

**FUTUROS DA ÁGUA**  
RESILIÊNCIA,  
GOVERNAÇÃO  
E ADAPTAÇÃO 

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## Avaliação do perigo e da exposição à subida do nível do mar em Portugal Continental

*Hazard and Exposure Assessment to Sea Level Rise in Mainland Portugal*

**Andreia Alves da Silva**

**Jorge Trindade**

**Jorge Rocha**

### Resumo

O aumento do nível do mar representa um desafio crescente para as zonas costeiras portuguesas. Este estudo avaliou a exposição das áreas urbanas do território continental português a diferentes cenários de subida do nível do mar (SNM) para os horizontes temporais de 2040, 2070 e 2100, com base no cálculo do Total Water Level, que integra maré astronómica, tempestades, runup, e projeções de SNM (RCP 2.6, 4.5 e 8.5). Os resultados indicam que 23% das áreas costeiras perigosas já são urbanas, podendo atingir 30% até 2100. Foram identificados 12 municípios prioritários para adaptação, evidenciando a urgência de políticas públicas integradas de gestão costeira sustentável.

Palavras-chave: Riscos Costeiros, Subida do Nível do Mar, Ordenamento do Território.

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### Abstract

Sea level rise (SLR) poses an increasing threat to Portugal's coastal zones. This study assessed the exposure of urban areas along mainland Portugal to sea level rise scenarios (2040, 2070, and 2100) using Total Water Level estimation, integrating tidal, storm surge, runup, and IPCC/NASA SLR projections (RCP 2.6, 4.5, and 8.5). Results show that 23% of coastal hazard zones are currently urbanized, potentially rising to 30% by 2100. Twelve municipalities were identified as high-priority for adaptation. The findings highlight the urgent need for integrated coastal management policies and spatial planning strategies to mitigate risks and promote sustainable coastal resilience.

Keywords: Coastal Risks, Sea Level Rise, Environmental Management.

### Introduction

Sea level rise is a global concern, with present and future consequences for coastal areas, populations, and ecosystems. Portugal, as a coastal country (Figure 1), has one of the most dynamic coastlines in the world, making it naturally exposed. Along the 948 km mainland Portuguese coastline, lies the highest population density and the largest share of the country's GDP. The intensification of human occupation along the coast has been evident since the mid-19<sup>th</sup> century and continues to show a positive trend today. Initially marked by a seasonal dynamic linked to fishing communities, coastal occupation saw a significant increase in urban growth starting in the mid-20th century (Gaspar de Freitas, 2007).

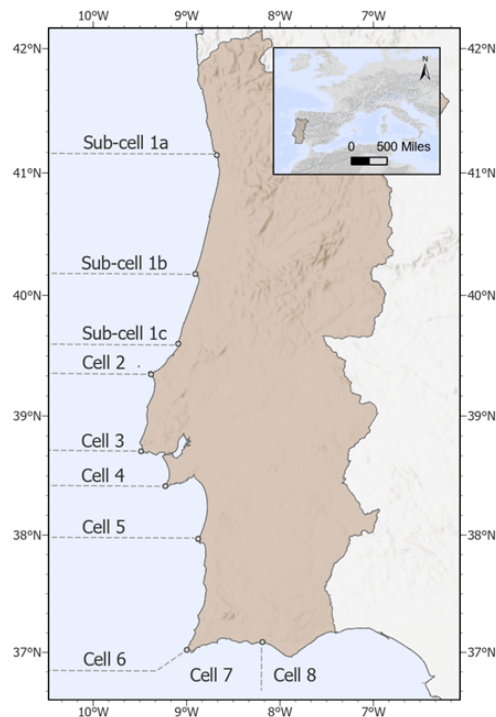


Figure 1. Mainland Portugal and its sedimentary cells.

In addition to the anthropogenic pressure on the coastal areas and the consequences of climate change (e.g. sea level rise and higher frequency of storms), another forcing factor for those areas is the coastal erosion hotspots, induced by the reduction of sediment inflow coming from fluvial systems – which are being trapped by dams built since the 1950s (Dias, 2005). This phenomenon is more pronounced in low-lying, sandy coastal systems.

Sea level rise will impact Portugal's coastline differently, affecting both biophysical communities and urban coastal systems. This study aims to assess the exposure of urban communities to sea level rise in mainland Portugal. To achieve this objective, a methodology for the assessment of exposure of urban cities facing sea level rise scenarios was defined.

### Methodology

To understand the impact of sea level rise in coastal areas, this work is divided into three parts. The first aims to define What If Scenarios to Sea Level Rise, based on Total Water Level estimation for three years (2040, 2070, and 2100). The formula aims to obtain the total water level elevation for all the sedimentary cells for mainland Portugal (Figure 1), for each year and scenario, by including the quantification of the sum of i) high astronomical tide (HAT); ii) influence of Storm Surge; iii) runoff (50% in rocky coasts; Dodet *et al.*, 2018); and iv) the Sea Level Rise scenarios provided by NASA/IPCC. The SLR scenarios are defined for three RCP projections: 2.6, 4.5, and 8.5, to provide information for a low, intermediate and high emissions scenario, respectively. Regardless of the sea level rise scenario considered, the trend points towards an expansion of the areas affected by coastal erosion, as Ponte-Lira *et al.* (2016) nationwide projection calculated. These hydrodynamic components are mapped onto sandy, rocky, and anthropogenic systems, using biophysical, altimetric, and land-use criteria.

On the other hand, changes in land use land cover were projected to the analysed years, to understand the potential of exposure in the mainland territory. The input variables were the land use and occupation Portuguese charts (COS), slope gradients, proximity to the urban fabric, proximity to roads, and legal restrictions.

Furthermore, the hazard area and the exposure area were combined to identify the hazard and exposure hotspots for mainland Portugal. Applying a cluster hierarchical analysis and the Ward's method, it was possible to generate an adaptation index for sea level rise.

### Results & Discussion

The results (Table 1) show the hazardous area of mainland Portugal, which was 62 km<sup>2</sup> in 2018, and 23% of it corresponds to urban areas that are exposed to coastal hazards, including sea level rise and coastal erosion. The percentage of exposed coastal communities can increase to 30 % of the hazard areas by the end of that century, in the worst-case scenario (RCP 8.5).

	Hazard areas (km <sup>2</sup> )	Exposure areas (km <sup>2</sup> )
2018	62	14
2100 (RCP8.5)	86	29

Table 1. Total of Hazard and Exposure areas for Mainland Portugal.

A hierarchical classification of clusters has been conducted to assess four types of municipal interventions for adaptation, which are later classified into intervention levels: (I) lower priority; (II) warning municipality; (III-A) higher priority for hazard; and (III-B) higher priority for exposure. The municipalities included in the III-A level in 2018 are four: Vagos, Faro, Olhão, and Tavira. In the year 2040, it is expected that this level will increase the number of municipalities from four to six, with the addition of Ovar and Vila Real de Santo Antonio, for both RCP scenarios

considered (2.6, 4.5, and 8.5). In case of higher priority for exposure, at present, there are also four municipalities in that III-B priority level: Póvoa de Varzim, Vila do Conde, Matosinhos, and Grândola. In 2040, Vila Nova de Gaia may become an III-B level, and Loulé in the year 2070, for both RCP scenarios.

### Conclusion

Portugal is a coastal country with numerous hotspots for coastal flooding. For a long-term analysis, it is expected an increase in these areas. This work identifies current and future hazard zones for coastal flooding and the urban areas exposed to that hazard. Approximately one-quarter of coastal municipalities of Mainland Portugal are classified as high-priority intervention municipalities (levels III A and B) by the end of the century. These twelve municipalities must adopt strategic political measures to prevent and mitigate potential risks on their coastlines. Political decisions must be informed by comprehensive environmental impact assessments to avoid unintended consequences in neighbouring municipalities, such as those caused by hard engineering solutions.

This prioritization framework serves as a critical tool for decision-making and territorial safeguarding. To minimize the impacts of coastal risks on communities, a rethinking of territorial management is essential. This includes promoting more efficient cities, sustainable spatial planning, and implementing policies that prohibit construction in high-risk areas while preserving safeguarded zones.

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