MedSeaRise - Supporting Adaptation to Mediterranean Sea Level Rise

Mission: Protecting, restoring and valorising the natural environment and heritage

RSO2.4: Promoting climate change adaptation and disaster risk prevention, resilience, taking into account eco-system based approaches

Case studies for evaluation of sea level rise anthropic impacts risk

Deliverable 2.2.1

Project partner in charge: UM (PP6)

Project partners involved: ANATOLIKI S.A. (LP1)
ARPA FVG (PP2)
CCINCA (PP3)
UoM-IBMK (PP4)
BCC (PP5)

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1. Introduction and Objectives

This document presents a specific contribution to the achievement of the general MedSeaRise WP2 objective, namely the evaluation of the likelihood of Mediterranean Sea level trends scenarios, to develop a methodology for a proper use of such data in the risk assessment processes and to provide guidelines and benchmarks for the methodology application.

Specifically, one of the results expected from Activity 2.2 is to conduct the risks and impacts analyses on a set of case studies, with the aim of distilling key points to be included in the methodology. .

To this end, selected classes of impacts, which are consequences of the sea level rise, have been considered for the risk assessment. The selection is based on the data and information collected during the participatory process of the stakeholders, which was organised and carried on in WP1, by each Project Partner.

The number of case studies for each selected class depends on the available information. Each case study includes the adopted assessment process, its application to the specific case and the review of the sensitivity of the resulting impact and even risk, if feasible, from the sea level trends, which are foreseen in the XXI century. Impact indexes are developed according to a few fundamental constraints and then they are applied to best represent the impact and to explore its sensitivity from hazard uncertainty.

Due to the multidisciplinarity and the complexity of the assessment, Project Partners are supported by Associated Partners and external experts in the case study conduct and results analysis.

In the following, this deliverable reports the set of case studies dealing with sea level rise impacts potentially caused to anthropic activities. Details of each case study are included as appendices since each case study has produced specific documentation and data files.

This deliverable creates synergies with deliverables D.1.2.1, D.1.2.2, D.2.3.1 and D.3.1.1 [1.1].

2. Methodology for case study conduction

Each case study has been conducted according to an approach developed in the frame of the MedSeaRise project. See [2.1] for details. The case studies have been selected during the work done as project Activity 1.2, Sea level rise risks survey and stakeholder awareness, with results collected, described and analysed by means of two deliverables, i.e. D.1.2.1 [2.2] and D.1.2.2 [2.3].

Leaving the reader to assess the methodology details through Appendices A1 [2.1] and A2 [2.4], here it is important to recall that the assessment of risks deriving from sea level variations requires a robust quantification of all the elements that contribute to the sea level becoming a hazard.

The hazardous source is defined by numerical projections of sea level for the XXI century. Those data are surveyed, collected and organised in project activity 1.1, and their reliability is the result of activity 1.2.

In the case study, the method defined to assess the risk will be applied, changing the hazard input data, for each set of sea level scenarios available. The resulting risk assessment is going to be associated with the reliability of the sea level scenario used as input. Then, using the set of risk assessments, the sensitivity of the risk to the hazardous source and its reliability is evaluated. See Figure 1.1

The core of the case study is the definition of one or more indices that will be used to quantify the impact caused by the future projections of sea level. The index is a function of the input hazard, and it can be a continuous variable or a set of classes. What is mandatory, in each of the two possibilities, is that the index has to hold an order relation, that is its values can be sorted according to the impact severity. So the computed values of the index can be ordered besides to be linked to the hazard input, leading to the study of the sensitivity of the impact to the change of the hazard, see figure 1.2.

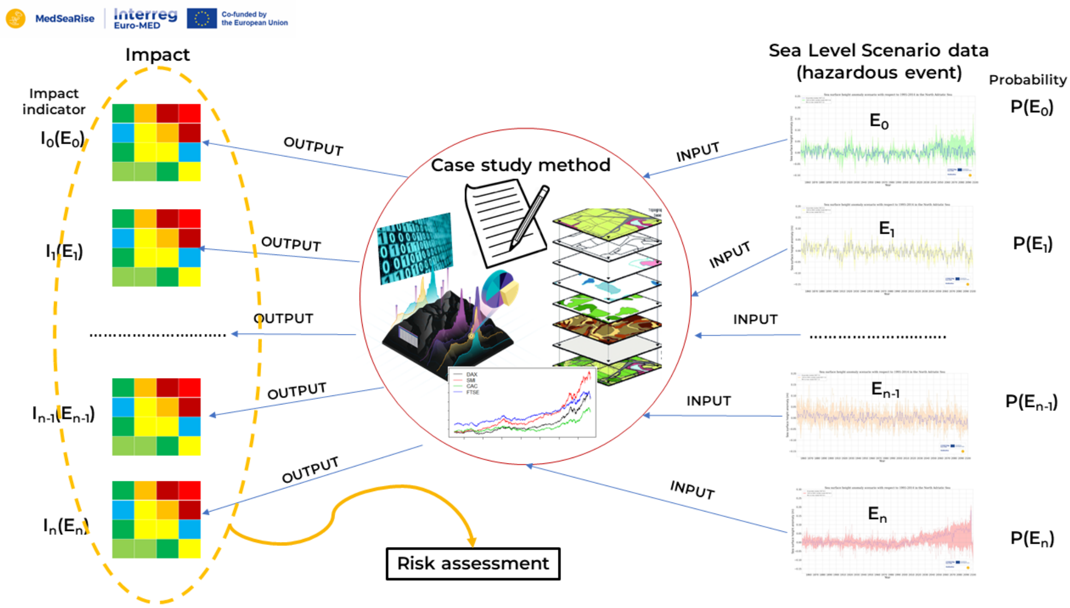

Figure 1.1: the procedure applied in the MedSeaRise case studies to assess the sensitivity of the impact to the sea level scenarios.

If, besides the impact sensitivity analysis, the risk sensitivity analysis is considered in the case study too, then the exposure and the vulnerability are used in the risk evaluation. The goal of the case study analysis is to reach conclusions based on clear criteria, concrete data, and sound reasoning.

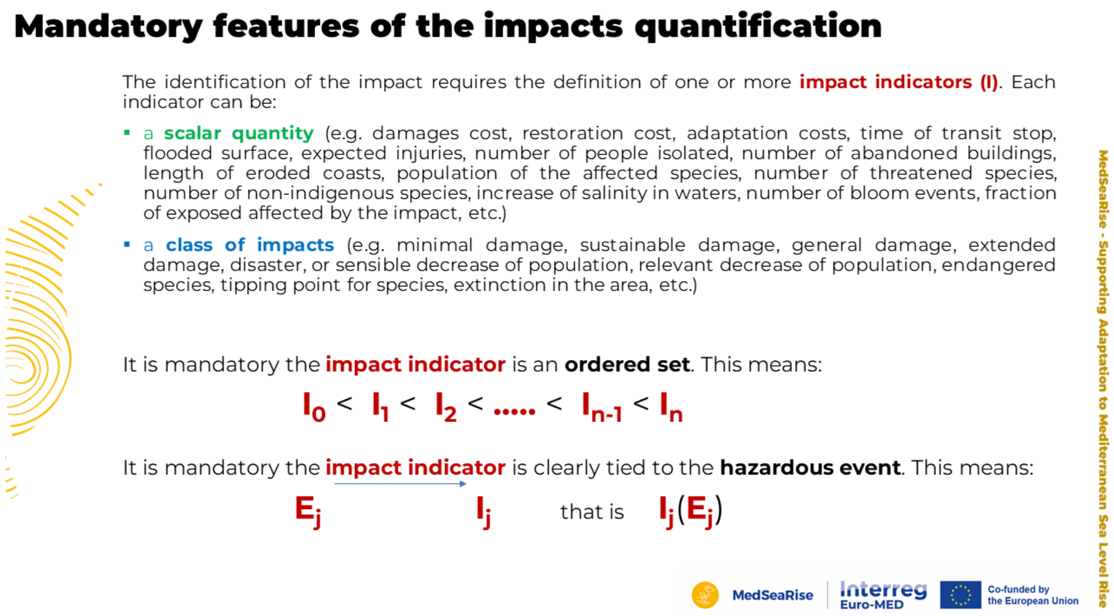

Figure 1.2: Basic and mandatory elements the impact index has to hold to be useful in the case study analysis.

Each case study includes the assessment process selection, its application to the specific case and the review of the sensitivity of the resulting risk from the sea level trends, which are foreseen in the XXI century.

In reporting the case study, a standard structure of the document has been defined, including an introduction, the case study essential information, the impact description, the impact indexes, the method and its application, to concluding with the impact analysis and results and further information.

Here is the description of the content expected in each section of the case study report, and a template is available in Appendix A3

Introduction
Information considered useful to introduce the reader in understanding why the impact has been selected among other possible choices and why the case study is considered useful in contributing to achieving the overall project objective.

Case study essential information
A schematic summary of the case study.

Impact description
Description of the expected impact due to the sea level increase, as described by stakeholders and elaborated by PP.

Impact indexes
Description of the indices adopted to evaluate the impact sensitivity from hazard uncertainty and likelihood.

Method and its application
Description of how the adopted indices are computed starting from the sea level scenarios and all the other needed data. A step-by-step description of data, software, computation techniques, required competences, expertise, etc.

Impact analysis and results
Analysis of the achieved results according to the computed indexes, which have been adopted to evaluate the impact sensitivity from hazard uncertainty and likelihood. If it is possible, generate risk plots and curves that will be used in benchmarks. Here you can add your comments on the strengths and the weaknesses of the applied method.

Available information
Description of the available information considered relevant in conducting the study. Reference to bibliographic sources, websites and the data folder, if you think it is useful to describe the case study.

3. Case studies on anthropic impacts

In this section, there is a summary of the case studies conducted to achieve the goals foreseen by Activity 2.2. Case studies are listed following the Project Partner ID. The full details of each case study are included in this deliverable as an appendix. The set of is linked to the following list. The main document of each case study has been generated according to the template [3.1].

LP1 – Case study A-01

This case study, conducted by LP01–ANATOLIKI within the MedSeaRise project, assesses the impacts of coastal flooding in the Kalamaria area (Thermaikos Gulf, Greece) due to projected sea level rise (SLR) and storm surges under RCP4.5 and RCP8.5 scenarios. Impacts were quantified through integrated hazard-exposure-vulnerability indexes using both the Climate Central platform and the high-resolution CoastFLOOD model. The study used regional climate projections (Med-CORDEX), the MeCSS storm surge model, and harmonic tidal data (HNHS and TPXO) to estimate future Sea Level Elevation (SLE = SSH + Tide + SLR). Flood extent, depth, intensity, velocity, and duration were mapped, revealing that flooded areas could increase by over 150% under extreme SLR scenarios. Impact indexes included Built-Up, Infrastructure, Population, and Economic Exposure. Exposure mapping combined cadastral, land-use, and elevation data, while vulnerability was assessed through building typologies and socio-economic factors. The methodology supports adaptive planning for climate-resilient coastal zones.

PP2 – Case study A-01

This case study is focused on the impacts of sea level rise on the archaeological assets of the city of Aquileia. This city hosts a UNESCO site due to the outstanding value of the remains of the Roman city, which was once Aquileia.

The city is located 4 kilometres from the mouth of the Natissa River, which flows nearby several archaeological sites. This river has already flooded archaeological areas during extreme tidal and rainfall events, and rising sea levels are expected to increase both the frequency and severity of such flooding.

Stakeholders have also reported problems with rising groundwater levels, which are causing archaeological sites to flood from below. On top of that, unexplored archaeological remains risk being submerged and deteriorating before they can be properly studied and documented.

These factors are projected to increase the costs of protecting, maintaining, and restoring archaeological assets, while likely rendering some areas of archaeological potential permanently inaccessible before being explored.

Using a Digital Elevation Model, projected sea level scenarios, historical tide records, monitoring of the Natissa and stakeholder expertise, this case study explored which archaeological sites may fall below projected sea levels. The research included both existing archaeological sites and areas with archaeological potential, alongside a detailed study of the *Fondo Pasqualis*, which is directly affected by its proximity to the Natissa River.

PP2 – Case study A-03

This case study investigated the impacts of sea level rise on the city of Grado: a city located on a spit of land in the southeastern part of the Grado–Marano Lagoon, in the Autonomous Region of Friuli Venezia Giulia, Italy (RAFVG).

The city is vulnerable to sea level rise due to its low elevation, its proximity to tidal lagoons and its exposure to the dynamics of the Adriatic Sea. Grado has already experienced many flooding events, caused by extremely high tides, which are expected to increase in both frequency and intensity as Mediterranean sea levels continue to rise. This could lead to the shrinking of beaches that are vital for the tourism and economy of the city, while also damaging urban areas and infrastructure.

The key data used for the case study are: a) the sea level rise projections, corresponding to different global warming level (GWL) scenarios b) the historical series of tide records, measured at the local tide gauge station and c) the digital elevation model (DEM), provided by the RAFVG.

With the support of GIS software, the DEM was analysed to compute the floodable fraction under every combination of tidal event and sea level rise scenario; a total of 195 simulations were conducted while taking into account both the sea level rise and the atmospheric component. The output of this process was then used to generate a risk curve, where the probability of occurrence and the severity of flooding are related to the projected Global Warming Level (GWL) scenario.

PP3 – Case study A-01

This case study should be focused on the ports of Antibes and Vallauris-Golfe-Juan. The area includes the Old Port Vauban in Antibes and Port Camille Rayon, as well as the nautical base of Vallauris–Juan-les-Pins. During stakeholder workshops organised by CASA (the local grouping of municipalities), participants emphasised that quays and related port facilities are increasingly vulnerable. While current conditions are manageable, projections indicate that low-lying quays will be more frequently overtopped by waves, particularly during extreme events. The eastern section of the Vallauris port has already experienced sporadic marine submersion events, leading to the installation of wave bumpers to reduce immediate risks.

Further challenges come from ageing infrastructure and drainage limitations, linked to flooding risks. Adapting these facilities is complicated by strict regulations on artificial works on the seabed, as well as the need to coordinate multiple stakeholders. Therefore, this study could assess long-term vulnerability by combining data on sea level anomalies, tide records, shoreline evolution, and damage reports. The CASA observatory, currently under development, will also play an important role by centralising physical and socio-economic monitoring. The expected outputs include impact indicators such as projected flooding frequency, affected surface areas, and economic exposure.

PP3 – Case study A02

This case study on Saint-Laurent du Var, is next to Nice and should evaluate impacts of sea level rise on highly urbanized sector. This area combines critical infrastructure—including Cap 3000 shopping center (employing over 2000 people), beaches, a walking seaside, and major hydrological challenges related to the Var River delta.

Building on previous assessments of coastal defenses, the study will model long-term risks such as marine submersion, shoreline erosion and accretion, and if possible saltwater intrusion into groundwater. Analyses will integrate datasets from MedSeaRise scientific partners, including projections of sea level anomalies, tides, and climate scenarios up to 2100.

The objectives are to produce impact indicators (e.g., flooded areas, economic vulnerability), and adaptation strategies based on previous and updated studies. Local stakeholders, with experts, will be involved in defining priorities and validating findings. Specifically, the study will assess a combination of risks:

- Marine submersion, modeling the frequency and severity of flooding events that could impact commercial facilities, public spaces, and transport corridors.

- Shoreline erosion and sediment dynamics, particularly as they interact with sea level rise and extreme weather.

- Economic vulnerability indicators, such as the extent of potentially flooded surface areas, projected damage to buildings (extreme events) and infrastructure, and potential disruptions to commercial activity.

- Saltwater intrusion could be studied (if possible), which could affect soil quality and groundwater resources, with indirect consequences for local ecosystems and water management.

This work will contribute to MedSeaRise's benchmarks, as it focus on multiple aspects.

PP4 – Case study A-01

This study investigates the potential risks associated with sea level rise in Kotor Bay by the end of the 21st century. The analysis begins with a comparison between sea level rise scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) and long-term observational data from mareographic stations located along the Adriatic coast.

The findings reveal that the IPCC projections tend to overestimate future sea level rise in Kotor Bay. This overestimation is primarily attributed to the ongoing tectonic uplift of the coastline, which occurs at an average rate of approximately one mm/y. This vertical land movement offsets a portion of the global sea level increase, thus reducing the net relative sea level rise observed in this part of the Adriatic. As a result, three adjusted, locally relevant scenarios were developed to reflect the specific geophysical conditions of Kotor Bay more accurately.

Kotor city

The first scenario assumes a sea level rise of 7.5 cm by the year 2100 and is assigned a probability of 25 per cent. The second scenario, considered the most likely, projects a sea level rise of 17.5 cm and carries a probability of 50 per cent. The third and most extreme scenario anticipates a sea level rise of 37.5 cm, with a probability of occurrence also set at 25 per cent.

These three scenarios were used to evaluate potential impacts on four key categories of coastal infrastructure in the city of Kotor: beaches, marinas and the port, coastal streets, and the historic Old Town, which is a protected cultural heritage site. The assessment for each scenario was carried out in three distinct phases: exposure analysis, impact assessment, and risk estimation.

In the first phase, the exposure of each infrastructure type to sea level rise was assessed. This included the analysis of historical flooding records, most of which are associated with episodes of intense precipitation rather than direct marine inundation. The second phase involved evaluating the potential impacts under each sea level rise scenario. This was conducted both qualitatively and quantitatively. Finally, in the third phase, the overall risk was determined by combining the probability of each scenario with the estimated consequences for each type of infrastructure.

Risan city

Based on historical records of flooding (not directly by sea level rise, but by intensive precipitation) and estimation of pier height in marinas and the port, inclination of beaches, height of coastal streets surrounding the town, the consequences of the three scenarios are investigated for each identified infrastructure. First, exposure is estimated for each scenario. Then, the impact of each scenario is assessed qualitatively and quantitatively. Finally, the risk is computed both qualitatively and quantitatively (in k Euro) for each infrastructure (beaches, marinas and the port and coastal streets).

PP5 – Case study A-01

The Delta del Llobregat, near Barcelona city, may face economic impacts from sea level rise (SLR) by the end of the century, under a 4 °C global warming level (GWL) and 99th percentile scenario. This projection suggests permanent inundation of several port areas. Using geospatial flood overlays and port-specific economic benchmarks, the analysis estimates that 81% of the 35 ha projected to flood are linked to port infrastructure, potentially placing over €2.16 billion in annual economic contribution at risk—approximately 15.12% of Catalonia's projected 2100 GDP.

Replacement costs may reach €76 million, based on the proportion of exposed asset area and assuming partial disruption. Disaggregated indicators show that about 4% of cruise terminal revenues, 5% of container terminal revenues (BEST and APM), and 11% of revenues from waterfront recreational and commercial areas (e.g., Nautic Centre, Port Med, Marina Barcelona, Hotel W) could be impacted by 2100. Logistic and fishery docks, and breakwaters may also be exposed, but were excluded from the current analysis due to data gaps in the elevation model used.

Stakeholder input from the Port of Barcelona and AMB indicates past damages from high winds and storm surges. Planned port expansions—such as the BEST extension and a new terminal southeast of it—may also be at risk if adaptation is not integrated into development plans.

PP6 – Case study A-01

The University of Malta is investigating how sea level rise will affect the town of Msida. This coastal town connects several inland areas to the sea and frequently floods during heavy rainfall, as large volumes of stormwater pass through it. With approximately 8,500 residents and significant daily traffic, Msida serves as a key link between central Malta and the capital, Valletta.

Flooding in the area is expected to worsen due to rising sea levels. To better assess this risk, a high-resolution Digital Terrain Model (DTM) with a spatial resolution of one metre was used. The data was obtained from a LiDAR survey conducted on 17 February 2018 as part of the ERDF156 project.

The study focuses on specific locations that are likely to be affected, including the central piazza, nearby restaurants and parking areas, a hotel, two marinas, the Armed Forces of Malta's maritime base, and the stormwater outflow point to the sea. These areas were selected due to their importance and are being analysed individually. The stormwater outflow, in particular, is a critical feature that releases runoff collected through a network of underground tunnels to prevent road flooding. If sea level rise causes this outlet to become submerged, the drainage system will no longer function effectively.

Msida is also currently undergoing major redevelopment to address traffic congestion. This makes it a particularly suitable case study for assessing human influences on vulnerability to future sea level rise, underlining the need for informed planning and adaptive infrastructure.

4. Deliverable indicators

This deliverable is summarised by means of the indicators reported below. For each of them, the expected indicator value and the actual one are presented. In addition, comments are reported too, if any.

Indicator	Expected value	Actual value	Comments
Number of conducted case study	1	8	Case study focusing on anthropic impacts

For each case study, a specific summary document is available as an appendix. Furthermore, the full documentation for each case study is available on the project Google Drive shared area [4.1], due to the number of files required to describe the case study.

5. Conclusions

MedSeaRise Activity 2.2 is expected to be conducted from the 2nd project period to the 4th, and in the 3rd period deliver this document. So, the bulk of the work has been carried out up to the deliverable deadline. Anyway, this document acts as the deliverable describing the set of case studies conducted by the Project Partners, representing the full scope of work carried out under Activity 2.2.

In accordance with the planned interactions foreseen by the MedSeaRise project between the Work Package 2 and the Work Package 3, the case study summarised in this deliverable are presented to stakeholders and validated thanks to their feedback, up to the project end, that is the 4th period.

Furthermore, case studies are the foundations for the benchmarks realisation, Activity 2.3, which are going to support the MedSeaRise methodology on the selection and use of the sea level data on future climate scenarios, Activity 2.4.

These case studies may be further refined after the completion of this deliverable, up to the end of the 4th period. The improvements, if any, are going to affect the deliverable appendix only.

This deliverable contributes to achieving the goal of the Activity 2.2 which is summarised as providing the project with the analysis of the sea level rise impacts on classes of anthropic activities and ecosystems.

Specifically, this deliverable collects all the case studies focusing on the potential consequences of anthropic activities.

6. References to additional material

[1.1] Basecamp Key Production WP1

[1.2] Google Drive MedSeaRise shared area (MedSeaRise_Interreg Euro-MED)

[2.1] Advices on case study preparation and conduction. Document available as Appendix A1

[2.2] MedSeaRise deliverable D.1.2.1 Stakeholders of risks affecting anthropic activities

[2.3] MedSeaRise deliverable D.1.2.2 Stakeholders of risks affecting ecosystems

[2.4] Slides of presentation used during the Activity 2.2 meeting for PPs and experts on case study guidelines. Document available as Appendix A2

[3.1] Template file used to generate the documentation of the case study. Document available as Appendix A3

[4.1] MedSeaRise Google Drive share area in which the full information on case studies is stored Activity 2.2

7. Appendixes

Appendix A1:

Advices on case study preparation and conduction. The file in PDF format is available in the folder attached to this deliverable. File name: **Act_2.2_D.2.2.1_case_study_guidelines_appendix_A1.docx**

Appendix A2:

Slides of presentation used during the Activity 2.2 meeting for PPs and experts on case study guidelines. These slides describe schematically the main concepts of the case study impact analysis. File name: **Act_2.2_D.2.2.1_case_study_on_anthropic_impacts_appendix_A2.pdf**

Appendix A3:

Template file used to generate the main documentation of the case study. The case study is reported according to this file sections. File name: **Act_2.2_D.2.2.1_case_study_on_anthropic_impacts_appendix_A3.docx**

Appendix B1:

Case study **A-01** by Project Partner **LP1** full documentation and data: files are available following this link: LP1 ANATOLIKI S.A.

Appendix B2:

Case study **A-01** by Project Partner **PP2** full documentation and data: files are available following this link: PP2 ARPA FVG.

Appendix B3:

Case study **A-03** by Project Partner **PP2** full documentation and data: files are available following this link: PP2 ARPA FVG.

Appendix B4:

Case study **A-01** by Project Partner **PP3** full documentation and data: files are available following this link: PP3 CCINCA.

Appendix B5:

Case study **A-03** by Project Partner **PP3** full documentation and data: files are available following this link: PP3 CCINCA.

Appendix B6:

Case study **A-01** by Project Partner **PP4** full documentation and data: files are available following this link: PP4 UoM-IBMK.

Appendix B7:

Case study **A-01** by Project Partner **PP5** full documentation and data: files are available following this link: PP5 BCC.

Appendix B8:

Case study **A-01** by Project Partner **PP6** full documentation and data: files are available following this link: PP6 UM.