SEA LEVEL RISE PROJECTIONS: RISK AND IMPACTS ON POPULATIONS IN THE MEDITERRANEAN BASIN

Federico Martellozzo, Filippo Randelli, Matteo Dalle Vaglie, Carolina Falaguasta

Abstract: Extreme Sea Level Rise (ESLR) refers to the significant elevation in ocean levels driven by climate change and other anthropogenic and geophysical factors. This phenomenon poses a substantial threat to coastal populations, particularly as climate change accelerates the rate of sea level rise. Reducing greenhouse gas emissions and addressing climate change causes are essential to slowing ESLR and minimizing its impacts on coastal communities. However, achieving significant global reductions in GHG emissions is a complex, long-term endeavour. As a result, many coastal regions, and even some inland areas, will inevitably face the impacts of ESLR sooner or later, with certain areas being more vulnerable due to their land use and topography. Currently, numerous institutions have modelled ocean volume expansion at various geographical scales. However, to the best of our knowledge, a spatially explicit, detailed map illustrating the potential impacts of ESLR on the European population is not freely available. This study aims to create geographically detailed datasets that depict the inland extent of ESLR impacts under future climate change conditions, focusing on the Atlantic coast of Europe and the Euro-Mediterranean basin. By integrating ESLR projections under IPCC 4.5 and 8.5 scenarios, our estimates reveal that ESLR poses a significant threat to coastal populations. The data indicates that, on average, the potential impact on human settlements is substantial. The study identifies that between 2050 and 2100, ESLR could affect areas where millions reside, emphasizing the urgent need for adaptive strategies to protect vulnerable populations and mitigate the adverse effects of rising sea levels.

Keywords: Extreme Sea Level Rise

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Introduction

Sea level rise (SLR) represents a critical challenge for coastal populations, driven primarily by the melting of land-based ice and the thermal expansion of seawater due to global warming. Human activities, such as fossil fuel combustion and deforestation, have significantly accelerated SLR, leading to an increase of approximately 20 cm in global average sea levels since 1880 [1]. This acceleration underscores the urgent need for monitoring and addressing SLR due to its profound implications for coastal communities and infrastructure [2; 3].

The impacts of SLR are particularly severe in low-lying and densely populated coastal regions. Cities such as Miami, New York City, and Shanghai are highly susceptible to increased flooding and erosion, which can damage homes, businesses, and critical infrastructure like airports, ports, and transportation networks [4; 5]. River deltas, including the Nile Delta and the Ganges-Brahmaputra Delta, face the dual threats of flooding and saltwater intrusion, which can lead to significant economic and social disruptions [6].

Adaptation measures, such as constructing sea walls, elevating buildings, and establishing natural barriers, are being implemented to mitigate these impacts. However, reducing greenhouse gas emissions remains vital for slowing the progression of SLR and protecting coastal communities in the long term. The interaction between SLR and the increasing frequency and intensity of storms due to climate change further exacerbates these risks, resulting in more destructive storm surges and accelerated coastal erosion [7].

This study aims to evaluate the impact of Extreme Sea Level Rise (ESLR) on coastal populations in Europe, with a focus on the Atlantic coast and the Euro-Mediterranean basin. By utilizing projections from the IPCC scenarios 4.5 and 8.5, this research seeks to create comprehensive and geographically detailed datasets that delineate the potential future impacts of ESLR under various climate change conditions. The goal is to provide a nuanced understanding of the vulnerability and resilience of coastal populations, thereby informing the development of effective adaptation and mitigation strategies to protect human settlements from the threats posed by rising sea levels.

Methods and Data

Data Collection and Selection - This study utilizes sea level rise scenarios provided by the Joint Research Center (JRC), based on climate models and projections from [8]. These scenarios account for factors such as global warming, glacier melting, and ocean thermal expansion. For our analysis, we used Extreme Sea Level Rise (ESLR) data under the IPCC RCP 4.5 and RCP 8.5 scenarios, projecting impacts up to 2050 and 2100 for the Mediterranean basin and the Atlantic coast of Europe.

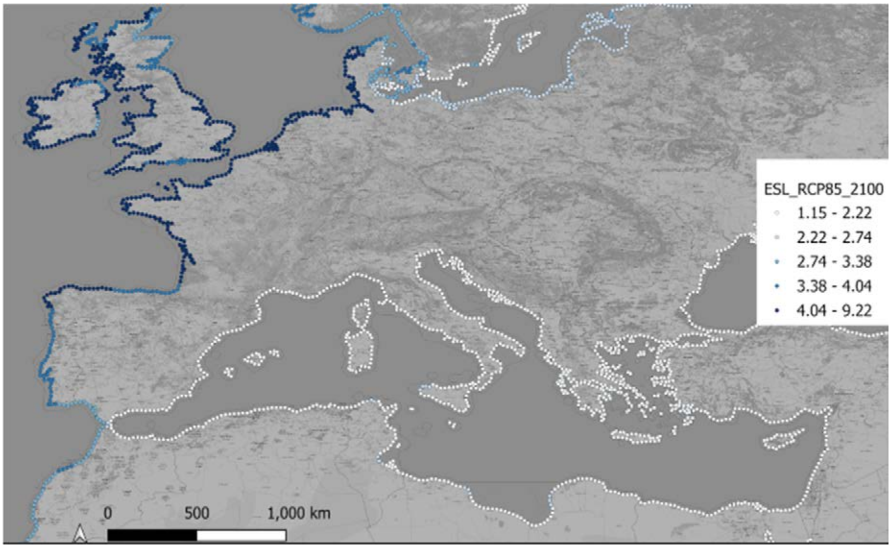

Figure 1 - Variance and location of JRC ESLR projections for the Mediterranean basin and the North Atlantic coast of Europe.

Thiessen Polygon Tessellation - To map the impact of ESLR, we implemented a Thiessen polygon (Voronoi diagram) tessellation, which divides the region into contiguous areas based on proximity to a set of source points. In this case, the source points are coastal locations with JRC ESLR projections. This method provides a detailed spatial representation of tidal elevation distribution. A Digital Terrain Elevation Data (DTED) from the USGS with a resolution of approximately 30 meters was used to generate these polygons, enabling the spatial association of inland pixels with the closest ESLR forecast values. This approach allows for precise comparison of projected ESLR values with current elevations along the coast.

Quantifying Uncertainty and Vulnerability - The JRC provides three ESLR projection values for each sample point: a conservative estimate (5th percentile), a median estimate (50th percentile), and a severe estimate (95th percentile). These values represent the uncertainty in the model outputs. We use this uncertainty as a proxy for vulnerability, generating spatial maps that indicate the likelihood of regions being impacted by ESLR. This approach aligns with risk assessment literature [9; 10; 11; 12], illustrating that more severe estimates, while broader in impact, are less probable and therefore represent lower risk. Conversely, conservative estimates, being more likely, indicate higher vulnerability. It is essential to recognize that vulnerability in this context is primarily derived from geophysical properties rather than the interplay of social and physical factors.

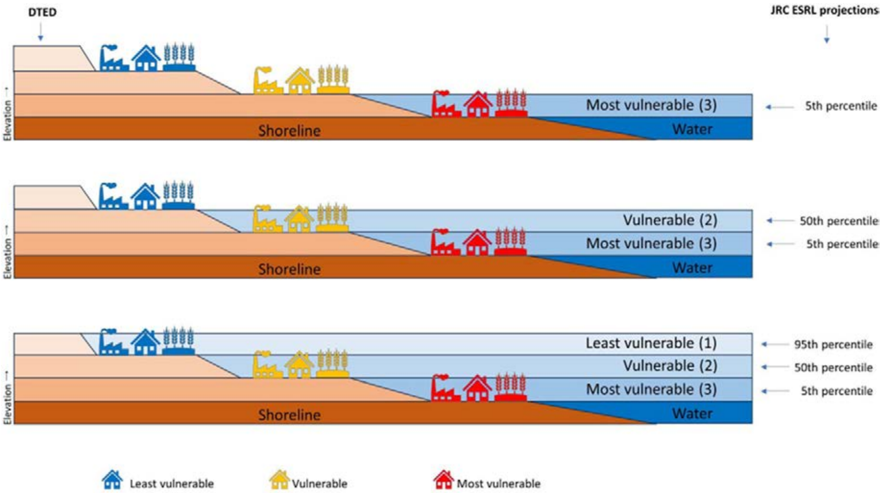

Figure 2 - Diagram illustrating the rationale for characterizing land vulnerability through ESLR projection uncertainty.

Filtering False Positives - To refine our results, we implemented a filtering approach based on the Bathtub-Based Inundation rationale [13]. This method addresses the potential inclusion of false positives, such as inland depressions below sea level without hydrological connection to open waters. We overlaid initial ESLR impact maps with the geographical extent of persistent water bodies (using data from Copernicus EU-Hydro and global HydroSheds) to ensure spatial contiguity. Pixels contiguous with permanent inland water bodies and coastlines were retained, while isolated pixels without hydrological continuity were excluded. This filtering, repeated until no differences were observed, was critical for accurately representing areas at risk of submersion under IPCC. scenarios RCP 8.5 and 4.5 up to 2050 and 2100, eliminating erroneous inclusions (Fig. 3). scenarios RCP 8.5 and 4.5 up to 2050 and 2100, eliminating erroneous inclusions (Fig. 3).

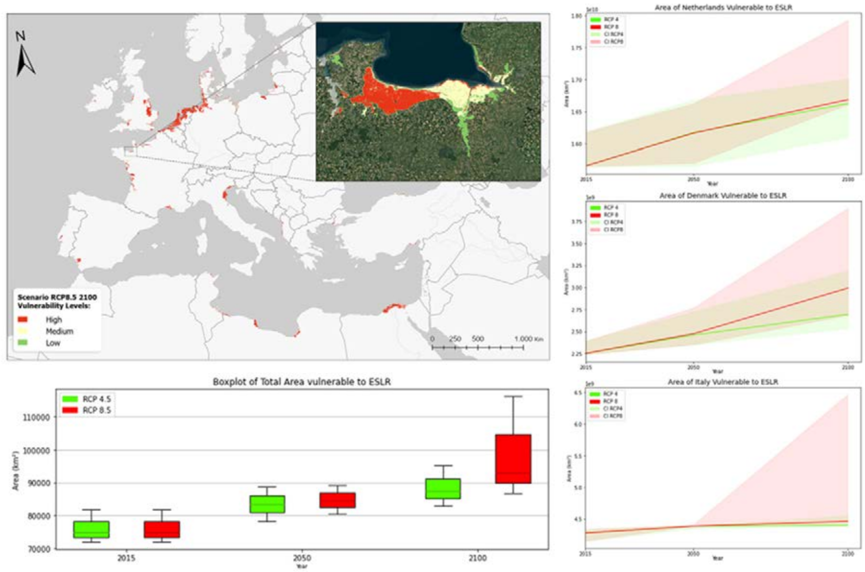

Figure 3 - Final filtered maps showing regions likely to be impacted by ESLR, excluding false positives.

Estimating Population Impact and Vulnerability Due to ESLR - In alignment with similar studies in the literature, we estimated the potential impacts of Extreme Sea Level Rise (ESLR) on populations by maintaining a consistent assumption: current population distributions and associated socioeconomic values remain constant into the future. This study utilized population data from the GHSL Copernicus Programme to evaluate the magnitude of potential impacts on populations within various land-use classes. Our methodology involved overlaying future ESLR projections onto current population distribution maps to identify areas at risk and assess the cumulative impact within each scenario. The analysis was divided into two main components.

Results of Population Impact of ESLR

The analysis identifies significant variations in projected population impacts due to Extreme Sea Level Rise (ESLR) under different scenarios (RCP 4.5 and RCP 8.5) and timeframes (2050 and 2100). Population data from the GHSL Copernicus Programme was utilized to assess exposure across various European and neighboring countries.

Baseline Scenario - Currently, countries such as Egypt, the Netherlands, and the United Kingdom have the highest populations at risk, with millions of people potentially affected (fig. 4).

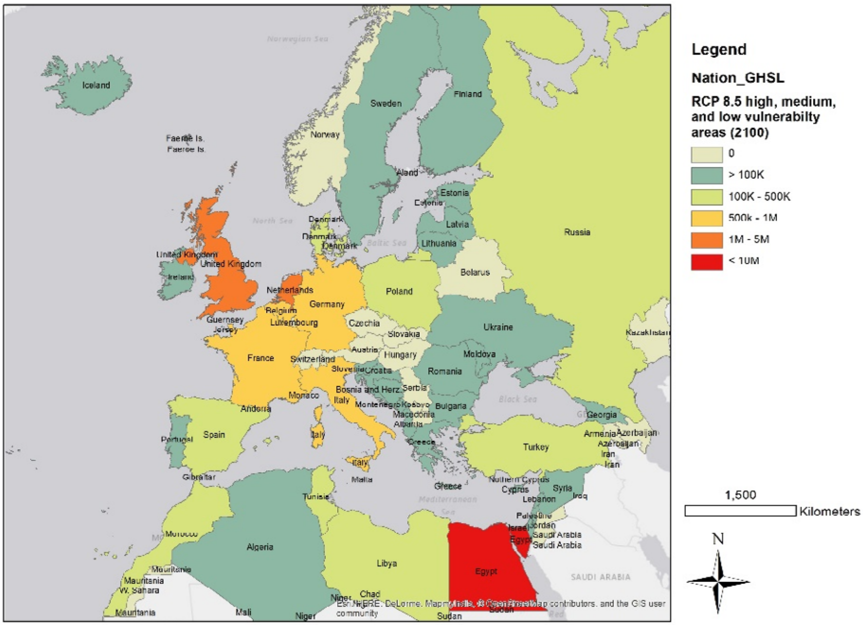

Figure 4 - Population impacted by ESLR in 2100 under RCP 8.5 scenario considering areas under high medium and low vulnerability.

RCP 4.5 Projections (2050 and 2100): if focusing exclusively on the highly vulnerable areas by 2050 (thus the smaller spatial extent of impacted land), Egypt's population at risk sets at around 4.3 million, while Spain having approximately 170 000. By 2100, Egypt’s at-risk population remains similar, while Spain's increases to around 180 000. If we include also medium vulnerability areas Spain's population remains more or less stable at 170 000 both in 2050 and (slightly) increasing further by 2100. By extending the analysis also to low vulnerability areas similar trends are shown for the populations at risk, with Spain's impacted population topping to approximately 200 000 by 2050 and slightly higher by 2100, whereas. Egypt is somewhat stable through all the RCP 4.5 analysis.

RCP 8.5 Projections (2050 and 2100): regarding RCP 8.5 scenario in high vulnerability areas by 2050 Egypt's population at risk is foreseen to still remaining around 4.3 million, while Spain's population settling at approximately 180 000. By 2100, Egypt’s impacted population soars to around 7.4 million, with Spain's reaching about 350 000. If including also the medium vulnerability area, Spain's population at risk increases steadily, reflecting the broader impact under more severe climate scenarios. Expanding the analysis to areas with low vulnerability shows similar trends, with significant increases in populations at risk, especially by 2100, where Egypt’s affected population also rises dramatically.

Besides, all the Netherlands shows consistently high numbers of affected populations, with projections reaching up to approximately 4.7 million people under the most severe scenario by 2100. In the UK significant impacts are foreseen, with up to around 1.8 million people at risk under the severe scenario by 2100, whereas Germany's impacted population could reach up to about 880 000 people under the severe scenario by 2100.

The projections indicate a considerable increase in the population at risk from ESLR under both RCP 4.5 and RCP 8.5 scenarios, with more severe impacts observed under RCP 8.5. The highest impacts are noted in Egypt, the Netherlands, and the United Kingdom, underscoring the urgent need for targeted adaptation and mitigation strategies. These findings highlight the importance of incorporating ESLR projections into coastal planning and policy-making to protect vulnerable populations and enhance resilience.

Discussion

The projections of Extreme Sea Level Rise (ESLR) and their associated impacts on populations hold profound policy, economic, and social implications. If these projections are realized, the consequences could be substantial and far-reaching, necessitating comprehensive and multifaceted intervention strategies. From a policy perspective, the integration of ESLR projections into coastal zone management becomes critical. Policymakers must prioritize the updating of urban planning frameworks, zoning laws, and infrastructure development guidelines to effectively mitigate future risks. This involves not only the construction of physical sea defenses but also the restoration of natural barriers such as mangroves and wetlands, and the design of resilient infrastructure capable of withstanding rising sea levels. The findings underscore the urgency of global climate action, emphasizing the necessity for stronger commitments to reduce greenhouse gas emissions to slow the progression of sea level rise and mitigate its impacts on coastal communities.

Economically, protecting critical infrastructure from ESLR will demand substantial investment. This encompasses both the upgrading of existing infrastructure, and the construction of new, resilient structures designed to endure the effects of rising sea levels. The increased risk of flooding and damage in coastal areas will likely lead to higher insurance premiums, reflecting the greater exposure to ESLR. Moreover, the potential displacement of large populations from vulnerable coastal areas could result in significant economic impacts, including the loss of property values, increased unemployment, and economic strain on areas that accommodate displaced populations.

Socially, large-scale displacement due to ESLR poses considerable challenges. Housing shortages, increased pressure on urban services, and potential conflicts over resources in areas that receive displaced populations are likely outcomes. The stress and uncertainty associated with displacement and the threat of flooding can adversely affect the mental health and overall well-being of affected populations. Furthermore, communities that have resided in coastal areas for generations may face the loss of cultural heritage and social cohesion if forced to relocate due to ESLR.

While this study provides valuable insights into the potential impacts of ESLR, several limitations must be acknowledged. The projections are based on population data and sea level rise models that may not capture local variations at a finer scale. This could lead to underestimations or overestimations of impacted populations in specific areas. The study relies on RCP 4.5 and RCP 8.5 scenarios, which are based on specific assumptions about future greenhouse gas emissions. Changes in global policies or unforeseen technological advancements could alter these trajectories, affecting the accuracy of the projections. Furthermore, the analysis primarily focuses on sea level rise and does not account for other climate change-related factors, such as increased frequency and intensity of storms, which could exacerbate the impacts on coastal populations.

In conclusion, the study underscores the urgent need for targeted policy measures, significant economic investment, and comprehensive social strategies to mitigate the potential impacts of ESLR on vulnerable coastal populations. Future research should aim to refine data resolution, incorporate additional climate variables, and explore adaptive strategies to enhance community resilience. This comprehensive approach will be essential to safeguarding populations and infrastructure in the face of rising sea levels and ensuring sustainable development in coastal regions.

Conclusion and Key Findings

This study highlights the significant potential impacts of Extreme Sea Level Rise (ESLR) on populations in Europe and neighboring regions under various climate scenarios. Key findings include:

1. High-Risk Areas: Countries such as Egypt, the Netherlands, and the United Kingdom are identified as having the highest populations at risk, with millions potentially affected by 2100 under severe scenarios.
2. Scenario Projections: Under the RCP 8.5 scenario, the population impact is substantially greater, underscoring the importance of strong climate action to mitigate these effects.
3. Policy and Economic Implications: The study underscores the need for comprehensive policy measures, substantial economic investments in resilient infrastructure, and social strategies to address potential displacement and health impacts.

These findings highlight the urgency for integrating ESLR projections into coastal planning and policy-making, emphasizing the necessity for proactive adaptation and mitigation strategies to protect vulnerable populations and enhance resilience against future sea level rise.

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