to **11,898,886 EUR.** More detailed information on the costs for each pipeline size can be found in Table 6-5.

Table 6-5 Cost estimation for enlarging the stormwater drainage system crossing areas prone to floods by 50 mm

Pipe diameter [m]	Pipe length crossing areas prone to floods [m]	Estimated costs for pipeline enlargement [EUR]
160	262	35,856.46 €
250	1944	444,556.94 €
300	704	202,960.01 €
315	663	203,791.30 €
400	3837	1,634,378.41 €
500	2371	1,394,576.29 €
600	4212	3,264,219.64 €
800	434	530,476.85 €
2000	501	2,991,082.17 €
UNKNOWN	2375	1,196,987.94 €
TOTAL	**17303**	**11,898,886.01 €**