Flooding occurrences in the Portuguese continental coastal zone: a database for the period 1980-2018

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The Portuguese continental coastal zone is characterized by its lithological, morphological, biological and landscape diversity. With a coastline extension of approximately 987 km, this zone has great importance in the national context. The increasing anthropic occupation of the coastal zone in the last seven decades led to a conflict with the natural dynamics of these areas. The project MOSAIC.pt emerges from the need of a comprehensive flood risk management framework for the Portuguese coastal zones, including estuaries. One of the innovative challenges of this project is to identify the coastal critical typologies affected by flooding, based in historical data. Hence, a historical database of coastal flood occurrences was created for the period 1980-2018. Historical data was collected in national and regional newspapers. The database includes relevant information such as flood triggering factors and impacts. For the period 1980-2018, a total of 398 occurrences of coastal overtopping and flooding were identified. The analysis shows that the vast majority of occurrences are located on the Portuguese western coast. In terms of impacts, the typologies associated with material, natural, environmental and lastly human impacts stand out. Results provide relevant temporal and spatial information about coastal historical flood occurrences and contribute for the design of a risk framework.

Keywords: Coastal zone, Flood, Database, Impacts, Occurrences

1. Introduction

Coastal zones are complex systems where different factors interact (hydrosphere, geosphere, atmosphere and biosphere). Worldwide, several coastal zones are at high risk of flooding, including densely populated and economically vital areas, making them particularly vulnerable to extreme events (Fortunato et al., 2017). The risk of coastal flooding and overtopping is further aggravated by climate change through sea level rising and, in some areas, by the increasing intensity and frequency of extreme events (Antunes and Freitas, 2002; Bertin et al., 2013; Santos et al., 2014; Fortunato et al., 2017).

The coastline of Europe is one of the most densely populated and developed in the world, with almost half of the population and main cities located in coastal regions (Collet, 2010). In Europe the risk and impacts associated to flooding, overtopping and erosion has been increasing throughout 20th and 21st centuries (Nicholls and Cazenave, 2010; Weisse et al.,2014; Silva et al., 2017). Aware of the high risk of flooding, EU Floods Directive creates a common framework to provide adequate and coordinated measures to reduce flood risk in water courses and coastlines. To increase the response capability to these events, the coastal floods prediction ability has to be improved and integrated with the others components of risk, such as vulnerability and exposure, in developing methodologies that more adequately contribute to emergency planning and response (Freire et al., 2016).

In Portugal, the coastline is approximately 987 km long and is characterized by high lithological, morphological, biological and landscape diversity (Santos et. al., 2014). In the national context, the coastal zone stands out as an extremely important area, where ¾ of the population and 80% of GDP are located (Santos

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et al., 2014) and where the risk of sea level rise is high (Veloso et al., 2004; Antunes and Taborda, 2009). The threat of climate change effects leads to the need of providing the territory with knowledge and methodologies to mitigate their potential impacts. The Mosaic.pt project thus emerges with the objective of developing an innovative methodology to support flood risk management, supported by a better ability to forecast overtopping and flooding occurrences in different coastal typologies. The research plan of the project was built on 10 interlinked activities with several milestones. The construction of a historical database of coastal flooding and overtopping occurrences for the continental Portuguese coastal zone between 1980 and 2018, based on a hemerographic analysis, is included in the first activity that addresses the evaluation of the main coastal flood occurrences in the Portuguese coast (including estuaries, natural and artificialized beaches). A critical analysis of this information will help the selection of the coastal typologies most affected by floods and a particular study site. The development of loss and damage database related with natural disasters is important for risk assessment and for regional and local management (Santos et al., 2014).

The main objective of this study is to present the structure of the database and the temporal and spatial analysis of the results related to coastal overtopping and flooding occurrences.

2. Study area characterization

The study area of the present work is the entire 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, totalling about 987 km (Figure 1). As mentioned above, the Portuguese coast has a great diversity of morpho-sedimentary systems such as estuaries, lagoons, barrier islands, beaches, dunes and cliffs (Ferreira and Matias 2013; Ponte Lira et al., 2016). The analyzed coastal zone is also characterized by a multiplicity of uses, occupation and activities that makes it an area of strategic importance at the economic, social and environmental levels. In this sense, ¾ of the Portuguese population resides in coastal municipalities and generates about 80% of the GDP (Santos et al., 2014). The strong human occupation of the coastal zone over the last 7 decades, combined with oceanographic and atmospheric forcings and distinct geological and morphological contexts contributes decisively to the evolution and current configuration of the coastal zone. The area of study is also characterized by an asymmetry in terms of wave direction and energy (Andrade and Freitas, 2002). The western coast is characterized by high energetic waves with dominant northwest swell, contributing to high sedimentary transport values (Andrade and Freitas, 2002). As protected from the northwest swell, the south coast presents a more moderate wave energy (Ferreira and Matias, 2013). The coastal zone presents itself as a multi-hazard zone, with emphasis on overtopping and coastal flooding, cliffs instability and coastal erosion. With regard to the latter, the decline of the sedimentary input to the coast as a result of the anthropogenic pressure in the watersheds and in the coastal zone itself,aggravates the erosion process, contributing to the current shoreline configuration (Dias, 2005; Veloso Gomes 2007; Pereira and Coelho, 2013; Santos et al., 2014; Ponte Lira, 2016).

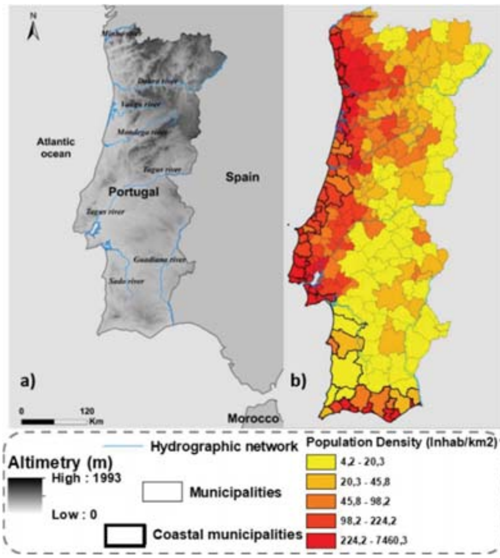

Fig. 1. Location of the area: a) Continental Portugal; b) Population density of Continental Portugal by municipality

3. Methodology

Worldwide there are a large number of disaster databases, which differ in their methodology (sources, hazards typology, spatial incidence) and in their inclusion criteria (Santos et al. 2014b). Some of the best known are the Emergency Events Database (EM-DAT), the NatCatSERVICE created and managed by Munich RE and the DesInventar databases. At the national level, the creation of the Disaster database for hydro-geomorphologic disasters between 1865 and 2010 (Zêzere et al., 2014) and the creation of a historical flood events in the Tagus estuary (Rilo et al., 2015) stands out. Another highlight is the existence of the SurgeWatch database that identifies coastal flooding in the United Kingdom between 1915 and 2016 (Haigh et al., 2017).

The absence of a consolidated coastal flood database for the Portuguese coast combined with the need for identification and selection of coastal critical typologies most affected by floods, under the Mosaic.pt project, led to the creation and development of the database presented here. The construction of the historical flooding occurrences database for the Portuguese continental coastal zone was based in the hemerographic analysis for the period between 1980 and 2018. A total of six daily newspapers were analyzed, two of them national and the other four regional. However, not all newspapers have the same temporal coverage because some of them were founded after 1980 (Figure 2). With regard to national newspapers, Público was chosen for presenting a more homogeneous national coverage compared to Jornal de Notícias. However, since it was only founded in March 1990, the period from January 1980 to February 1990 was analyzed using the Jornal de Notícias (Figure 2).

Fig. 2. Newspapers analyzed for the database construction

In order to have a homogeneous coverage of the study area, the four selected and analyzed regional newspapers have a distinct spatial coverage. Thus, the regional coverage of the four newspapers is as follows: a) northern coastal region; b) north central coastal region; c) south-central coastal region; d) coastal region south of the Tagus River (Figure 1). Regarding the structure of the database, it is based in six major topics (Figure 3), each divided into a total of 50 fields that identify and characterize each occurrence in its multiple strands. All occurrences were validated by crossing the information obtained in more than one newspaper, as well as in the analysis of academic works and existing reports. Each occurrence was georeferenced using a Geographic Information System (GIS), based in satellite images provided by the World Imagery service provided by Esri®. Each one was also characterized in terms of typology of associated impacts: occurrences with human impacts (casualties, injured, missing, homeless and evacuated), occurrences with material impacts (road infrastructure, buildings, collective equipment and other infrastructures) and occurrences with impact on natural and environmental systems (dune destruction, agricultural damage, field salinization, sand reduction).

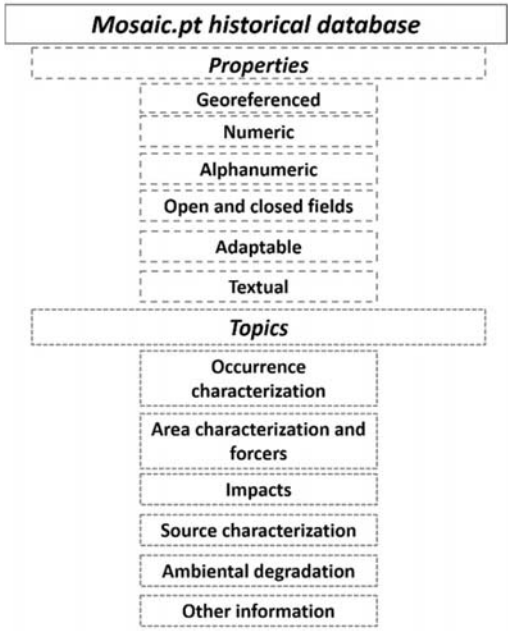

Fig. 3. Database topics and properties.

4. Results

The hemerographic analysis allowed to identify a total of 398 occurrences of flooding and coastal overtopping for the period between 1980 and 2018. The analysis shows that the occurrences present a temporal and spatial variability that will be displayed below.

4.1 *Geographic distribution of the occurrences*

The occurrences between 1980 and 2018 evidence a great variability. Figure 4 shows that the spatialization can be divided into two sectors: north and south of the Tagus River. Occurrences in the south sector represent only 21% of the total occurrences. In this area, Costa da Caparica (in Almada municipality) and Faro Island (in Faro municipality, Figure 4) stand out. Regarding the north area of the Tagus, the occurrences represent 79% of the total observed. However, even in this area there is a huge variability of the geographic distribution. In this sense, the area north of the Mondego River stands out, with 61% of the total number of occurrences, especially in the coastal areas of Ovar, Porto and Ílhavo municipalities. Table 1 presents the 10 municipalities with the highest number of occurrences. From a total of 51 coastal municipalities, only 11 have no occurrences.

Table 1. The 10 municipalities with the higher number of occurrences

Municipality	Nº occurrences
Ovar	52
Porto	45
ílhavo	45
Almada	32
Caminha	16
Esposende	16
Vagos	14
Cascais	14
Figueira da Foz	13
Vila Nova de Gaia	11

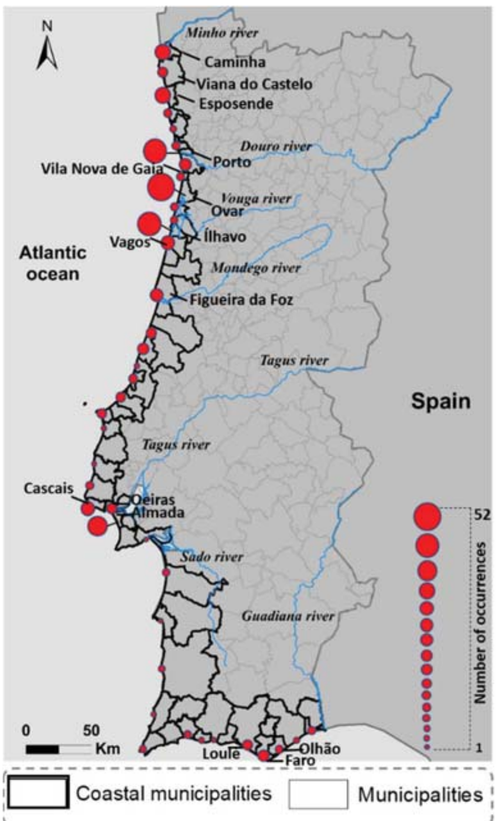

Fig. 4. Geographic distribution of the occurrences

The coastal areas of Ovar, Porto and Ílhavo municipalities represent 36% of the registered occurrences. Nevertheless, even in these areas there is a great variability in spatialization. Figure 5 presents these three areas in detail. In the Porto municipality, the occurrences are concentrated mainly in the Foz do Douro zone, as well as in the innermost area of the Douro estuary (Figure 5 b). In Ovar, it is possible to identify three zones: Esmoriz, Cortegaça and Furadouro (Figure 5a) that present a consolidated historic of occurrences during the period under review. Finally, the municipality of Ílhavo, with Praia da Barra and Costa Nova (Figure 5 c) as the most relevant areas in terms of occurrences history.

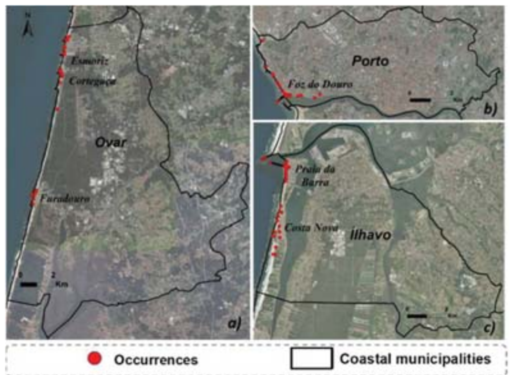

Fig. 5. Detail of the three areas with the higher number of occurrences: a) Ovar; b) Porto; c) Ílhavo

4.2 *Temporal analysis*

In terms of temporal analysis, the results show a decennial, annual and monthly variability. The years with highest number of occurrences are 2014 (90), 1996 (59) and 1998 (35) (Figure 6), representing 46% of the total. From the whole period of analysis, only four years (1980; 1993; 2004; 2012) have no record of occurrences. A decennial analysis shows that the periods 1990/1999 and 2010/2018 represent 74% of the total of occurrences. In this regard, 2014 is the year with the highest number of occurrences, most of them related to the Hercules storm that occurred between the 3rd and 7th of January.

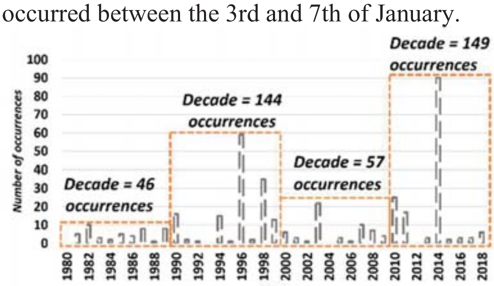

Fig. 6. Decennial and annual analysis of the number of occurrences

Regarding the monthly analysis, the month with the highest number of occurrences is January (Figure 7). It is also verified that the majority (93%) of the occurrences are concentrated in the winter months, from October to March.

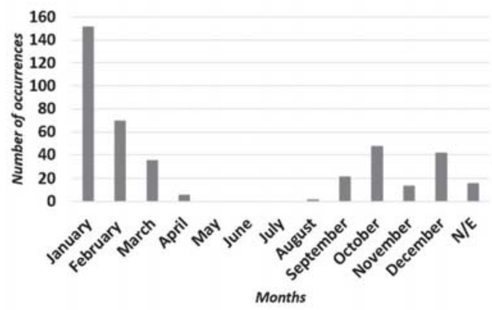

Fig. 7. Monthly analysis of the number of occurrences

4.3 *Impact Analysis*

Regarding the impacts associated with coastal flooding and overtopping, the distribution of the different impacts is presented in Figure 8. Note that each occurrence may report one or more impacts. In this sense, material impacts predominate, followed by natural and environmental impacts and human impacts (Figure 8). In terms of material impacts, the results highlight the damage on urban streets, residential/commercial buildings and coastal protection infrastructures, which together represent 70% of the total for this typology. It is noteworthy that from the historical analysis, a total of 231 buildings were affected, but this value is probably underestimated as many newspapers refer that buildings were affected without mentioning a specific number. Regarding the impacts on the natural and environmental systems, evidences point out the destruction of the dune ridge and sand reduction as the main observed impacts. In terms of human impacts, the results show that the evacuated and homeless are the categories with the most affected people.

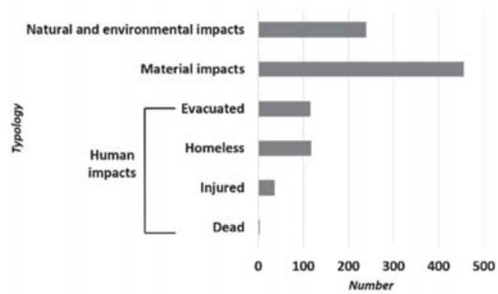

Fig. 8. Distribution of the impacts by typology

5. Discussion

The analysis of coastal flooding occurrences for the period of 1980 to 2018 shows that the coastal zone of mainland Portugal is divided between the western coast, where 90% of the occurrences are located, and the southern coast with only 10%. It is also important to note that most occurrences (79%) are located in the north of the Tagus River. The results show that the anthropic coastal zone is the more affected area, translated by the fact that 60% of the occurrences are identified in areas with anthropic occupation. The spatialization of occurrences and their relationship with population density also shows that 89% of occurrences occur in municipalities with a moderate to high population density, ranging from 98.2 to 7460.3 inhab / km^2. The results highlight the coastal zone between the mouth of the river Minho and the mouth of the Mondego as presenting the highest number of occurrences during the analyzed period. This coastal zone is characterized by the predominance of low-lying sandy coast and beach – dune systems (Santos et al., 2014; Ponte Lira et al., 2016). It is also an area that includes various coastal protection structures. The results of the present study demonstrate that the areas with the largest number of coastal flooding occurrences match with the ones that were identified in other studies as vulnerable locations due to factors such as energetic wave climate, coastal erosion and significant decrease in sedimentary supply (Andrade and Freitas, 2002; Coelho et al., 2009; Pereira and Coelho, 2013, Santos et al., 2014; Ponte Lira et al., 2016). The highest number of coastal flooding occurrences between 1980 and 2018 correspond to several built-up areas that depend directly on these coastal defence structures, namely Esmoriz, Cortegaça, Furadouro and Costa Nova. Between 1995 and 2014, 196 million euros were spent on this type of works, with 53% of this investment (Silva, 2014) being made in the 10 municipalities with the highest number of coastal flooding occurrences. This indicates that despite the importance of making these investments, they have not prevented flooding and overtopping. In this regard, the database shows that 27% of occurrences cause impacts on coastal protection infrastructures, increasing to 33% if only the 10 municipalities with the highest number of occurrences are considered. Regarding human impacts, the database results shows a clear different spatial distribution between the typologies included in this impact category. The occurrences leading to casualties, injury and evacuation, are all located on the western coast. Here, most occurrences are in municipalities located in the north of the Mondego river (Viana do Castelo, Porto, Ovar, Vagos and Figueira da Foz), with the only exception being the municipality of Almada, located south of the Tagus River. However, in relation to the occurrences that caused homeless, the majority are located on the south coast, in the Loulé and Olhão municipalities, particularly in the island of Fuseta (Olhão), with the only exception being the Oeiras municipality (north of the Tagus river).

The construction of the present database and the corresponding results is important for the characterization of the coastal overtopping and flooding occurrences in the continental Portuguese coast, contributing to increase the hazard prediction capacity.

6. Conclusions

The present work shows the structure and the preliminary results of the coastal flood and overtopping occurrences database for the continental Portuguese coast for the period between 1980 and 2018. The construction of a historical database is crucial for the evaluation of the main coastal flood events, allowing the identification of flood hazards and its impacts. The obtained results contribute to identify the most vulnerable zones and characterize the coastal flood hazards spatially and temporally. In addition, the historical data allows the spatial and temporal distribution of the occurrences and the identification of its characteristics, impacts and associated forcers. These results can also be used to validate overtopping and flooding forecasting models and forcing prediction models as well.
They also contribute to the identification, analysis and assessment of existing vulnerability factors in different coastal typologies. The results obtained in this database and their incorporation in the different activities and tasks of the Mosaic.pt project will contribute with innovative approaches to emergency planning and response, promoting safer and more resilient communities, in line with the national and regional key strategies and towards the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015). The database presented here can also serve as a working and support tool for changing the Portuguese coastal defence strategy. From an imminently reactive strategy based in coastal protection that promotes the artificialization of the coast to adaptation measures that, besides protection, also promote strategies related to relocation and accommodation.

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