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OVERWASH AND OCEAN FLOODING IN PORTUGAL: CASE STUDY OF FONTE DA TELHA, COSTA DA CAPARICA

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Resumo: Povoações costeiras em Portugal são atingidas frequentemente por tempestades, algumas das quais são capazes de induzir galgamentos, levando a inundações severas. Este estudo foca-se nos potenciais danos que a povoação de Fonte da Telha pode sofrer na ocorrência de inundações por galgamento oceânico. Dos 222 elementos identificados na povoação, cerca de 70% está na faixa de risco de inundação. Áreas de ocupação do solo definidas por Praias e Floresta de espécies invasoras são totalmente abrangidas pela área de risco. De modo a combater o presente cenário, foi realizado um Plano de Pormenor, definindo os 11m como a altitude mínima para construção de edificado.

Palavras-chave: Risco; Maré de tempestade; Mudanças climáticas; Oceanografia

Abstract: Coastal settlements in Portugal are routinely hit by storms, some of which produce significant overwash, leading to severe floods. In this study we focus on the possible damages Vale da Telha settlement could incur in the event of severe overwash and flooding following a storm. It was found that of the 222 elements comprising the settlement, roughly 70% were at risk of flooding. Most of the areas classified as Beaches and Invasive species forest are within the risk area. To reduce this scenario, artificial construction should not be carried out below the 11m altitude threshold.

Keywords: Risk; Storm surge; Climate change; Oceanography

1. Introduction

The main hazards for human settlements close to shore are overwash and flooding. Overwash refers to the "flow of water and sediment over the crest of the beach that does not directly return to the water body (ocean, sea, bay, or lake; hereafter, ocean) where it originated" (Donnelly et al. 2006). Certain conditions must be met for overwashing to occur. The most impactful factor is strong sea agitation (Silva et al. 2013). Storm surge events are prime time for overwash to occur, especially when combined with high tides and/or river discharges (Silva et al. 2017; Pinto, 2014). Additional factors include beach morphology and topography, as well as the bathymetry just offshore of the coastline in question (Rodrigues et al. 2012). Coastal flooding often comes as a consequence of overwash. Silva et al. (2013) define coastal flooding as the submergence of coastal elements for at least a couple of hours. These only happen if the oceanographic conditions persist long enough to transpose a significant amount of sea water over the dune system (Silva et al. 2013). Overwash, along with the associated flooding, are the cause of vast material and natural damages.

Continental Portugal has around 845km of shoreline (Morais, 2010), all of it facing the Atlantic Ocean. As such, it is often subjected to intense ocean and atmospheric activity during the European Windstorm events that scour Western Europe on a yearly frequency. Such was the case with Cyclone Christina in January 2014, colloquially known as Hercules Storm. Hercules affected the entirety of the country´s shoreline, with total damages estimated at the 16.489.915,00€ mark (Pinto, 2014). Knowing the extent of the damage these storms and the associated overwash and flooding cause, it seems imperative to understand and model the effects they have on the Portuguese shore. Verily, there are a good number of scientific studies on the matter, for various stretches of coast. These are usually made by engineers and geographers well versed in mathematic modelling and GIS (Geographic Information Systems). Even so, in Portugal, scientific studies focusing on an observational perspective are scarce and even fewer studies deal with post-disaster field surveys (Santos et al. 2015). This lack of post-disaster studies can be problematic as the scope of the effect the storm has can be diminished. Researchers working on the few reports that are published in the theme often need to look for occurrences in news articles or witness testimony as there are no official databases about the damages (Santos et al. 2015). As such, we propose doing a summary catalog of the structures potentially affected by a strong storm event in Fonte da Telha, Almada, Portugal.

2. Methodology

This study was produced using a simple methodology. As the scope of this article is not to model overwash nor erosion, but to try and comprehend the damages it can cause, we started by searching literature that could provide us with the data needed to map the elements at risk in the study area. Silva et al. (2013) proved to be the most impactful piece of literature at this stage, as it provided a map of the area susceptible to overwash and flooding in the next 50 and 100 years, according to their model. As such, the identification of elements at risk in the present article rests on the model of Silva et al. (2013). The elements considered for mapping were the following: residences, restaurants/coffee shops, parking lots, hotels and others. The latter can include anything from churches to government buildings. These were identified both inside and outside the area considered for flooding. Garages and storage facilities were ignored for this study. We then processed the data to extract valuable information about the damages caused following an overwash and flooding event in the area.

An additional branch of analysis was made relating to the shoreline itself. Using GIS software, specifically the DSAS add-in (Digital Shore Analysis System) for ESRI´s ArcMap, we analyzed the evolution of the coastline in the past 15 years. The indexes used were the NSM (Net Shoreline Movement), SCE (Shoreline Change Envelope) and EPR (End Point Rate).

3. Results and Discussion

3.1 Elements at risk and land use

Having delimited both the settlement of Fonte da Telha (black) and the area subjected to flooding (blue), we identified and mapped the elements in both areas (Fig. 1). The settlement area was drawn using its northernmost and southernmost feature as the limit on each corresponding direction. The western limit was established at the shoreline and the eastern one at the cliff´s edge. The flood susceptible zone was based on the Silva et al. (2013) model, and its area comes at about 402,090.67m2, around 66.79% of Fonte da Telha total area (602,001.01m2). The statistical analysis is laid out in Table 1. As we can see, most of the structures in the settlement are residences, totaling at 167. Consequently, they suffer the greatest number of losses in case of severe flooding. Even so, both restaurants/coffee shops and parking lots are hit harder when compared to their respective totals. Restaurants/coffee shops

Figure 1. Identification of study area and elements within.

lose 84.37% and parking lots sport an astonishing 100% incidence rate. This is most likely related to do with their location. Both types of elements are commonly located near the shore, with prompt access to the beachfront.

On the other hand, the two hotels identified are out of the proposed flooding area, in sharp contrast with the former elements. Both hotels are found a bit above the mean height of the settlement and considerably inland, relatively to the maximum width of the area. On the other elements category, we identified a church and a coastguard post. The church represents the half that stays dry in the event of a flood, whereas the coastguard post, built on top of the sand dunes, will most likely be heavily affected by the flooding and the overwash itself.

Table 1. Accounting of exposed and non-exposed elements in Fonte da Telha.

Element Type	No. Elements	No. Inside Flood Area	No. Outside Flood Area	Affected (%)
Residence	167	109	58	65.27
Restaurant/ Coffee Shop	32	27	5	84.37
Parking Lot	19	29	0	100
Hotel	2	0	2	0
Other	2	1	1	50
Total	222	156	66	70.27

As far as land use goes, using the Portuguese Land Use Chart (2018), six different land use types were identified (Fig. 2). The number of features pinpointed in each land use class are discriminated in

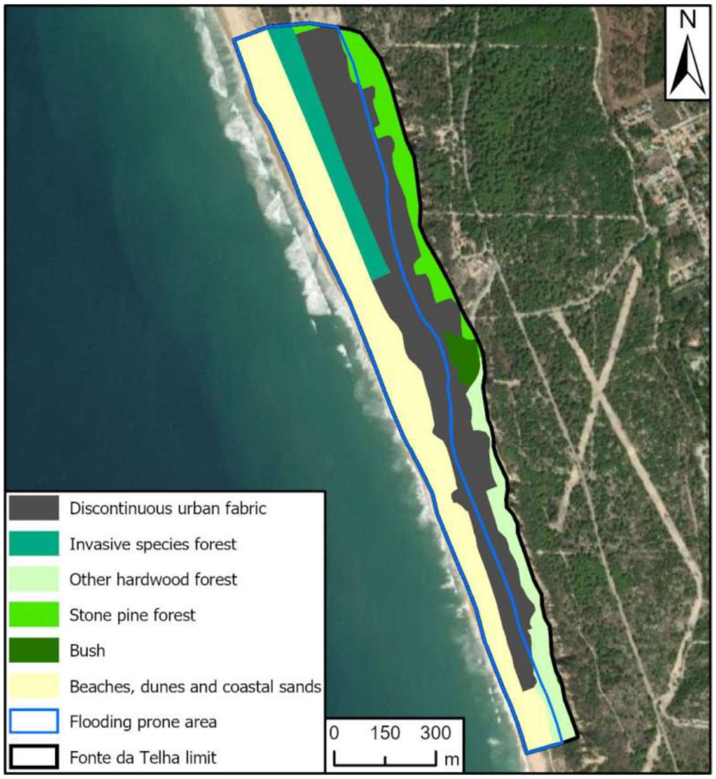

Figure 2. Land Use at Fonte da Telha (Source: Laud Use Chart, 2018).

Table 2. As expected, most elements are within the discontinuous urban fabric class. Some elements are spread throughout the different forested areas, but the real problem concerns the features located in the beaches, dunes and coastal sands class. The elements located here are in an especially vulnerable spot, as it is here that the processes in question in this analysis are the most impactful. These are entities not only at risk of flooding, but of being hit by the overwash itself.

Table 2. Accounting of elements by Land Use class.

Element Type	Discontinous urban fabric	Invasive species forest	Other hardwood forest	Stone pine forest	Bush	Beaches, dunes and costal sands
Residence	160	0	2	2	2	2
Restaurant/ Coffee Shop	28	0	0	0	0	7
Parking Lot	13	2	1	1	0	3
Hotel	2	0	0	0	0	0
Other	1	0	0	0	0	1
Total	204	2	3	3	2	13

3.2 Digital Shoreline Analysis System (DSAS)

As mentioned before, a brief analysis was preformed using the DSAS add-in for ArcMap. For this analysis six shorelines were identified between 2004 and 2019 using Google Earth satellite imagery. 113 transects were cast, 20m meters apart, for a total of 2,260m of shoreline (Fig. 3). Immediately we notice the proximity of all the shorelines over the span of 15 years, suggesting little movement between years. The NSM index expresses the difference in shoreline between the initial and final year. Our results indicate that 92.04% of the transects are classified as erosive. Only 9 of the transects are experiencing accretion, with a maximum growth of 11.23m, as opposed to the maximum loss of 32.96m elsewhere, for an average loss of 14.52m over the span of the coastline. As for the SCE index, which identifies the biggest difference between shorelines in meters, exhibits a maximum value of 40.73m and a minimum of 15.53m, for an average of 24.99m. The EPR index measures the rate at which the coast is moving each year, in meters per year. This naturally supports the findings in the NSM index, namely that the accretion rate is much slower than the erosion one, and the coast is retreating at an average of 0.97m per year.

Figure 3. Coastlines, baseline and accretion/erosion transects.

Vale the Telha is in fact an area prone to ocean flooding, as was expected given the location and characteristics of the township. As we found, a good portion of the structures in the settlement are at risk of flooding, with some in the way of the overwash itself. The government of the Almada municipality published in 2015 a “Plano de Pormenor” for Fonte da Telha. This plan uses Silva et al. (2013) to determine a set of rules with the objective of deterring the effects of flooding in the area. These include having the urban center buildings and beach support structures no lower than 11m, as the projected overwash height is 10.9m. One other policy is the reconstruction of the dune system with deposition and stabilization of sands at approximately 12m high. Both these policies seem difficult to implement or outright impossible. Given the average height of 6.65m, according to NASADEM data, which admittedly lacks the spatial resolution for an analysis of this scale, it seems unfeasible to place most of the settlement's buildings above 11m without a large-scale remodeling of the village. As most of the buildings are residential, it would also mean either the construction of the new residences before the demolition of the current ones, which poses the question of where to build the new structures given the free space available, or the temporary displacement of the affected population after the demolition of their current home and the construction of the new. Even if possible, it would take large amounts of financing to implement and would most likely be an unpopular move among the local populace. The dune system reconstruction is more realistic, but even so runs into major problems. As we saw previously, there are a not insignificant number of structures on top of the main sand dune. To reconstruct the system would mean the removal of such buildings, or their ascension above the 12m mark using various technics, the same way beach access walkways are placed. There is also the need to fixate the dunes after reconstruction. While there are technics for this, it would mean an additional expense and no concrete course of action is given in the plan regarding this. There are several demolition jobs planned, although these are related to illegal residences and not the policies mentioned beforehand. There is also the fact that the shoreline is retreating at a rate of approximately 0.97m per year. This increases the risk to the town over time.

4. Conclusion

The lack of studies that focus on post-disaster field surveys (Santos et al. 2015) are concerning, given the enormous impact storm events can have in coastal communities. The results found here are of vital importance to effective urban planning in these areas and yet most studies focus purely on the pure technical and scientific aspect of the question as seen in Silva et al. (2013), Hermínio (2015), Pires (2017), Silva et al (2017) and Duarte et al. (2020), among others. While these are by no means trivial, more research must be done in the vein of Pinto (2014), Santos et al. (2015), Sousa (2015) and this very article. Additionally, we believe that easy access to reliable information concerning the damages of previous events could increase interest in this type of research. Detailed cartography of coastal settlements, and access to it, should also be a priority of the authorities. As such we propose the development of a national database to store these kinds of occurrences for future reference, such the work of Tavares et al. (2021). Given the possible damages that coastal settlements can suffer, it seems imperative that more studies with this perspective are done for the remaining Portuguese coast, supported the in overwash and coastal flooding modeling akin to those mentioned above. Only with the conjunction of these two perspectives will it be possible to fully understand the effects these events have in coastal communities, not only physically but also socially, and prepare accordingly.

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