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ORIGINAL PAPER

DISASTER: a GIS database on hydro-geomorphologic disasters in Portugal

J. L. Zêzere · S. Pereira · A. O. Tavares · C. Bateira · R. M. Trigo · I. Quaresma · P. P. Santos · M. Santos · J. Verde

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Abstract In the last century, Portugal was affected by several natural disasters of hydro-geomorphologic origin that often caused high levels of destruction. However, data on past events related to floods and landslides were scattered. The DISASTER project aims to bridge the gap on the availability of a consistent and validated hydro-geomorphologic database for Portugal, by creating, disseminating and exploiting a GIS database on disastrous floods and landslides for the period 1865–2010, which is available in http://riskam.ul.pt/disaster/en. Data collection is steered by the concept of disaster used within the DISASTER project. Therefore, any hydro-geomorphologic case is stored in the database if the occurrence led to casualties or injuries, and missing, evacuated or homeless people, independently of the number of people affected. The sources of information are 16 national, regional and local newspapers that implied the analysis of 145,344 individual newspapers. The hydro-geomorphologic occurrences were stored in a database containing two major parts: the characteristics of the hydro-geomorphologic case and the corresponding damages. In this work, the main results of the DISASTER database are presented. A total of 1,621 disastrous floods and 281 disastrous landslides were recorded and registered in the database. These occurrences were responsible for 1,251 dead people. The obtained results do not support the existence of any exponential increase in events in time, thus contrasting with the picture provided to Portugal by the Emergency Events Database. Floods were more frequent during the period 1936–1967 and occurred mostly from November to February.

J. L. Zêzere (✉) · S. Pereira · I. Quaresma · M. Santos · J. Verde
Centre for Geographical Studies, IGOT, Edifício da Faculdade de Letras da Universidade de Lisboa, University of Lisbon, Alameda da Universidade, 1600-214 Lisbon, Portugal
e-mail: zezere@campus.ul.pt

A. O. Tavares · P. P. Santos
Department of Earth Sciences, Centre for Social Studies, University of Coimbra, Coimbra, Portugal

C. Bateira · M. Santos
CEGOT, University of Oporto, Oporto, Portugal

R. M. Trigo
Instituto Dom Luiz (IDL), University of Lisbon, Lisbon, Portugal

Landslides were more frequent in the period 1947–1969 and occurred mostly from December to March.

Keywords Disaster project · Database · Floods · Landslides · Portugal

1 Introduction

In the framework of the United Nations (UN) International Decade for Natural Disaster Reduction (IDNDR 1995), natural disaster was defined as "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" (ISDR 2009, p. 9). Therefore, the concept of natural disaster includes the direct and indirect negative impacts to society (in social, economic and environmental terms), resulting from the occurrence of a hazardous natural phenomenon (Alexander 2000; Wisner et al. 2004; NRCNA 2006).

The economic growth and the technological development observed during the twentieth century were not accompanied by the reduction in natural disasters. According to EM-DAT (2013), more than 12,000 natural disasters occurred worldwide in the period 1900–2012, but more than 86 % of events occurred after 1974 (EM-DAT 2013). Moreover, the yearly average number of disasters increased almost 4 times from 1974 to 2012. Within this period, 2.8 million people died and 6.1 billion people were affected by natural disasters (albeit some were affected more than once). In addition, economic, social and environment losses amounted to more than US$ 2.46 trillion (EM-DAT 2013).

The exponential growth of natural disasters in the last decades has been widely discussed by the scientific community. In the case of hydro-meteorological disasters (e.g., droughts, storms, floods), the increasing occurrences may be related to the increasing frequency and magnitude of natural dangerous phenomena, as a direct consequence of climate change (Dore and Etkin 2000; Parry et al. 2007; Gupta et al. 2009). Nevertheless, the increase in disaster number is also noticeable for geophysical disasters (Alcántara-Ayala 2002), and there is no evidence of increment concerning the activity of related natural phenomena (e.g., earthquakes, tsunami and volcanic eruptions).

Therefore, the growth of natural disasters is also related to the uncorrected land use planning, which have been responsible for the increment of risk exposure and people vulnerability, namely in large metropolis and along the coastal zone (Hervás 2003; McInnes 2006).

The inventory, development and exploitation of natural disaster databases have been made worldwide in recent years for different purposes (Tschoegl et al. 2006; Guha-Sapir and Vos 2011). The Global Risk Information Platform (GRIP) provides the access to a world disaster database catalog, facilitating centralized access to disaster loss databases worldwide. The EM-DAT (Tschoegl et al. 2006) is the most important and well-known international database on disasters. Since 1988, the Centre for Research on the Epidemiology of Disasters (CRED) of the University of Louvain maintains the EM-DAT (EM-DAT 2013). This database is compiled from several sources and includes data on natural and technological disasters occurred in the world from the beginning of the twentieth century to the present. At the regional level, the Network for Social Studies on Disaster Prevention in Latin America (La Red 2003) developed in 1994 the DesInventar methodology. This methodology regards the collection of typical disaster standard data (e.g., number of casualties and affected people), but also data on economic and infrastructural damages, as well as data on disaster social effects (La Red 2003). More recently, the DesInventar methodology has been applied in several countries located in Northern Africa, Southeastern Asia and Oceania. At the national level, public services related to civil protection supported the creation of disaster databases in Australia (EMA, Emergency Management Australia), Canada (CDD, Canadian Disaster Database) and the United States (SHELDUS, Spatial Hazard Event and Losses Database for the United States) (Tschoegl et al. 2006).

In Europe, the European Commission empathized the need to have wide monitoring capacities, where the standardization of data collection should be a priority (ECDGE 2008). In this framework, the Spanish Civil Protection promoted the database on floods occurred in Catalonia during the twentieth century to contribute to flood risk assessment and mitigation (Barnolas and Llasat 2007). In Italy, an important effort has been made regarding the production, exploitation and dissemination of disaster information (Guzzetti and Tonelli 2004; Guzzetti et al. 2005; Salvati et al. 2010). Since 1992, a historical database on floods and landslides is maintained under the institutional support of the Italian Civil Protection. The information system on historical landslides and floods in Italy is available online at SICI (http://sici.irpi.cnr.it). A second Web site (http://webmap.irpi.cnr.it/) exploits GIS-based Web technology to display maps of the distribution of sites affected by the historical hydrologic and geomorphologic events in Italy.

The development of natural disaster databases is absolutely decisive for risk management purposes (Devoli et al. 2007) because it highlights the relationships between the occurrence of dangerous natural phenomena and the existence of vulnerable elements (e.g., people, assets and activities) that can be quantified through human and material losses. Recently, risk prevention was assumed to be a priority in Portugal by the National Programme on Politics for Territorial Management (MAOTDR 2006). Furthermore, this general guide for the Portuguese territorial management states that risk management and prevention must be considered in all instruments dealing with territorial planning and management.

Besides earthquakes and volcanic eruptions, hydrologic (floods) and geomorphologic (landslides) events are on the top of natural disasters worldwide as well in the Portuguese territory (Ferreira and Zêzere 1997; Ramos and Reis 2002). Nevertheless, the basic information on past floods and landslides which occurred in Portugal was scattered and incomplete and this is a shortcoming for the implementation of effective disaster mitigation measures.

In 2010, the Portuguese Foundation for Science and Technology funded the project "DISASTER—GIS database on hydro-geomorphologic disasters in Portugal: a tool for environmental management and emergency planning." The DISASTER project aims to create, exploit and disseminate a GIS database on disastrous floods and landslides occurred in the Portugal mainland from 1865 to 2010. Within this subject, the main objectives of this paper are the following:

1. To discuss the concept of hydro-geomorphologic disaster in the Portuguese context;
2. To present the methodological aspects related to hydro-geomorphologic data collection and the construction of a disaster database linked to a GIS;
3. To explore the DISASTER database, including the presentation and discussion of the geographic and temporal distributions of hydro-geomorphologic disasters, the discussion on the completeness of the database, the evaluation of societal risk and the comparison between the DISASTER database and the EM-DAT.

2 Concept of hydro-geomorphologic disaster

Hydro-geomorphologic disasters are natural processes of hydrologic (floods, flash floods) or geomorphologic (various types of landslides) nature that generate adverse consequences as loss of life or injury, property damage, economic disruption or environmental degradation.

Prior to initiate any data collection to build a database on disasters, it is critical to define quantified criteria for the inclusion of any particular event in the database. For example, the entry criteria for NatCat (Munich RE disaster database) are the occurrence of any property damage and/or the existence of any person sincerely affected (injured, dead) (Below et al. 2009). The Insurance Services Office considers a disaster an event that causes $25 million or more in insured property losses and affects a significant number of property–casualty policyholders and insurers (Thywissen 2006). In the case of EM-DAT, for a disaster to be registered, at least one of the following criteria must be fulfilled: (1) 10 or more people reported dead; (2) 100 or more people reported affected; (3) declaration of state of emergency; or (4) call for international assistance.

The EM-DAT criteria are relatively strict if applied at national level, and this may explain the inclusion in this database of only 32 natural disasters occurred in mainland Portugal (Azores and Madeira islands were not considered) during the period 1900–2010 (Fig. 1). In addition, the EM-DAT includes 13 disasters of hydro-geomorphologic origin for the same period (41 % of total natural disasters) (Fig. 1; Table 1). According to the EM-DAT, these hydro-geomorphologic disasters were responsible for 567 death people and 32,966 affected people. Quite surprisingly, the EM-DAT does not report any natural disaster in Portugal for the period 1900–1960. Moreover, for both natural disasters and hydro-geomorphologic disasters, the increase in occurrences with time is apparent, and the distribution of events by decade may be fitted by second-order polynomial trends: $y = 0.1783x^2 - 0.9126x$ ($R^2 = 0.81$) for natural disasters; $y = 0.072x^2 - 0.3666x$ ($R^2 = 0.94$) for hydro-geomorphologic disasters.

Besides the events reported in the EM-DAT to Portugal, many floods and landslides that have resulted in relevant social and economic losses are known to have occurred in the past and should be considered at the national level. Therefore, the entry criteria for the DISASTER project database are the following: any flood or landslide that, independently of the number of affected people, caused casualties, injuries or missing, evacuated or homeless people. We can assume that such consequences are relevant enough to be reported by the press, namely daily newspapers, which are the main source for data collection in the DISASTER project.

In the context of the DISASTER project, the concepts of DISASTER case and DISASTER event need to be clarified. A DISASTER case is a unique hydro-geomorphologic occurrence, which fulfills the DISASTER project database criteria, and is related to a unique space location and a specific period of time (i.e., the place where the flood or landslide harmful consequences occurred in a specific date). A DISASTER event is a set of DISASTER cases sharing the same trigger which can have a widespread spatial extension and a certain magnitude. For example, on November 18, 1983, an intense storm struck the Lisbon area, triggering dozens of floods in this district that were responsible for widespread economic losses, including road and power cuts and led to several casualties (Liberato et al. 2013).

3 The DISASTER project database

The DISASTER project aims to bridge the gap on the availability of a consistent and validated hydro-geomorphologic database for Portugal, by creating, disseminating and exploiting a

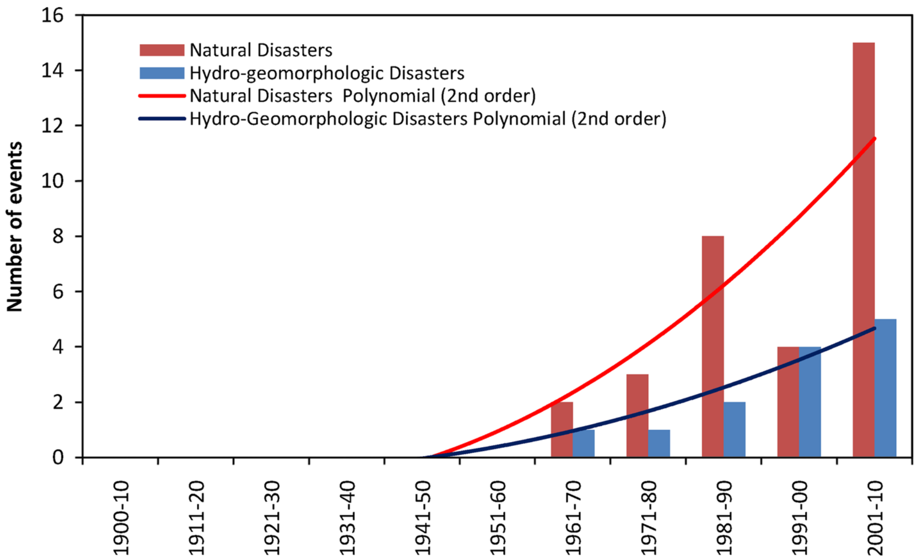


Fig. 1 Natural disasters and hydro-geomorphologic disasters reported for Portugal by the EM-DAT for the period 1900–2010

GIS database on disastrous floods and landslides which occurred in Portugal (Azores and Madeira were not considered) since 1865 (the earliest date for available newspaper records) until 2010.

3.1 Data collection

The methodology used in the DISASTER project for data collection and storage is summarized in Fig. 2. The data collection started with the selection of newspapers to be analyzed by three research teams belonging to the Oporto, Coimbra and Lisbon Universities. Newspapers were selected for systematic survey according to two criteria: (1) The newspaper must have been published continuously for at least 30 years and (2) the set of selected newspapers should guarantee the best regional spatial distribution of the news, in order to cover the entire country.

The set of newspapers that were selected and systematically surveyed for collecting data on disasters is shown in Table 2, which includes the corresponding reference period, category, coverage and spatial incidence. The national daily newspaper *Diário de Notícias* provides the longest time period, having been published continuously since 1865. Two other daily newspapers having a regional coverage were systematically surveyed: the *Jornal de Notícias* published in Oporto (North of Portugal) since 1888 and the *Diário de Coimbra* published in Coimbra (Central Portugal) since 1931. The remaining 8 newspapers are weekly regional and local newspapers published in different regions of the country, thus ensuring the necessary regional coverage. Occasionally, five additional newspapers (*O Século*, *Comércio do Porto*, *O Primeiro de Janeiro*, *Público* and *Correio da Manhã*) were surveyed for some specific dates in order to complete or validate some DISASTER cases (Table 2). In total, 145,344 newspapers specimens were surveyed in order to identify DISASTER cases.

Table 1 Details of hydro-geomorphologic disasters reported for Portugal by the EM-DAT for the period 1900–2010

Disaster code	Start date	End date	District code (see Fig. 12)	Type	No. of deaths	No. of affected people
A	26/11/1967	26/11/1967	12	Flood	462	1,100
B	00/02/1979	00/02/1979	3, 4, 9,11	Flood	4	25,000
C	29/12/1981	29/12/1981	12	Flood	30	900
D	18/11/1983	18/11/1983	12	Flood	19	2,000
E	08/01/1996	08/01/1996	3, 4, 6, 7	Flood	10	1,050
F	22/12/1996	24/12/1996	1, 2, 3, 4, 5	Flood		2,000
G	30/10/1997	08/11/1997	17, 18	Flood	29	200
H	06/12/2000	06/12/2000		Landslide	4	70
I	26/01/2001	29/01/2001	3, 4	Flood	6	200
J	26/12/2002	26/12/2002	1, 3, 4	Flood	1	60
K	01/01/2003	08/01/2003	6, 9	Flood		36
L	22/10/2006	08/11/2006	18	Flood		240
M	18/02/2008	18/02/2008	12, 15	Flood	2	110

Disasters G and H are originally typified as storms in the EM-DAT

District codes: 1—Viana do Castelo; 2—Braga; 3—Porto; 4—Vila Real; 5—Bragança; 6—Aveiro; 7—Viseu; 8—Guarda; 9—Coimbra; 10—Leiria; 11—Castelo Branco; 12—Lisboa; 13—Santarém; 14—Portalegre; 15—Setúbal; 16—Évora; 17—Beja; 18—Faro

Figure 3 shows the temporal coverage of newspapers used for collecting data on hydro-geomorphologic disasters occurred in Portugal. Three distinct periods can be identified according to the number of available newspapers. The first period spans from 1865 until 1907 and is characterized by the existence of up two newspapers (*Diário de Notícias and Jornal de Notícias*) and punctual information gathered from other two newspapers in the end of the period (*Comércio do Porto* and *O Primeiro de Janeiro*). In the subsequent period from 1907 to 1936, four newspapers were available for systematic survey, but only three of them are extended until the twenty-first century (*Diário de Notícias*, *Jornal de Notícias* and *O Algarve: semanário independente*). As for the previous period, punctual data were collected from the *Comércio do Porto* and *O Primeiro de Janeiro*. The 75-year period lasting from 1936 to 2010 is the best covered by newspapers whose number varies between a minimum of nine and a maximum of twelve.

After the selection of titles, the next task was related to the time-consuming reading and interpretation of the news (newspaper analysis) on the newspapers' specimens whose majority were in analogical support (paper or microfilm). During this process, DISASTER cases and events were identified according to the DISASTER project concepts. The complete set of news reporting hydro-geomorphologic DISASTER cases/events was subsequently scanned and converted into digital support (.PDF). Next, all DISASTER cases were validated using the newspaper main report and cross-checking different news sources (national, regional and local newspapers).

3.2 Database structure

The details of characteristics and damages of DISASTER cases were introduced in an online database which was used by the project partners as a client/server model. For maximum

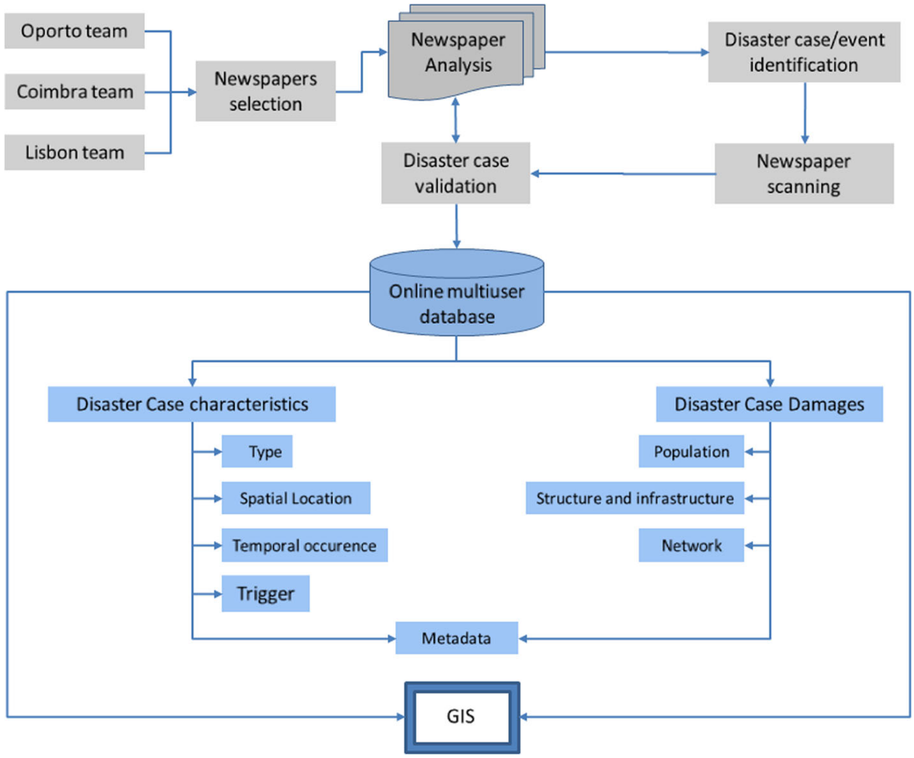


Fig. 2 Methodological scheme for data collection and storage in the DISASTER database

portability, the database was developed on a LAMP platform, comprised of an Apache Web server, a MySQL database engine and using the PHP programming language built on a Linux Server. In addition to portability, this platform also provides an efficient, secure and cost-free solution. The back-office handles all data loading and exporting, as well as future data provision on a public interface.

The multiuser online database comprises two major parts (Fig. 2): (1) the DISASTER case characteristics and (2) the DISASTER case damages. The first part includes data on type (flood or landslide), subtype (flash flood, progressive flooding, urban floods; debris flow; translational slide; rotational slide; earth fall; rock fall; complex slope movement), date (year, month, day and hour), location (council, parish and coordinates of the x and y points according to PT-TM06/ETRS89 projected coordinate system), triggering factor and information source (name, source type and reliability of the news). The size and location of the news of DISASTER cases and events within the newspaper page were also recorded in order to evaluate in a future work the importance given by the media to news on disaster over time.

The complete DISASTER cases were georeferenced using a point shapefile. The precision of location was classified into five classes depending on the quality of the case description in the news: (i) location with exact coordinates (accuracy associated with scale 1:1,000); (ii) location based on local toponymy (accuracy associated with scale 1:10,000); (iii) location based on local geomorphology (accuracy associated with scale 1: 25,000 scale); (iv) location in the centroid of the parish; and (v) location in the centroid of the

Table 2 Newspapers explored for data collection

Newspaper	Reference period	Category	Distribution	Spatial incidence
Systematic survey				
Diário de Notícias	1865–2010	Daily	National	Portugal (mainly the metropolitan area of Lisbon and the Tagus valley region)
Jornal de Notícias	1888–2010	Daily	Regional	North region (mainly the metropolitan area of Oporto)
Diário de Coimbra	1931–2010	Daily	Regional	Center region (mainly the Coimbra area)
Notícias de Chaves	1950–2010	Weekly	Local	North region (Alto Tâmega)
Correio de Mirandela	1907–1937	Weekly	Local	North region (Trás-os-Montes)
Soberania do Povo	1936–2010	Weekly	Local	Center region (mainly northwest area)
Região de Leiria	1935–2010	Weekly	Regional	Center region (southwest area)
Jornal do Fundão	1946–2010	Weekly	Regional	Center region (mainly east area)
Reconquista	1950–2000	Weekly	Regional	Center region (Castelo Branco and Guarda)
Diário do Alentejo	1933–2002	Daily until 1982 and after then weekly	Regional	South region (Alentejo)
O Algarve: o semanário independente	1908–2001	Weekly	Regional	South region (Algarve)
Punctual survey				
O Século	1934–1968	Daily	National	Portugal (mainly the metropolitan area of Lisbon and the Tagus valley region)
Comércio do Porto	1899–1926	Daily	Regional	North region (mainly the metropolitan area of Oporto)
O Primeiro de Janeiro	1904–1955	Daily	Regional	North region (mainly the metropolitan area of Oporto)
Público	1996–2010	Daily	National	Portugal (mainly the metropolitan area of Oporto)
Correio da Manhã	2010	Daily	National	Portugal (mainly the metropolitan area of Lisbon and the Tagus valley region)

municipality. Classes (iv) and (v) were considered only when the disaster news did not provide any detailed geographic information.

The second part of the DISASTER database records flood or landslide damages: number of casualties, injuries, missing, evacuated or homeless people, type of damages in buildings (superficial, structural or functional), number of affected buildings, type of damage in networks (superficial, structural or functional), extent of interruptions in road and railroad circulation.

The DISASTER database is linked with a geographic information system in order to facilitate the analysis of both DISASTER cases and DISASTER events.

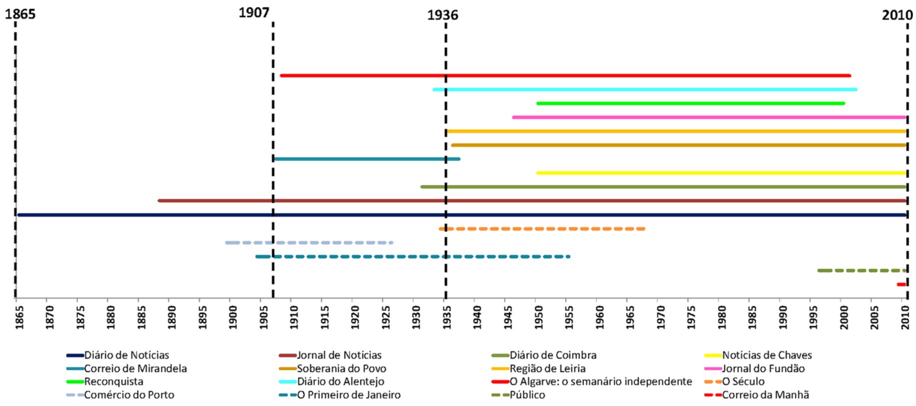


Fig. 3 Temporal coverage of newspapers used in the data collection for the DISASTER database

3.3 Web-GIS design

The DISASTER project Web-GIS server is hosted in the University of Lisbon in the URL riskam.ul.pt/disaster/en and has been implemented with the software GeoServer©, which is an open source software server written in Java that allows users to share and edit geospatial data. This software was designed for interoperability, and it publishes data from any major spatial data source using open standards (http://geoserver.org/display/GEOS/Welcome).

The DISASTER Web-GIS has three main purposes: (1) to make available and free of charge synthesized results from the DISASTER database; (2) to provide location of DISASTER cases (floods and landslides) in Portugal, using the Google Earth© base map; and (3) to provide information about spatial distribution and temporal trends of DISASTER cases and of social damages for hydrographic regions and several administrative units: municipality, district, and NUTS 2 and NUTS 3. The Nomenclature of Territorial Units for Statistics (NUTS) is a geocode standard developed and regulated by the European Union for referencing the subdivisions of countries for statistical purposes (EC Eurostat 2013).

With the DISASTER Web-GIS, it is possible to make geographic queries, visualize spatial relationships and download data reports with synthesized results (Fig. 4). Geographic queries are made to points of DISASTER floods and landslides. It is also possible to obtain information about location (district, municipality and parish), occurrence date (year, month and day) and precision of location (exact coordinates, based on local toponymy, based on local geomorphology, in the centroid of parish, in the centroid of municipality). It is possible to interactively visualize the location of the DISASTER cases overlapping hydrologic layers (rivers, hydrographic regions), geomorphologic layers (morphostructural units and DTM—50 m pixel resolution) and administrative layers (NUTS 2, NUTS 3, district, municipalities and parishes). However, due to uncertainty regarding the precision of DISASTER cases location, visualization is limited to the maximum scale 1:25,000. In this application, the user has the possibility to zoom in and zoom out the area, select layers to visualize, consult their attributes, do measurements and print the viewing area.

There are 337 profiles available online (in Portuguese) with synthesized disasters data in tables, maps and reports for different administrative units (NUTS 2, NUTS 3, district and municipality) and hydrographic regions. These data reports provide information on the following topics: (1) number of DISASTER cases recorded; (2) spatial location of DISASTER cases; (3) number of fatalities, displaced and homeless people recorded; (4) relative

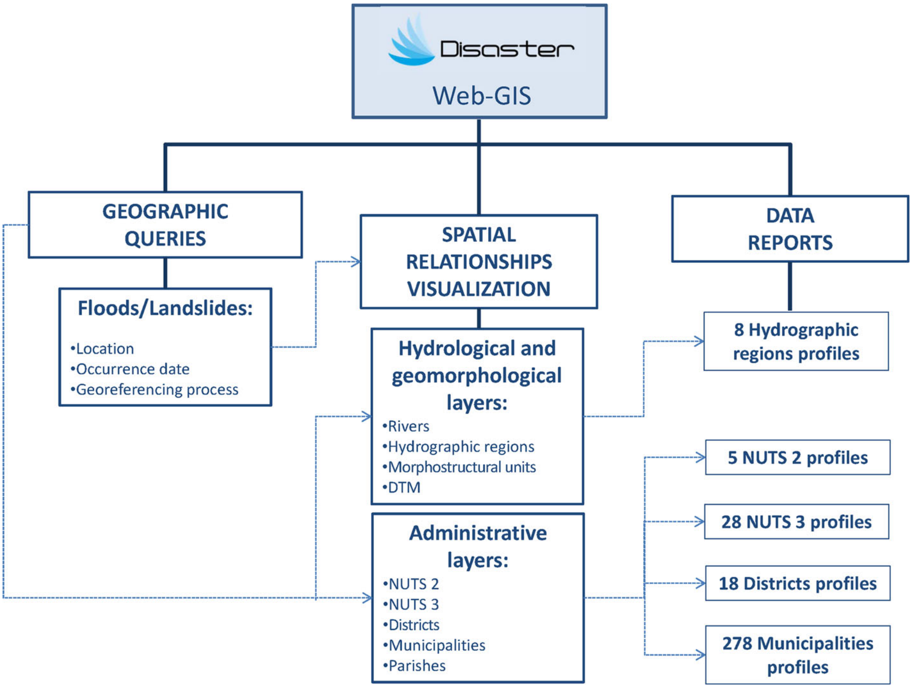


Fig. 4 DISASTER project Web-GIS structure

position of the territorial unit in terms of national ranking; and (5) temporal trends of disaster cases and social damages.

4 Database exploitation

The number of cases within the DISASTER database and their social consequences are summarized in Table 3. In total, 1,902 DISASTER cases were identified (13 per year, on average) which were responsible for 1,251 deaths (average of 8.6 per year), 14,191 displaced people and 41,844 homeless people. The majority of cases (85.2 %) were floods that generated 81 % of total deaths, 94.2 % of total displaced people and 96.3 % of total homeless people.

4.1 Geographic distribution of hydro-geomorphologic disasters

Disastrous floods occurred in Portugal in the period 1865–2010 were widespread in the country (Fig. 5a, b). Nevertheless, some clusters with high density of flood cases are evident, namely in the Lisbon region and the Tagus valley, in the Oporto region and the Douro valley, in the Coimbra region and the Mondego valley and along the Vouga river valley (Fig. 5a).

Table 4 summarizes the density and impacts of disastrous floods occurred in the eight hydrographic regions of the country. The density of disastrous floods registered in Portugal in the period 1865–2010 is 18.2 per 10^3 km^2. The highest density is observed in the

Table 3 Disaster cases and their social consequences in the period 1865–2010

	Disastrous floods	Disastrous landslides	Hydro-geomorphologic disasters
Number of cases	1,621	281	1,902
Number of deaths	1,012	239	1,251
Number of missing people	71	23	94
Number of injured people	478	422	900
Number of displaced people	13,372	819	14,191
Number of homeless people	40,283	1,561	41,844

Cávado, Ave and Leça region (29.5 cases per 10^3 km^2), which is within the rainiest zone of the country (Fig. 5b). The Tagus region and the Mondego, Vouga, Lis and West river region are in the following positions with 26.3 cases per 10^3 km^2 and 22.3 cases per 10^3 km^2, respectively. The lowest density of disastrous floods is registered in the southern half of the country, including the Guadiana region (3.6 cases per 10^3 km^2) and the Sado and Mira region (5.1 cases per 10^3 km^2). These are dry regions with mean annual precipitation (MAP), typically less than 600 mm (Fig. 5b).

The majority of death and missing people due to floods occurred in the Tagus region (67 % of total). This feature is strongly influenced by a single flash flood event occurred in the Lisbon region in November 25–26, 1967, that generated 522 death people (more than half of total death people due to floods in Portugal in the period 1865–2010). The Tagus hydrographic region registered 59 and 60 % of total homeless and total displaced people, respectively, which results predominantly from frequent flash floods in the Lisbon region (e.g., 1967 and 1983) and general floods in the lower Tagus valley (e.g., 1979 and 1997). The social consequences of floods are also relevant in the Douro region and the Mondego, Vouga, Lis and West river region. The former registered 35.6 % of total homeless people, and the latter registered 14.5 % of total displaced people.

The majority of disastrous landslides that occurred in Portugal in the period 1865–2010 are overwhelmingly constrained in the north of the Tagus valley where the highest hill slopes are to be found (Fig. 6a, b) and where the highest rainfall is registered (Fig. 6d). The majority of landslide cases (91.5 %) are located in areas where the MAP is higher than 600 mm, and 39.5 % of landslides concentrate in area with MAP higher than 1,000 mm.

A large number of landslide cases (39.1 % of total) affected stratified sedimentary and volcanic rocks (Fig. 6c), namely those integrated in the Western Meso-Cenozoic borderland (Fig. 6a). Granites and schists and greywackes belonging to the Hercynian Massif are also within the most landslide-prone lithologic units in the country (34.2 and 17.4 % of total landslide occurrences, respectively) (Fig. 6c).

In Portugal, the average density of disastrous landslides that occurred in the period 1865–2010 is 3.4 per 10^3 km^2. The density of landslide cases is highest in the Lisbon area (including the Lisbon city) and along the Douro valley.

Table 5 summarizes the density and impacts of disastrous landslides occurred within the four morphostructural units that constitute the country. The density of disastrous landslides is the maximum in the Western Meso-Cenozoic borderland (10.3 cases per 10^3 km^2). The remaining morphostructural units have similar landslide density (1.9–2.3 cases per 10^3 km^2).

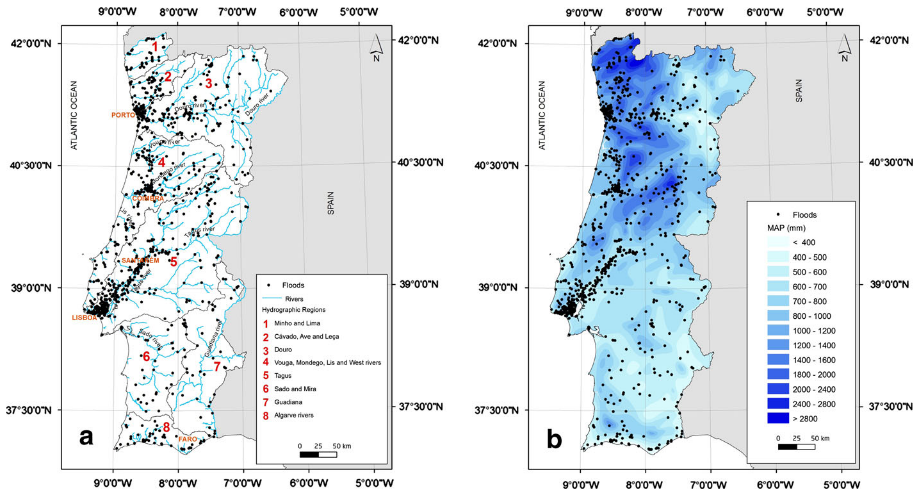


Fig. 5 Spatial distribution of disastrous floods in Portugal in the period 1865–2010 and relationship with hydrography (**a**) and mean annual precipitation (MAP) (**b**). Rainfall data from 1931 to 1960

Table 4 Density and impacts of disastrous floods occurred in the Portuguese hydrographic regions

Hydrographic region	Area (%)	DISASTER cases density (#/10^3 km^2)	Death and missing people (%)	Displaced people (%)	Homeless people (%)
1	2.7	18.7	2.6	1.0	0.0
2	3.8	29.5	3.8	3.6	0.7
3	21.2	18.8	9.5	11.1	35.6
4	15.6	22.3	8.3	14.5	2.7
5	28.2	26.3	67.5	60.0	59.0
6	11.2	5.1	2.8	1.9	0.6
7	13.0	3.6	3.7	0.5	0.4
8	4.3	16.2	1.8	7.4	1.1
Total	100.0	18.2	100.0	100.0	100.0

Hydrographic region codes: see Fig. 5

The majority of death and missing people due to landslides occurred in the Hercynian Massif (72.9 of total), affecting granite and schist, namely in the north part of the country, where disastrous landslides are typically rapid debris flows and rockfalls (Ferreira and Zêzere 1997).

The majority of displaced people due to landslides occurred within the Western Meso-Cenozoic border. In this morphostructural unit, disastrous landslides are typically deep-seated rotational and translational slides. Such landslides have the potential to destroy buildings, but as a rule, they are enough slow moving to allow people to evacuate prior the building collapse.

Homeless people due to landslide activity in Portugal are relevant in the Hercynian Massif (39.7 of total), in the Western Meso-Cenozoic borderland (37 % of total) and in the Tagus-Sado Tertiary sedimentary basin (23.3 % of total). In the latter morphostructural

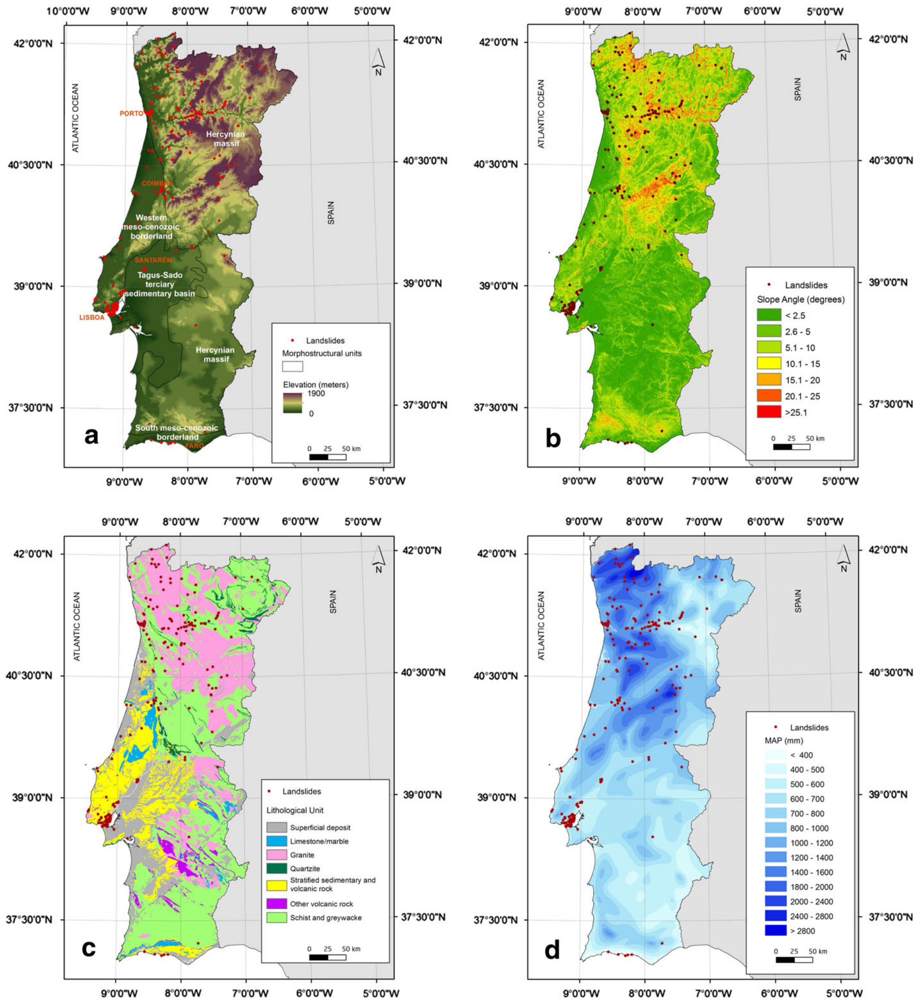


Fig. 6 Spatial distribution of disastrous landslides in Portugal in the period 1865–2010 and relationship with elevation and morphostructure (**a**), slope angle (**b**), lithology (**c**) and MAP (**d**). Rainfall data from 1931 to 1960

unit, disastrous landslides are concentrated in the Santarém region as well as in the south margin of the Tagus estuary.

4.2 Temporal trends of hydro-geomorphologic disasters

The annual distribution of floods and landslides that generated social consequences in Portugal in the period 1865–2010 is shown in Fig. 7. The blue and red lines represent the normalized cumulative disastrous floods and disastrous landslides. The increased slope of these curves is indicative of the increasing number of floods/landslides with time.

It is possible to identify three distinct time periods regarding the temporal trends of hydro-geomorphologic disasters in Portugal: 1865–1934; 1935–1969; and 1969–2010.

Table 5 Density and impacts of disastrous landslides occurred in the Portuguese morphostructural units

Morphostructural unit	Area (%)	DISASTER cases density (#/10^3 km^2)	Death and missing people (%)	Displaced people (%)	Homeless people (%)
Hercynian Massif	84.0	2.3	72.9	21.1	39.7
Western Meso-Cenozoic border	13.1	10.3	21.0	69.2	37.0
South Meso-Cenozoic border	2.9	2.2	2.3	0.0	0.0
Tagus-Sado Tertiary sedimentary basin	17.2	1.9	3.8	9.6	23.3
Total	100.0	3.4	100.0	100.0	100.0

The incidence of disastrous floods and landslides was typically low in the first time period that last 70 years (1865–1934). This time period represents 48 % of the total time series and includes just 20.5 and 17.1 % of disastrous flood and landslide cases registered in Portugal, respectively. The number of flood cases per year was above the annual average (11 cases) in only 7 years (i.e., 10 % of considered years). In the case of landslides, the annual number of occurrences was above the average (2 per year) in just 4 years (5.7 % of considered years). Nevertheless, this first time period includes the year that registered the maximum number of disastrous flood cases in the complete time series (1909: 73 cases). The year of 1909 was marked by an exceptional rainfall period during the second half of December, which generated a disastrous event that spread in the north and central Portugal and was responsible for 34 death people.

The second time period is 35 years long and extends from 1935 to 1969. This time period is the one characterized by the occurrence of the highest number of both disastrous floods and landslides. A total of 781 flood cases (48.2 % of total flood cases) and 133 landslide cases (47.3 % of total landslide cases) were registered during this time period that represents just 24 % of the total time series. For different reasons, 1966 and 1967 were marked by the occurrence of a large number of hydro-geomorphologic disasters (1966: 61 flood cases and 15 landslide cases; 1967: 69 flood cases and 1 landslide case). The hydrologic year 1965–1966 was very rainy in the north and central zones of Portugal where disastrous floods and landslides occurred during more than one month, from January 12 to February 24, 1966. The hydrologic year 1966–1967 was relatively dry, but was marked by a very intense shower in the Lisbon region in November 25-26, 1967, that generated a catastrophic flash flood (Zêzere et al. 2005), which was responsible for the complete flood cases registered in 1967 in the DISASTER database.

The last time period (1970–2010) corresponds to 28 % of the total time series. During this period, 508 flood cases (31.3 % of total flood cases) and 100 landslide cases (35.6 % of total landslide cases) were registered. This time period exhibits an irregular pattern without any clear temporal trend: Years with a large number of disastrous occurrences (e.g., 1979, 1983) are followed by years without any occurrence (e.g., 1980, 1984). The occurrence of high number of disastrous floods and/or disastrous landslides is associated with very wet years: 1978, 1979, 1983, 1989, 1996, 1997, 2000, 2001 and 2006.

Despite the absence of a clear trend, it is impressive that the yearly number of 40 flood cases was exceeded 6 times after 1978, while that feature was reached in just 5 years in the entire previous period (1865–1978). In addition, the number of registered landslide cases exceeds the annual average value in just 13 years within the third time period (31.7 % of

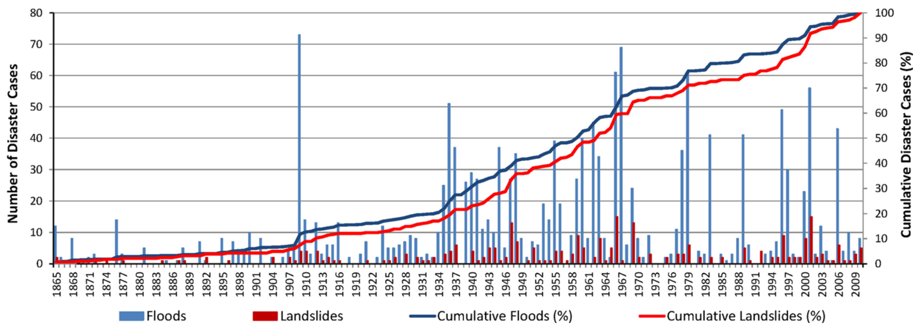


Fig. 7 Temporal distribution of disastrous floods and landslides occurred in Portugal in the period 1865–2010

total). This feature also confirms the irregular character of landslide disaster distribution, which concentrates in some critical years as was the case of 2000 and 2001.

4.3 Seasonal distribution

The seasonal cycle of disastrous floods and landslides occurred in Portugal relative to the entire 146-year period is shown in Fig. 8. Floods are more frequent in months from November to February (75.6 % of total flood cases), while landslides tend to concentrate from December to March (73 % of total landslide cases).

The concentration of landslide occurrences latter on the hydrologic year, when compared with flood occurrences, is consistent with the physical mechanisms involved in both processes, namely in what regards the rainfall-triggering conditions. Flash floods, as well as urban flooding, occur predominantly during the autumn and beginning of winter, usually in response to very intense and short-duration rainfall events (Zêzere et al. 2005; Zêzere and Trigo 2011; Liberato et al. 2013). The timing of landslide occurrence depends on the topography, geology and hydrologic processes in each slope. However, as a rule, landslides having deep failure surface are triggered by the rise of groundwater table, thus requiring the wide, and prolonged in time, water supply to the soil. Therefore, these landslides are typically associated with rainfall periods that may last from several weeks to several months (Zêzere et al. 2005; Zêzere and Trigo 2011) and tend to occur later in the hydrologic year. Such landslide events often occur simultaneously with floods that take place on the large fluvial valleys of the country (e.g., Tagus, Douro, Mondego).

4.4 Completeness of the database

As any other database based on newspaper exploitation, the DISASTER database has biases and is certainly incomplete. However, as Guzzetti (2000) pointed out, it is not straightforward to evaluate the completeness of a historical database on disasters, namely because conditions leading to disastrous floods and landslides (e.g., rainfall regime, land use and people exposition) may have changed over the time period covered by the database. Therefore, the lack of occurrences in a particular time span may result either from variation on conditions that generate floods and landslides (e.g., an anomalous dry period) or from the incompleteness of the database (Guzzetti 2000).

Figure 9 shows the cumulative curves of hydro-geomorphologic cases registered in the DISASTER database for the period 1865–2010. Concerning DISASTER cases, the database may

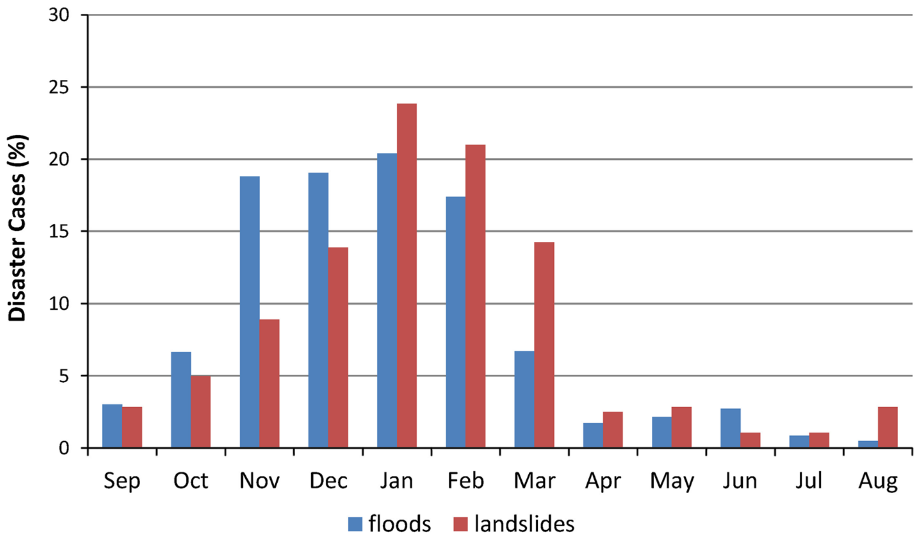


Fig. 8 Monthly distribution of disastrous floods and landslides occurred in Portugal in the period 1865–2010

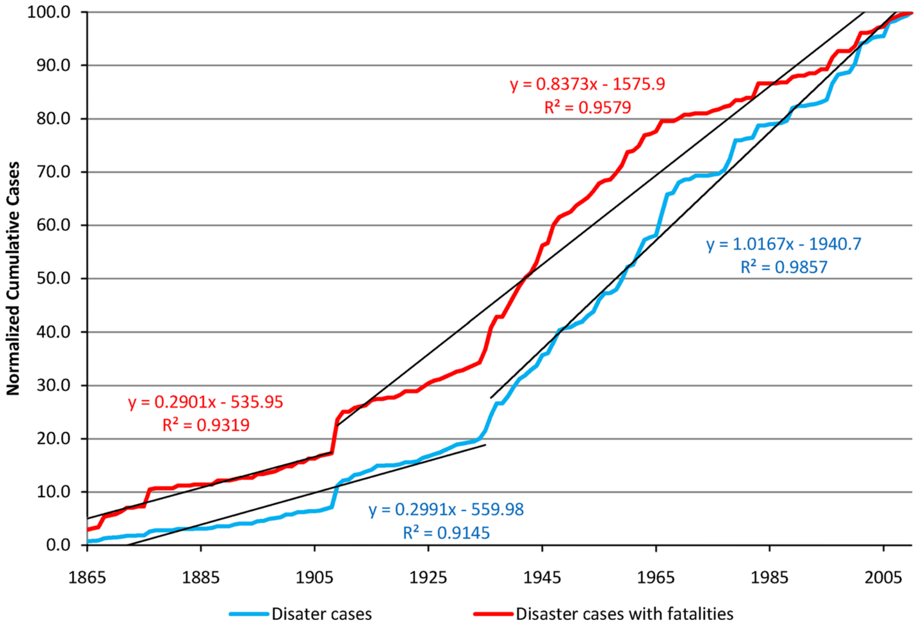


Fig. 9 Cumulative distribution of hydro-geomorphologic disasters occurred in Portugal in the period 1865–2010. The outlier cases of November 25–26, 1967, were not considered

be considered reasonably complete only after 1936, as it is attested by the very regular increase in cases with time since that date ($y = 1.0167x - 1{,}940.7$; $R^2 = 0.99$). In comparison, the first period of time (1865–1936) evidences a lower increase in cases with time

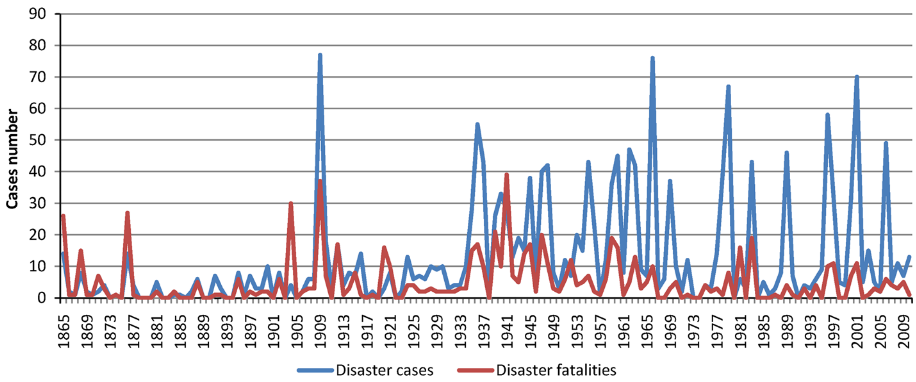


Fig. 10 Annual distribution of disaster cases and disaster fatalities in Portugal in the period 1865–2010. The outlier cases of November 25–26, 1967, were not considered

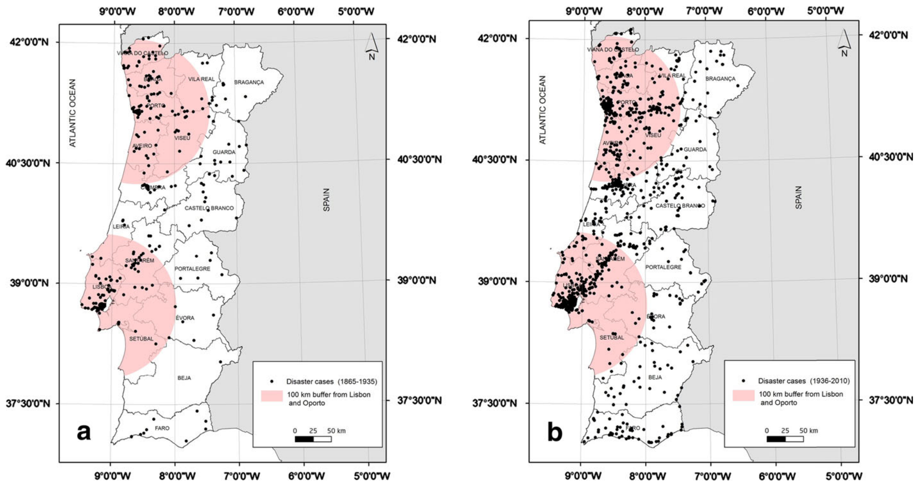
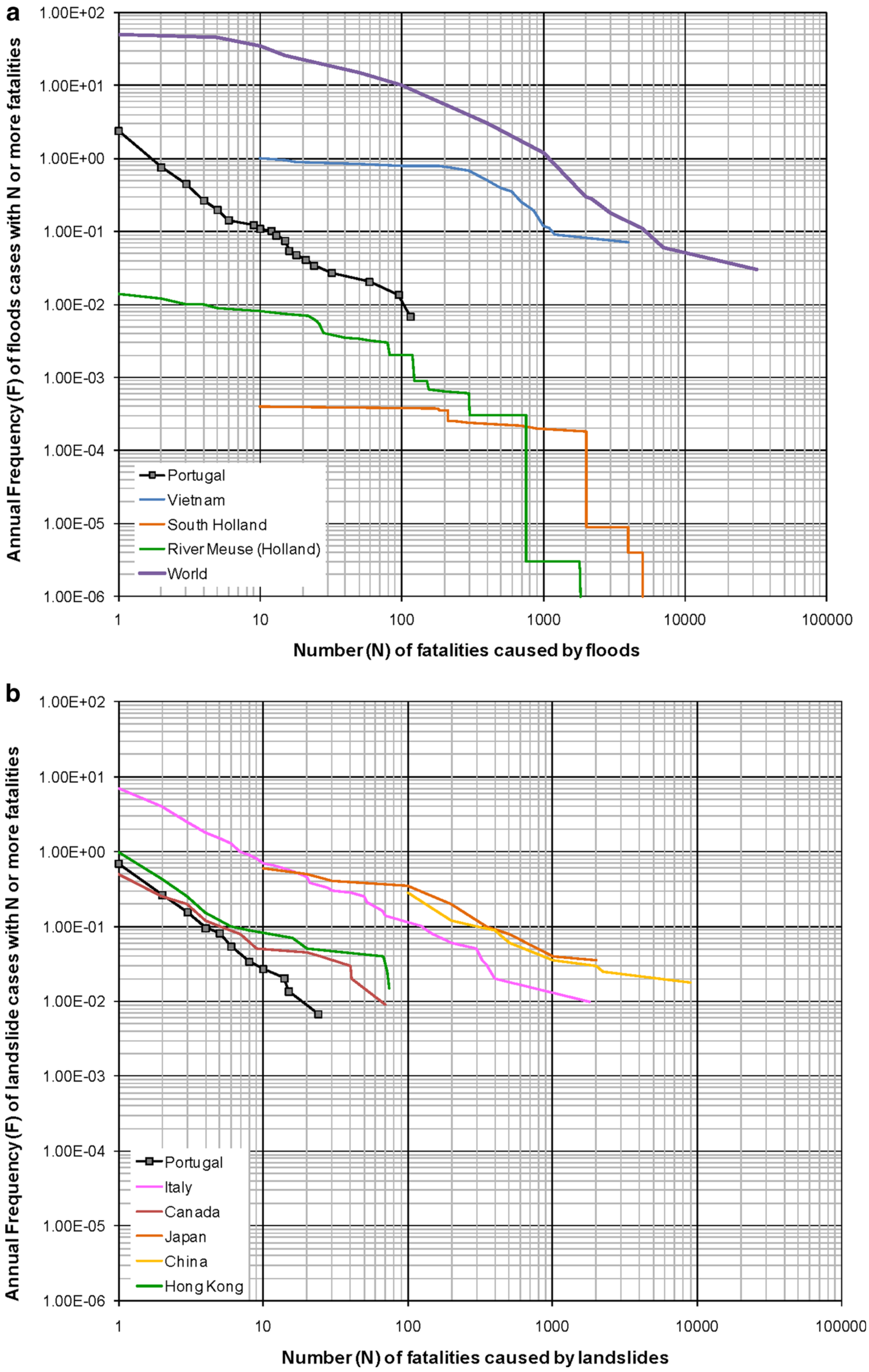


Fig. 11 Spatial distribution of hydro-geomorphologic disaster cases accounting distance from Lisbon and Oporto. **a**—period 1865–1935; **b**—period 1936–2010

($y = 0.2991x - 559.98$; $R2 = 0.91$), which indicates the relative incompleteness of the database. Using the same criteria in the analysis, we admit that DISASTER cases that produced fatalities may be reasonably complete after 1907, which is demonstrated by the regular increase in cases with time since then ($y = 0.8373x - 1{,}575.9$; $R^2 = 0.96$).

The annual distribution of disaster hydro-geomorphologic cases and disaster fatalities is shown in Fig. 10. From this figure, it is evident the incompleteness of disaster cases in the period 1865–1935 in comparison with reported fatalities. Taking into account the relationship established between DISASTER cases and DISASTER fatalities for the complete series and for the period 1936–2010, we estimated that hydro-geomorphologic cases unrecorded in the time period 1865–1935 may amount to 295 cases. This feature represents 42 % of the total DISASTER cases in the time period.


a
Annual Frequency (F) of floods cases with N or more fatalities
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1
10
100
1000
10000
100000
Number (N) of fatalities caused by floods
Portugal
Vietnam
South Holland
River Meuse (Holland)
World
b
Annual Frequency (F) of landslide cases with N or more fatalities
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1
10
100
1000
10000
100000
Number (N) of fatalities caused by landslides
Portugal
Italy
Canada
Japan
China
Hong Kong

◀ **Fig. 12** Frequency versus consequences (*F–N* plot) for floods (**a**) and landslides (**b**) that caused deaths in Portugal. Similar curves obtained for other countries are presented for comparison. **a** *Floods* World—Jonkman (2005); Vietnam—Mai et al. 2008; South Holland—Maaskant et al. (2009); River Meuse (Holland)—Van Alphen et al., 2011. **b** *Landslides* Italy—Guzzetti (2000); Canada—Evans (1997); Hong Kong—Wong et al. (1997); Japan—Morgan (1997); China—Tianchi (1989), cited in Guzzetti (2000)

The spatial distribution of hydro-geomorphologic disasters for periods 1865–1935 and 1936–2010 is shown in Fig. 11. This figure also shows 100 km distance buffers centered in Lisbon and Oporto. Percentage of cases located 100 km far from Lisbon or Oporto is higher in the period 1936–2010 (32.0 %) than in the period 1865–1935 (28.4 %), which is interpreted as a consequence of a better territorial coverage of newspapers in the latter time period. Therefore, we estimate that an important part (from 35 to 40 %) of unrecorded cases in the time period 1865–1935 should be located more than 100 km far from Lisbon and Oporto, where most newspapers were published.

4.5 The societal risk

The mortality index of both disastrous flood and landslide cases can be computed as the ratio of the number of deaths to the total number of cases for each dangerous phenomenon. The obtained mortality index for Portugal is higher for landslides (0.85) than for floods (0.62). Moreover, the value obtained for floods is strongly influenced by the extreme case (flash flood) occurred in the Lisbon region in November 1967. If we not take into account this event, the mortality index of disastrous floods drops to 0.32. Likewise, while 36.3 % of the landslide cases (102 cases) generated casualties, for flood cases the equivalent feature is just 21.7 %. In addition, this feature falls to 18.3 % when we remove the outstanding event occurred in November 1967.

Despite the apparent tendency for landslides to generate more deaths, the mortality index calculated only for disastrous cases (i.e., those that produced deaths) is higher for floods (2.9) than for landslides (2.3). However, again, the mortality index of floods falls to 1.7 if we not take into account the November 1967 event.

The societal risk is ascertained by calculating the annual frequency of flood and landslide cases that generated fatalities. Figure 12 shows the curves of frequency against consequences for floods (Fig. 12a) and landslides (Fig. 12b) that have caused deaths in Portugal. For comparison purposes, we show similar curves obtained for other countries and previously published (Guzzetti 2000; Jonkman 2005; Mai et al. 2008; Maaskant et al. 2009; Van Alphen et al. 2011).

The frequency of flood casualties in Portugal is lower than the one obtained for Vietnam, but higher than the one that characterizes Holland. The frequency of landslide casualties in Portugal is similar to those computed for Canada and Hong Kong, for cases below 10 fatalities. In addition, the Portuguese curve for landslides is considerably lower than equivalent data obtained for Italy, Japan and China.

Finally, the probability of cases with fatalities is consistently higher for floods than for landslides in Portugal, independently on the number of considered fatalities, which reflects essentially the large difference observed in the number of flood cases (11.1 cases per year in average) and of landslide cases (1.9 cases per year in average).

When compared with the most commonly used risk acceptable criteria (e.g., Fell et al. 2005), the societal risk in Portugal is unacceptable for floods and landslides.

5 Comparison between the DISASTER database and the EM-DAT

The EM-DAT has been maintained by the CRED, with the sponsorship of the United States Agency for International Development's Office of Foreign Disaster Assistance (Guha-Sapir and Below 2006). The database includes data on the occurrence and effects of over 18,000 natural and technological disasters occurred since 1900. The natural disaster category is divided into 5 subgroups covering 12 disaster types and more than 30 subtypes (EM-DAT 2013).

The EM-DAT database is compiled from various sources, including UN agencies, governmental and non-governmental organizations (e.g., the International Federation of Red Cross and Red Crescent Societies), insurance companies, research institutes and press agencies (Scheuren et al. 2008).

Entry criteria of EM-DAT were previously described in Sect. 2. For each reported disaster, three different levels are considered: (1) the event/disaster level; (2) the country level; and (3) the sources level. EM-DAT has historically entered disasters at the country level, but since 2003, disasters have been entered by event (EM-DAT 2013). This change in methodology generates biases in analysis, although according to EM-DAT (2013), regional, multicountry disasters represent only a small percentage of the total number of disasters that are compiled each year.

According to Scheuren et al. (2008), the entries are validated in order to avoid redundancy, inconsistencies and incompleteness. In the majority of cases, a disaster will only be entered into EM-DAT if at least two sources report the disaster occurrence in terms of people killed or affected (EM-DAT 2013). All data that have been validated by the EM-DAT team are made available to the public every three months. Revisions are made annually at the end of each calendar year.

Results of the DISASTER database cannot be directly compared with data for Portugal within EM-DAT for three reasons: (1) the DISASTER database lists disastrous cases, while the EM-DAT lists disastrous events (see Sect. 2 to detail differences); (2) the criteria to include any particular event in each database are not the same; and (3) the time period covered by the two databases is not coincident.

In order to allow a meaningful comparison between the two databases, the following procedures were applied to the DISASTER database: (1) the disastrous cases were grouped into disastrous events, considering as belonging to the same event those cases, spatially coherent, occurred in the same day or in consecutive days, i.e., disastrous cases associated with the same rainfall-triggering condition; (2) the previous defined DISASTER events were filtered using in alternative the two first entry criteria of the EM-DAT—(a) 10 or more people reported dead and (b) 100 or more people reported affected; and (3) events dating from 1865 to 1899 were ignored. Therefore, the time period in analysis becomes the same.

Table 6 summarizes 58 events extracted from the DISASTER database that fulfill the EM-DAT criteria, which are considerably more (446 % in excess) when compared with the solely 13 hydro-geomorphologic events included in the EM-DAT (see Table 1). Events identified in the DISASTER database were responsible for 865 death people and 53,014 affected people. These features are in excess, respectively, 153 and 161 % when compared with equivalent features within the EM-DAT.

The cross-checking between Tables 1 and 6 allows us to verify that, besides some minor differences regarding spatial location and precise number of death/affected people, nine events within the EM-DAT (69 % of total) are in accordance with the information gathered for the DISASTER database (EM-DAT Disaster codes: A, B, D, E; I, J, K, L, M; Tables 1 and 6).

Table 6 Events extracted from the DISASTER database that fulfill the EM-DAT criteria

DISASTER database events							
Disaster code	Start	End	District code	Type	No. of deaths	No. of affected people	EM-DAT code (see Table 1)
1	09/02/1904	10/02/1904	2, 3, 4, 6	F&L	30	50	
2	20/12/1909	28/12/1909	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	F&L	34	955	
3	08/12/1910	08/12/1910	3, 7, 13	F&L	2	213	
4	08/02/1912	08/02/1912	8, 12, 13	F&L	14	21	
5	07/01/1920	07/01/1920	14	Flood	15	15	
6	15/02/1936	25/02/1936	3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 17	F&L	10	292	
7	25/01/1937	28/01/1937	3, 6, 7, 9, 12, 13, 15,	F&L	6	211	
8	20/11/1937	20/11/1937	12, 13	F&L	1	315	
9	15/01/1939	19/01/1939	1, 2, 3, 4, 5, 6, 10	Flood	9	165	
10	02/01/1940	06/01/1940	1, 2, 3, 4, 5, 6, 10, 12, 13, 15, 16	F&L	7	1,088	
11	23/01/1941	27/01/1941	10, 12, 13, 14	Flood	3	422	
12	15/02/1941	15/02/1941	12, 15	Flood	33	138	
13	23/09/1943	23/09/1943	12	Flood	0	110	
14	18/11/1945	18/11/1945	12, 15	Flood	2	705	
15	18/12/1945	22/12/1945	3, 7, 9, 11, 12, 17	Flood	9	481	
16	17/02/1947	24/02/1947	1, 3, 6, 9, 11, 12, 13	F&L	6	257	
17	04/03/1947	08/03/1947	3, 4, 7, 12, 13, 16, 17	F&L	2	118	
18	27/01/1948	29/01/1948	2, 4, 5, 6, 7, 8, 9, 10, 14	F&L	9	401	
19	31/03/1952	31/03/1952	11, 12	F&L	11	67	
20	16/12/1953	18/12/1953	11, 18	Flood	3	164	
21	17/12/1955	19/12/1955	13, 16	Flood	0	2,007	
22	24/03/1956	24/03/1956	3, 4	Flood	0	102	
23	03/05/1959	03/05/1959	3	Landslide	8	85	

Table 6 continued

Disaster code	Start	End	District code	Type	No. of deaths	No. of affected people	EM-DAT code (see Table 1)
Disaster database events							
24	27/5/1959	27/5/1959	7	Landslide	6	10	
25	30/12/1961	03/01/1962	3, 4, 5, 7, 8, 9, 10, 12, 15	Flood	0	3,348	
26	04/02/1962	04/02/1962	8	Flood	0	200	
27	12/11/1963	16/11/1963	3, 4, 7, 8, 9	F&L	4	304	
28	14/01/1966	15/01/1966	12	F&L	0	332	
29	20/01/1966	24/01/1966	3, 4, 6, 9, 12	F&L	3	141	
30	02/12/1966	12/02/1966	2, 3, 4, 12	F&L	1	108	
31	18/02/1966	24/02/1966	1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 13, 15	F&L	4	2,087	
32	25/11/1967	26/11/1967	12, 15	Flood	522	2,042	A
33	12/03/1969	18/03/1969	3, 4, 7, 9, 12, 13, 15	F&L	3	822	
34	03/02/1972	03/02/1972	9, 12, 13	Flood	0	235	
35	26/02/1978	04/03/1978	2, 3, 4, 5, 9, 12, 13	F&L	0	4,996	
36	07/02/1979	16/02/1979	3, 4, 9, 11, 12, 13	F&L	8	18,473	B
37	27/12/1981	27/12/1981	2	Landslide	15	29	
38	18/11/1983	19/11/1983	12, 13	F&L	18	3,512	D
39	21/11/1983	21/11/1983	15	Flood	0	141	
40	25/11/1988	26/11/1988	18	Flood	0	417	
41	17/12/1989	22/12/1989	1, 2, 3, 4, 6, 10, 11, 13, 14, 15	F&L	1	2,116	
42	26/12/1989	26/12/1989	11, 13	Flood	0	187	
43	12/04/1990	12/04/1990	18	Flood	0	732	
44	29/12/1995	29/12/1995	12	Landslide	0	200	
45	06/01/1996	15/01/1996	3, 4, 6, 7, 12, 13	F&L	6	984	E
46	05/11/1997	06/11/1997	13, 17, 18,	Flood	11	296	G

Table 6 continued

Disaster database events							
Disaster code	Start	End	District code	Type	No. of deaths	No. of affected people	EM-DAT code (see Table 1)
47	05/03/2000	05/03/2000	12	Flood	0	139	
48	05/12/2000	08/12/2000	1, 2, 3, 4, 9, 10, 11, 13, 16	F&L	5	329	H
49	25/12/2000	27/12/2000	3, 9, 16, 17	F&L	1	150	
50	05/01/2001	07/01/2001	1, 3, 4, 6, 9, 13	F&L	1	122	
51	26/01/2001	27/01/2001	2, 3, 4, 6, 7, 8, 9, 10	F&L	6	983	I
52	06/02/2001	08/02/2001	3, 4, 5, 9, 10, 12, 15	F&L	0	114	
53	26/12/2002	27/12/2002	1, 3, 4	Flood	0	99	J
54	02/01/2003	03/01/2003	6, 7, 9	F&L	0	118	K
55	24/10/2006	26/10/2006	8, 9, 10, 11, 12, 13, 15	F&L	3	367	L
56	03/11/2006	06/11/2006	10, 13, 14, 15, 17, 18	F&L	0	199	
57	18/02/2008	18/02/2008	12, 15	Flood	3	90	M
58	22/12/2009	23/12/2009	3	Flood	0	195	

F&L flood and landslide

Two other events (Disaster codes G and H in Table 1) were misclassified by the EM-DAT regarding the disaster type, as both were originally classified as storm disasters. The event G (Disaster code 46 in Table 6) was characterized by the occurrence of a set of flash floods and floods triggered by a storm progressing from SW to NE that affected the southern part of the country (Faro, Beja and Santarém districts) on the November 5-6, 1997, and intensifying on the other side of the border (Lorente et al. 2008). The number of registered deaths in the DISASTER database is lower than that referred by the EM-DAT (11 against 29), and we admit that the latter may include people dead by floods in the Badajoz province, nearby the Portuguese border, but in Spanish territory where the official counting by the Spanish authorities reported 21 casualties (Lorente et al. 2008). Date and consequences of event H in the EM-DAT (Table 1) are coincident to a landslide case included in the DISASTER database. In December 6-7, 2000, a debris flow occurred in Frades (Viana do Castelo district), generating 4 death people and 12 displaced people. In addition, this landslide case is part of a flood and landslide event (Disaster code 48 in Table 6) occurred in the period December 5-8, 2000, that spread in the north and central Portugal and generated 5 death people and 329 affected people.

The main errors within the EM-DAT database are to be found in Disaster codes C and F in Table 1. According to EM-DAT, a flood caused 30 death people and 900 affected people in the Lisbon region on December 29, 1981 (Disaster code C). Despite the high rainfall registered in Lisbon in the second half of December 1981 (238 mm from December 17–31), there is no notice of any flood generating any death/injured/displaced/homeless people in Portugal during this period. On the other hand, the DISASTER database notices a debris flow occurrence in Cavez (Braga district) on December 27, 1981, that was responsible for 15 deaths and 14 injured people (Disaster code 37 in Table 6). We acknowledge that this disastrous case might be included in the EM-DAT event assigned to the December 29, 1981 (Disaster code C in Table 1). Nevertheless, this single case is not enough to justify the total number of dead and affected people reported by the EM-DAT. That number may also include people affected by severe wind storms that impacted the north and central Portugal during the period December 26–31, 1981. The Disaster code F (Table 1) is, following the EM-DAT, a general flood occurred in the north of Portugal on the December 22–24, 1996, affecting 2,000 people. The DISASTER database does not notice any hydro-geomorphologic case in December 1996 or in January 1997, in any district of the country. In addition, the total monthly amount of rain registered during December 1996 in Lisbon and Oporto (283 and 228 mm, respectively) is not enough to generate a disastrous flood.

The temporal evolution of hydro-geomorphologic disastrous events in Portugal assembled by decade according to the EM-DAT and the DISASTER databases is shown in Fig. 13. As it was previously mentioned in Sect. 2, the EM-DAT database does not report any hydro-geomorphologic disaster in Portugal prior to 1967 and the increase in events with time is apparent. In contrast, the distribution of events belonging to the DISASTER database is far more irregular in time. Twenty-four events included in this database (41.4 % of total events) occurred prior 1960, and the highest values occurred in 1961–1970 and 2001–2010. The distribution of DISASTER database events may be fitted by a logarithmic trend [$y = 2.5555\ln(x) + 1.2067$ ($R^2 = 0.41$)], which is far from any exponential growth tendency.

The MAP computed per decade for Lisbon is also shown in Fig. 13. We acknowledge that the rainfall registered in Lisbon is not illustrative of the triggering conditions of many hydro-geomorphologic events occurred in different zones of the country, but it provides a feasible overview of rainfall variation in time and the relationship with the registered

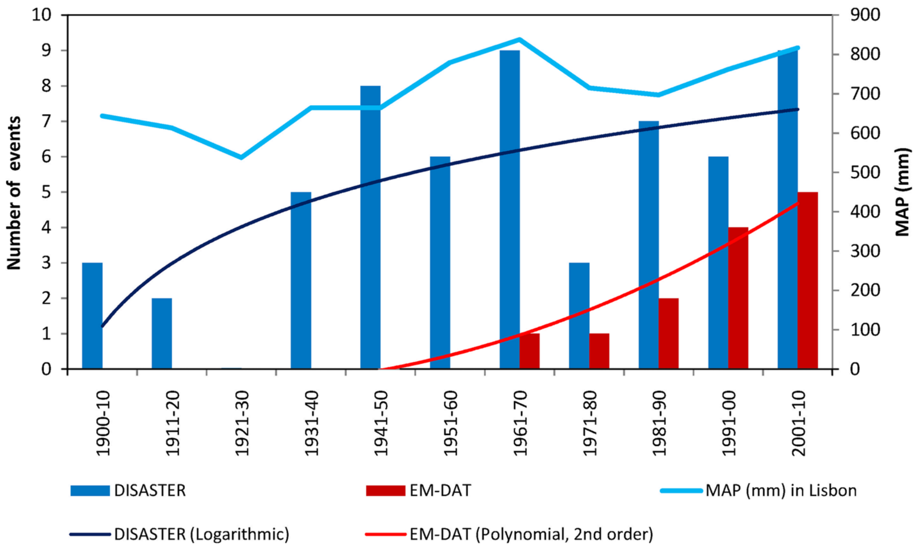


Fig. 13 Temporal evolution of hydro-geomorphologic disastrous events in Portugal according to the EM-DAT and the DISASTER databases. The DISASTER events fulfill the EM-DAT entry criteria

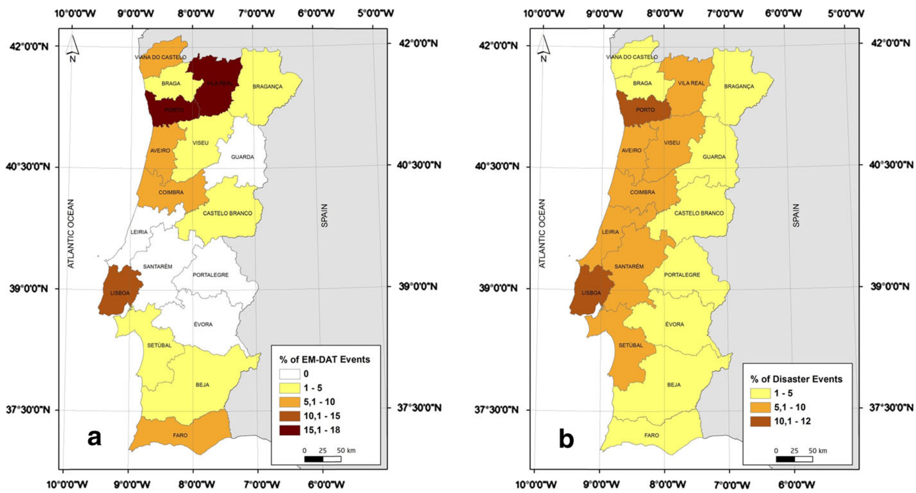


Fig. 14 Distribution of hydro-geomorphologic disastrous events (percentage) in Portugal at the district level according to the EM-DAT (**a**) and the DISASTER (**b**) databases (period 1900–2010). The DISASTER events fulfill the EM-DAT entry criteria

events. In fact, it is noticeable the tendency of DISASTER database events to increase with increasing decennial MAP, which is not the case with the EM-DAT database events.

The spatial distribution of hydro-geomorphologic events reported for Portugal in the EM-DAT (Fig. 14a) is very contrasting when compared with the equivalent map generated with the DISASTER databases (Fig. 14b).

According to the EM-DAT, Oporto, Vila Real and Lisbon are the Portuguese districts with the highest percentage of disastrous floods and landslides. However, reliability of spatial distribution of hydro-geomorphologic events in Fig. 14a is low as there is no logical justification to the absence of events in five districts located in the central–south of Portugal: Guarda, Leiria, Santarém, Portalegre and Évora.

According to the DISASTER database, Lisbon and Oporto are placed on the top rank position concerning percentage of events, followed by Setúbal, Santarém, Leiria, Coimbra, Aveiro, Viseu and Vila Real. These districts are bordering either Lisbon or Oporto and/or are located in the coastal zone. With the exception of the NW districts (Viana do Castelo and Braga) and the Faro district (Algarve), the distribution of hydro-geomorphologic events belonging to the DISASTER database follows the population density within the country (Fig. 15), which is highest in the urban areas along the west coastal zone northward Setúbal and in the south coast of the Algarve.

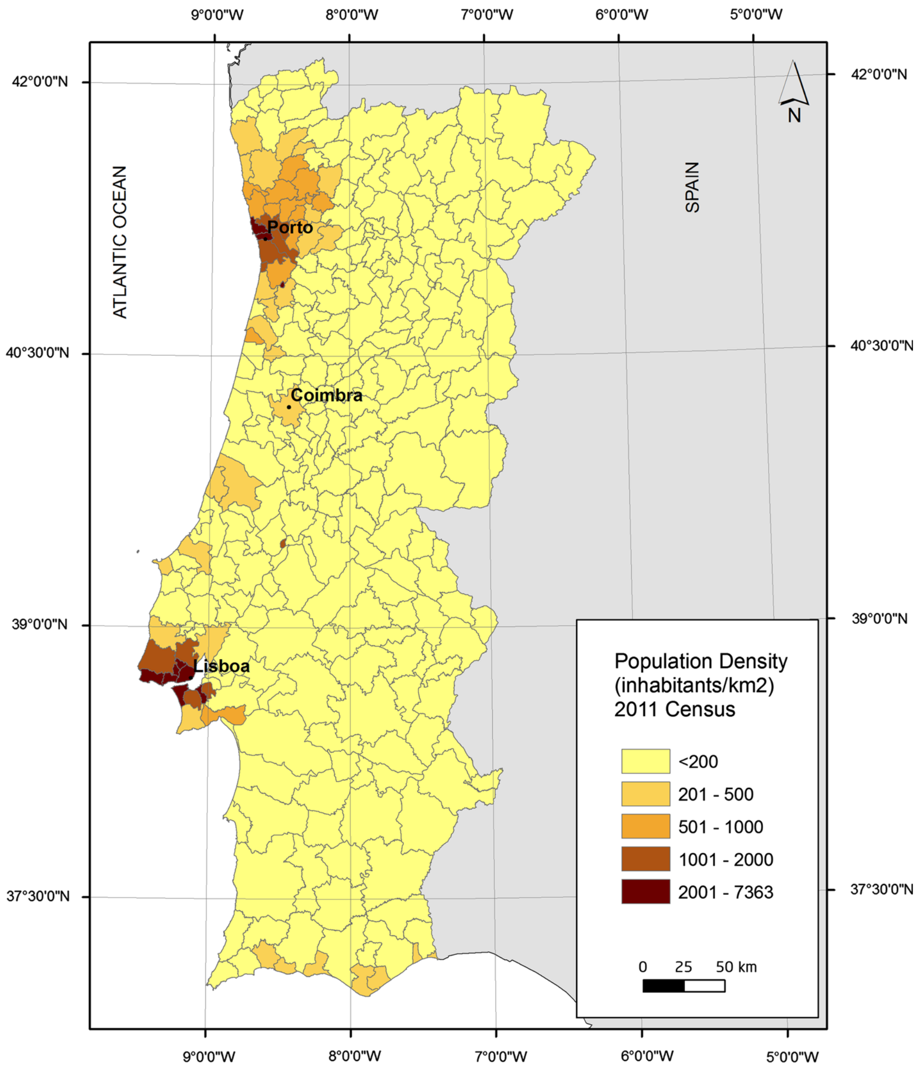


Fig. 15 Population density in Portugal in 2011. *Source of data* Census 2011

6 Concluding remarks

For the first time in Portugal, the DISASTER project created a GIS database on disastrous floods and landslides. The database includes DISASTER cases occurred in the period 1865–2010, which are unique hydro-geomorphologic occurrences related to a particular location and a specific period of time. Any hydro-geomorphologic case was stored in the database if the occurrence led to casualties or injuries, and missing, evacuated or homeless people, independently of the number of people affected. We assumed that such social consequences are relevant enough to be reported by the press, namely daily newspapers, which are the main source for data collection in the DISASTER project.

Data on disastrous floods and landslides were collected from the analysis of 145,344 newspaper pieces belonging to 16 national, regional and local newspapers. However, the temporal coverage of these newspapers is not the same, and the 146-year period under analysis is not uniformly covered regarding the number of existing newspapers. Three time periods were identified regarding the number of existing newspapers: 1865–1907; 1907–1936; and 1936–2010. Two newspapers were available for the first time period, while four newspapers were systematically surveyed for the second time period. The third time period is the best covered by newspapers (from 9 to 12). It is remarkable that the annual number of registered hydro-geomorphologic cases increased significantly since 1935. Besides other reasons (e.g., occurrence of very wet years), this increase might be associated with the higher reliability of sources for the third time period. However, 80 % of total hydro-geomorphologic cases were gathered from only two newspapers (*Diário de Notícias and Jornal de Notícias*) which cover the three time periods.

The DISASTER cases were stored in a multiuser online database which is linked with a geographic information system. In addition, a Web-GIS was implemented that allows making geographic queries, visualizing spatial relationships and downloading data reports with synthesized results.

In total, 1,622 disastrous floods (11.1 per year, on average) and 281 disastrous landslides (1.9 per year) were recorded and registered in the DISASTER database. These occurrences were responsible for 1,251 dead people (8.6 per year), 14,191 displaced people and 41,844 homeless people. Flash floods and floods were responsible for 81 % of total deaths, 94.2 % of total displaced people and 96.3 % of total homeless people. However, the mortality index, obtained as the ratio of number of deaths to number of cases, is higher for landslides (0.85) than for floods (0.62). The tendency for landslides to be more deadly than floods is confirmed by the fraction of landslide cases that produced fatal victims (36.3 % of total landslide cases in the database), which is higher than the correspondent feature for floods (21.7 % of total flood cases in the database).

The density of disastrous floods and disastrous landslides registered in the 146-year studied period is 18.2 and 3.4 per 10^3 km^2, respectively. The maximum density of flood cases is observed in the Lisbon, Oporto and Coimbra regions as well as along the Tagus, Douro, Mondego and Vouga river valleys. The maximum density of landslides occurs in the Lisbon area and along the Douro valley. Although the most affected areas exhibit natural predisposing conditions which favor flood and landslide occurrence, the spatial pattern of hydro-geomorphologic disasters strongly reflects the people exposition which is controlled by the population distribution in Portugal. Indeed, clusters with high density of hydro-geomorphologic cases are located in urban areas within the west coastal zone from Viana do Castelo to Setúbal where the highest density of population is registered.

Three time periods were established regarding the temporal trends of disastrous floods and landslides occurred in Portugal from 1865 to 2010. The first period (1865–1934) was marked by the low number of occurrences: 4.8 floods and 0.7 landslides per year on average, which are fairly below the average for the 146-year period. The second period (1935–1969) is the one with the highest number of hydro-geomorphologic disasters: 22.3 floods and 3.8 landslides per year on average. Floods were more frequent during the period 1936–1967, and landslides were more frequent in the period 1947–1969. Finally, the third period (1969–2010) was marked by the occurrence of 12.4 floods and 2.4 landslides per year, on average, and do not show any evident temporal trend.

We admit the existence of biases in the DISASTER database which is certainly incomplete for the period 1865–1935. Sources for this period are limited in number. In addition, importance given to human life and living conditions in that time was less compared to nowadays, namely in the less populated rural areas. Therefore, it is probable that many cases occurred in remote zones in the country have not been reported by newspapers published in Lisbon and Oporto.

The hydro-geomorphologic cases belonging to the DISASTER database were grouped in disastrous events (i.e., set of disastrous cases associated with the same rainfall-triggering conditions, occurred in the same day or in consecutive days) and constrained to the period 1900–2010 to be compared with the EM-DAT. Accordingly, the DISASTER events were filtered using the quantified entry criteria of the EM-DAT: (1) 10 or more people reported dead and (2) 100 or more people reported affected.

The DISASTER database includes 58 hydro-geomorphologic events that fulfill the EM-DAT criteria which contrast with the 13 events listed by EM-DAT. The incompleteness of EM-DAT regarding disastrous floods and landslides occurred in Portugal is notorious during the complete twentieth century and first decade of twenty-first century but is critical for the period 1900–1966: The EM-DAT does not report any event for this time period, while the DISASTER database lists 31 events that should be included in the EM-DAT according to the registered social consequences.

The incompleteness of EM-DAT regarding disasters of hydro-geomorphologic origin in Portugal generates an apparent increase in events with time, which is attested by a second-order polynomial trend that fits the distribution of events grouped by decade. The equivalent distribution of disaster database events is fitted by a logarithmic trend, which reflects a more irregular distribution of events in time.

Differences between DISASTER and EM-DAT databases are also perceptible in the relationship between events and the MAP computed per decade for Lisbon. In fact, it is perceptible the tendency of DISASTER database events to increase with increasing rainfall, which is not the case with the EM-DAT database events.

Besides the demonstration of non-existence of any exponential growth tendency of the hydro-geomorphologic events, the DISASTER database also shows a different picture regarding the spatial distribution of disastrous floods and landslides in Portugal. The hydro-geomorphologic events are mostly concentrated in districts located in the west coastal zone from Setúbal to Oporto. Natural conditions are favorable to floods and landslides in these districts, but the high density of events is also related to the high density of population which tends to enhance people exposition to risk.

The spatial distribution of hydro-geomorphologic events belonging to EM-DAT is less reliable. The districts of Oporto and Vila Real are apparently overrepresented, and some important districts are not represented as it is the case of Santarém, Leiria and Guarda.

The DISASTER project shows the need to create national databases on natural disasters, since the criteria of supranational databases, as the EM-DAT, do not fit detailed scalar context and distinctive organizational reporting. In the particular case of Portugal, the incompleteness of the EM-DAT may originate inadequate conclusions regarding temporal trend and spatial distribution of disastrous floods and landslides.

The national databases on disasters are also important to risk management, namely to prevent, reduce and mitigate disaster risk consequences. These databases should be considered by stakeholders both within the civil protection and the spatial planning, in order to identify critical spots for emergency management and to select safety places for future territorial development. For these purposes, it is decisive to maintain the data collection on disasters after 2010 and this is guaranteed by the RISKam Research Group of the Centre of Geographical Studies, University of Lisbon.

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