



## Coastal flooding in the Portuguese continental coastal zone: historical records and impacts between 1980 and 2018

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**Abstract:** Continental Portugal presents an extensive and diversified coastal zone where the main public and private infrastructures of the different economic sectors are concentrated, as well as the main critical infrastructures. This area is also characterized by its high population density, being a differentiating territory in geophysical, biological and landscape terms. It is also characterized by a high energetic wave regime, being frequently hit by storms, of which Hercules stands out more recently in 2014. The years 1996, 1998 and 2014 were selected for the present study as those with the highest number of occurrences of overtopping and coastal flooding (171 in total) between 1980 and 2018. In terms of impacts stand out the typologies associated with human, material, and ultimately natural and environmental impacts. Results provide relevant temporal and spatial information about coastal historical flood occurrences related with extreme hydrodynamic conditions storminess events and associated impacts.

**Keywords:** Coastal zone, database, occurrences, impacts, anthropic areas

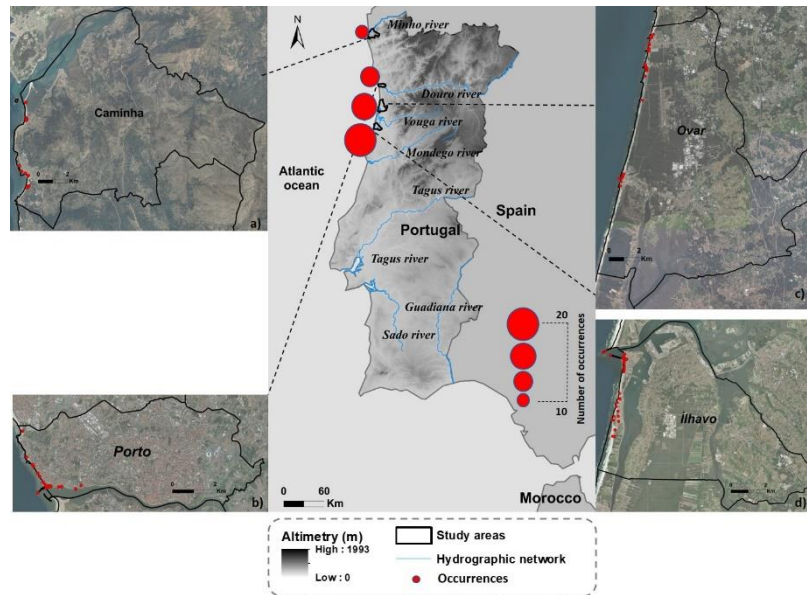
### 1. Introduction

The coastal area of mainland Portugal has an undeniable natural, cultural and economic value, where there is a great diversity of occupations and activities that have originated over the last decades different conflicts of interest (Santos *et al.*, 2014). The importance of this area is reinforced by the fact that  $\frac{3}{4}$  of the population lives in coastal municipalities, being responsible for the production of 80% of GDP (Santos *et al.*, 2014). The last 50 years have been marked by a continuous growth of the population and concentration of activities in the coastal zone, with an estimated 30% of land artificialized with different uses, namely related to housing, economic activities and port areas (Presidência, D.C.D.M., 2009). Coastal areas face a set of challenges related to anthropogenic pressure, with emphasis on population growth and urbanization. It also faces challenges arising from a set of risks related to coastal erosion, overtopping, flooding and cliff instability. The arising threats from climate change, namely those resulting from the rise in the mean sea level, as well as the increase in the intensity and frequency of extreme events, leads to the increase of the hazardous processes related to coastal areas mentioned above (Bertin *et al.*, 2013). In terms of wave climate, the coast of mainland Portugal, particularly the west coast, is characterized by a high energy regime strongly influenced by the northwest swell (Andrade and Freitas, 2002), being among the most active and vulnerable coastlines on the European Atlantic facade, presenting high values of coastal drift (Santos *et al.*, 2014). Related to the wave climate arises the regime of storms which Portugal is subject annually and which cause different impacts. The main objectives of this study are to identify the main events that caused overtopping or coastal flooding between 1980 and 2018 and to analyze the associated impacts.



## 2. Study area characterization

The Continental Portuguese coastal zone, extending from the mouth of the Minho river in the northwest to the mouth of the Guadiana river in the southeast, totals about 987 km (Figure 1). The study areas of the present work are located in the municipalities of Caminha, Porto, Ovar and Ílhavo, all of them in the Portuguese west coast (Figure 1), presenting distinct morphological and social characteristics.



**Figure 1** – Location of the study areas and respective number of occurrences: a) Caminha; b) Porto; c) Ovar; d) Ílhavo

The coastal area of the municipalities of Caminha and Porto is characterized by a low rocky coast, with some sandy and gravel beaches (Santos *et al.*, 2014). With regard to occupation, the importance of agricultural activity stands out in Caminha, with a growing human occupation of the coastal strip since the 1980s with the proliferation of the urban fabric with a longitudinal development (Santos *et al.*, 2014). The occupation of the coastal area of Porto is characterized by a great artificialization of the soil resulting from the intense process of human occupation of coastal and estuarine areas verified in the last decades. Further south are the municipalities of Ovar and Ílhavo, which are characterized by a low and sandy coast marked by intense erosive processes driven by both natural related to their geological fragility, intense wave climate, and anthropic features, related with high population concentration and soil artificialization. Ovar has an almost continuous urban front in the north, where there is a constant maintenance and reinforcement of the different coastal defense structures necessary for the protection of the different existing urban agglomerations. The Ílhavo's coast is strongly influenced by the jetties of the Aveiro port, with emphasis on a number of coastal protection interventions along the main urban fronts in the municipality.

## 3. Methodology

As part of the Mosaic.pt research project, a historical database of coastal flooding occurrences was built for the Portuguese continental coastal zone based on the hemerographic analysis of newspapers between 1980 and 2018. A total of six daily newspapers were analyzed, two of them national and the other four regional-scale. The database is based on six topics that includes 50 fields: a) occurrence characterization and triggers; b) area characterization; c) associated impacts; d) newspaper source characterization; e) environmental degradation; f) other relevant information. In the present work. Taking into consideration Zêzere *et al.*, (2014), a specific case related to flooding or coastal overtopping related to a unique space location and a specific period of time is defined as an occurrence. An event is considered a set of occurrences of flooding or coastal overtopping sharing the same trigger, which can have a widespread spatial extension and a certain



magnitude. Regarding the associated impacts, the following typologies of impacts were considered: human impacts (casualties, injured, missing, displaced and evacuated persons), material impacts (road network, buildings, collective equipment and other infrastructure) and impacts on natural and environmental systems (dune destruction, agricultural damage, field salinization, sand reduction).

#### 4. Results

The hemerographic analysis for the period between 1980 and 2018 identified the years 1996, 1998 and 2014 as those with the highest number of coastal flooding and overtopping occurrences. In these three years, a total of 8 events associated to extreme oceanographic and/or meteorological conditions (e.g. energetic wave conditions, meteorological surge, high spring tide levels) have been identified, with particular emphasis on the storm Hercules that hit the Portuguese coast between 3 and 7 of January. In this timeframe a total of 171 occurrences were identified, spread over 38 coastal municipalities, highlighting Ílhavo (20), Porto (17), Ovar (15) and Caminha (10), which represent 37% of the occurrences and 51% of the records of the associated impacts. A global analysis shows that 58% of the occurrences are located in the northern municipalities of the mouth of the Mondego River. In terms of events, the Hercules storm stands out as the event with the most occurrences (28%) and the highest number of associated impacts (26%). Regarding impacts, it is possible to observe a great variability among the three analyzed years (Figure 2). It should be noted that the events that occurred in 1996 resulted in a large number of human impacts, with emphasis on the number of evacuated people. In the 1998 and 2014 events, material impacts are clearly highlighted, followed by human impacts and natural impacts. With regard to the study areas, there is also a large annual and spatial variability in relation to the associated impacts (Figure 3).

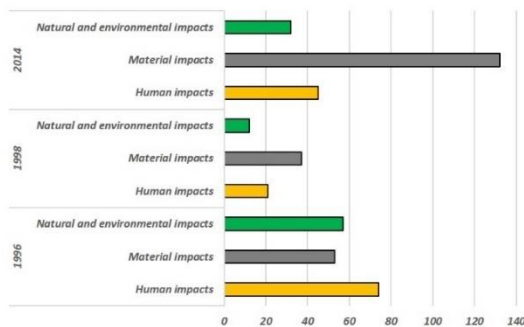


Figure 2 – Distribution of the impacts by typology and year

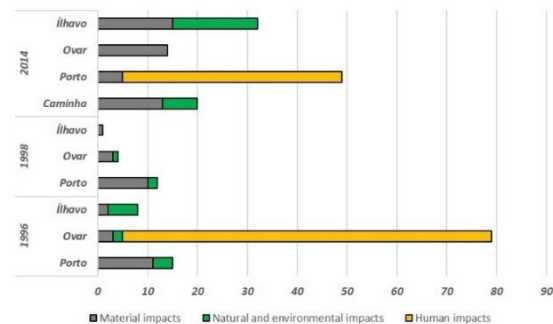


Figure 3 – Distribution of the impacts by year in each study area

In 1996, 2 events of wave climate or storm were identified, giving rise to a total of 55 occurrences. The high number of human impacts in Ovar stands out, contrasting with Ílhavo and Porto, where impacts on natural and environmental systems and material impacts predominate, respectively. The 2 events that occurred in 1998 gave rise to 33 occurrences, highlighting the material impacts. With regard to 2014, the 4 identified events gave rise to a total of 83 occurrences. In the coastal areas of Caminha and Ovar material impacts predominate, while in Porto predominate human impacts and natural and environmental impacts in Ílhavo. Inside the three major types of impacts considered (Figures 2 and 3) the newspapers allow a deeper description of their characteristics. In relation to Caminha, impacts on buildings and coastal protection infrastructures stand out. In Porto, most of the human impacts are the need to evacuate the affected population, as well as the damage to buildings, especially the commercial ones. In Ovar, the human impacts related to evacuees stand out, however, material damage related to buildings and coastal protection infrastructures is also important. Lastly in Ílhavo, the natural and environmental impacts related to the beach erosion and the retreat and destruction of dunes are highlighted. Material damage related to material impacts on urban streets is also noteworthy.



## 5. Discussion and Conclusions

The construction of the historical database allows the identification of the most vulnerable areas, as well as the characterization of the coastal flood hazard, spatially and temporally. The results highlight great variability in terms of the associated impacts. While in Ovar and Porto human impacts stand out, in Caminha and Ílhavo, occurrences with material and natural/environmental impacts predominate, respectively. Many of the artificial areas belonging to the study areas depend directly on different coastal protection structures, with emphasis on the urban agglomerations in the municipality of Ovar and Ílhavo. Between 1995 and 2014 a set of coastal protection works were carried out in the analyzed municipalities, valued in more than 30 million euros (Silva, 2014). However, the results show that despite the existence of these infrastructures, events with flooding or coastal overtopping still occur, with a tendency to worsen in some areas. At the national level, the preferential response strategy to the different coastal risks has been to invest in coastal protection. The analysis of the different Coastal Plans to which the study areas belong allows to confirm the predominance of this strategy. However, the results obtained by the Mosaic.pt database, as well as the intensification of risks and the growing impact of climate change in coastal areas defended by Santos *et al.*, (2014) presuppose a change in the coast defence paradigm, progressively moving from the concept of protection to the concept of adaptation, which in addition to the concept of protection also includes the concepts of relocation and accommodation. The Mosaic.pt database and its results appear as a support tool for different authorities and stakeholders in the identification, analysis and assessment of the different vulnerabilities of coastal areas, thus contributing to the development of innovative approaches to emergency planning and response, promoting safer and more resilient communities.

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