Landslide Societal Risk in Portugal in the Period 1865–2015

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Abstract

In Portugal, social impacts caused by landslides occurred in the period 1865–2015 are gathered in the DISASTER database. This database includes social consequences (fatalities, injuries, missing people, evacuated people and homeless people) caused by landslides documented in newspapers. The DISASTER database contains 291 damaging landslides that caused 238 fatalities. In this work we aim to: (i) analyse the spatio-temporal analysis of damaging landslides occurred in the last 150 years; (ii) analyse the frequency and the temporal evolution of fatal landslides; (iii) analyse the spatio-temporal distribution of landslide fatalities; (iv) identify the most deadly landside types; (v) verify gender tendencies in landslide mortality; and (vi) evaluate the individual and societal risk. Individual risk is evaluated computing mortality rates for landslides, which are calculated based on the annual average population and the annual average of fatalities. The societal risk is evaluated by plotting the annual frequency of landslide cases that generated fatalities. The results demonstrate the absence of any exponential growth in time of both landslide cases and landslide mortality in Portugal. The highest number of landslide cases and related mortalities occurred in the period of 1935–1969 in relation to very wet years. Most of landslide fatalities mainly occurred in the north of the Tagus valley where the geologic and geomorphologic conditions are more prone to landslides. The Lisbon area registered a mortality hotspot, which is explained by natural conditions combined with the high exposure of population to landslide risk. Falls and flows were responsible for the highest number of fatalities associated with landslides. Males were found to have the highest frequency of fatalities. In conclusion, the spatial patterns of landslide mortality can be related to the unequal distribution of predisposing conditions to landslides, changes in the land use and exposure and social vulnerability to landslide hazards.

Keywords

Landslides • Disaster database • Societal risk

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Introduction

Landslides activity usually causes direct human impacts (fatalities, injuries), but the quantitative assessment of landslide societal risk has been developed in a limited number of studies performed at global (Petley 2012), European (Haque et al. 2016) and national scales (Guzzetti 2000; Salvati et al. 2010; Pereira et al. 2016).

The existence of reliable databases on disasters is crucial to study mortality due to landslides in terms of temporal trends, spatial distribution and epidemiological topics (Pereira et al. 2016). Features on fatalities caused by different types of hazards can be found for instance in natural hazard databases (e.g. EM-DAT, DISASTER) based on documental sources, demographic statistics, death certificates and civil protection authorities.

There are some constraints in the inclusion criteria of mortality data in disaster databases. For instance, the EM-DAT only record disasters that have caused at least 10 fatalities, while the DISASTER database includes every landslide that caused fatalities regardless of their number. EM-DAT underestimates the numbers of fatalities and the fatalities are usually associated to the triggering event, such as earthquake, storm and floods (Haque et al. 2016).

Another constraint to study the mortality caused by landslides is the relatively short time span of the existing databases and the lack of field validation (Petley 2012).

In Portugal, social impacts caused by landslides and floods occurred in the period 1865–2015 are gathered in the DISASTER database. This database includes social consequences (fatalities, injuries, missing people, evacuated people and homeless people) caused by landslides documented in newspapers (Zêzere et al. 2014).

The DISASTER database contains 291 damaging landslides that caused 238 fatalities. In the present work we explore the mortality patterns resulting from damaging landslides occurred in Portugal since 1865.

In this work we aim to: (i) analyse the spatio-temporal analysis of damaging landslides; (ii) analyse the frequency and the temporal evolution of fatal landslides; (iii) analyse the spatio-temporal distribution of fatalities generated by landslides; (iv) identify the most deadly landside types; (v) verify gender tendencies in mortality resulting from landslides; and (vi) evaluate the individual and societal risk.

Data and Methods

Landslide mortality data for the period 1865–2015 was gathered in the DISASTER database (Zêzere et al. 2014). A set of national and regional newspapers were used to collect data from which landslide DISASTER cases and DISASTER events were identified. A DISASTER case is a unique landslide occurrence, which fulfils the DISASTER database criteria (i.e., any landslide that, independently of the number of affected people, caused casualties, injuries, or missing, evacuated, or homeless people), and is related to a unique geographic location and a specific period of time (i.e., the specific place and time where the harmful

consequences of the landslide occurred) (Zêzere et al. 2014). A DISASTER event is a set of DISASTER cases sharing the same trigger, which may have a widespread spatial extension and a certain magnitude (Zêzere et al. 2014).

A content analysis of the newspapers reports of DISASTER cases was made in order to organize the information in a standardized format. Each DISASTER case includes details on the disaster characteristics and damages (Zêzere et al. 2014). The first includes data on landslide subtype, date of occurrence, location, and triggering factor. The second includes structural damages (damage to buildings and damages to rail and road networks) and social consequences (human damage, gender of fatalities, and circumstances surrounding the fatalities). The total number of fatalities resulting from landslide disasters is certainly underestimated because deaths that did not occur immediately after the landslide would not have been reported, and then it is not possible to asses these mortalities using newspapers as the single data source.

Details on the circumstances related to fatalities associated with landslides were also obtained from newspaper reports. These circumstances were divided in three classes: inside a building, outdoors and inside a vehicle (motor or train). For cases where fatalities occurred due to debris accumulation of a landslide, or building collapse or a failed attempt to escape from inside a building, the circumstance of the fatality was classified as "inside a building". Individual risk was evaluated using mortality rates for landslides, which were calculated based on years with population census in Portugal (usually every 10 years) as proposed by Pereira et al. (2016). The annual mortality rates were computed for each decade using the annual average of fatalities, which were then divided by the annual average population. The result was multiplied per 100,000 to scale it according to the size of population per unit time (Pereira et al. 2016). Societal risk was evaluated by plotting F-N curves representing the annual frequency of landslide cases that generated fatalities.

Results

Frequency and Temporal Trends of Mortality

Figure 1 shows the number of fatalities in each landslide case against its rank in the Portuguese regions (1865–2015), from the highest to the lowest, represented using a log–log scale. South Region includes Alentejo and Algarve NUTs II.

The maximum rank achieved by the landslide fatalities distribution in Portugal and in the North region was 103 and 54, respectively. The relationships are almost linear on the
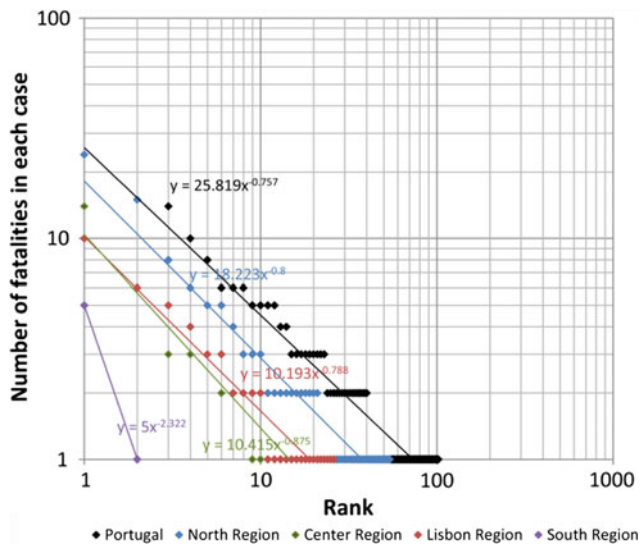
Fig. 1 Intensity of the landslide fatalities cases versus their rank in the Portuguese regions (1865–2015)

plot, indicating a power law distribution. Fatalities are higher for landslides occurred in the North region for all ranks.

Individual landslide cases that occurred in the North region generated more deaths when compared to other regions.

The evolution of the annual distribution of landslide DISASTER cases and the annual number of fatalities for the period 1865–2015 are illustrated in Fig. 2. For the 151 years three distinct time periods were identified by Zêzere et al. (2014): (i) 1865–1934; (ii) 1935–1969; and (iii) 1970–2015. Table 1 summarizes the statistics of landslide cases that generated fatalities in Portugal.

The first period (1865–1934) was characterized by a below-average number of cases (0.7 landslides per year) (Table 1). However, average mortality per year

(1.1 fatalities/year) is similar to average values for the complete time series (1.6 fatalities/year). This time period accounts for 33.6% of the total number of fatalities associated with landslides (Table 1). During this period, the number of fatalities was not regularly distributed, with two peaks of annual fatalities occurred in 1904 (24 fatalities) and 1912 (14 fatalities) for single landslide cases (Fig. 1).

The second period (1935–1969) was shorter in duration but registered the highest mean annual number of landslide cases (3.8 landslides per year) (Table 1). The mean annual mortality associated was highest during this period (2.6 per year) and also the percentage of fatalities (38.7%) (Table 1).

The third period (1970–2015) accounts on average 2.4 landslides per year. Fatalities associated with landslides correspond to 27.7% and the annual average is 1.4 fatalities (Table 1). The year 1981 stands out with the second highest annual landslide mortality (15 fatalities) for the complete period (Fig. 2).

There are clear differences among the Portuguese regions concerning the number and density of landslide disaster cases and landslide fatalities (1865–2015) as it can be seen in Table 2.

The first period registered the lowest percentage of landslide disaster cases in all the regions, but the highest percentage of landslide fatalities was registered in the Center region. North region on the contrary registered approximately 1/3 of landslide fatalities in each period, despite the number of landslide disaster cases reached 44% in the period of 1935–1969 and 39.7% in the most recent period. The highest percentage of landslide disaster cases and fatalities registered in the Lisbon region occurred in the period 1935–1969, 58.8 and 63.8%, respectively. South region only registered landslide fatalities in the last period (1970–2015).

These results suggest that population exposure to damaging landslides have changed over time.
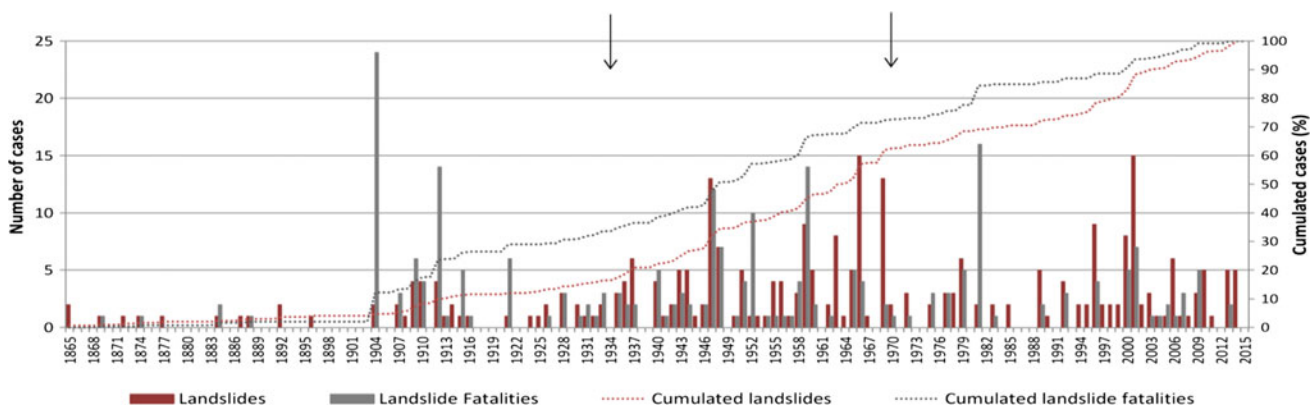

Fig. 2 Annual distribution of landslide disaster cases (*red*) and fatalities (*grey*) occurred in Portugal during the period of 1865–2015. Note *arrows* delimit the time periods referred in the text and in Tables 1 and 2

Table 1 Landslide disaster cases and fatalities per time period

	1865–1934	1935–1069	1970–2015	1865–2015
Number of cases	47	133	111	291
% of total cases	16.2	45.7	38.1	100.0
Landslide cases/year	0.7	3.8	2.4	1.9
Number of fatalities	80	92	66	238
% of total fatalities	33.6	38.7	27.7	100.0
Fatalities/year	1.1	2.6	1.4	1.6

Table 2 Number and density of landslide disaster cases and fatalities per regions and time period (1865–2015)

	Area (km^2)	1865–1934				1935–1969				1970–2015			
		% DC	DCD #10^3 km^2	% F	FD #10^3 km^2	% DC	DCD #10^3 km^2	% F	FD #10^3 km^2	% DC	DCD #10^3 km^2	% F	FD #10^3 km^2
North	21,286	16.4	0.9	33.8	2.1	44.0	2.4	33.1	2.0	39.7	2.2	33.1	2.0
Center	28,199	16.4	0.4	55.3	0.9	36.1	0.8	29.8	0.5	47.5	1.0	14.9	0.2
Lisbon	3002	16.5	5.3	18.2	3.3	58.8	19.0	63.6	11.7	24.7	8.0	18.2	3.3
South	36,602	0.0	0.0	0.0	0.0	20.0	0.1	0.0	0.0	80.0	0.3	100.0	0.2
Portugal	89,089	15.6	0.5	33.6	0.9	46.0	1.5	38.7	1.0	38.4	1.2	27.7	0.7

Note DC disaster cases; *DCD* disaster cases density; *F* fatalities; *FD* fatalities density
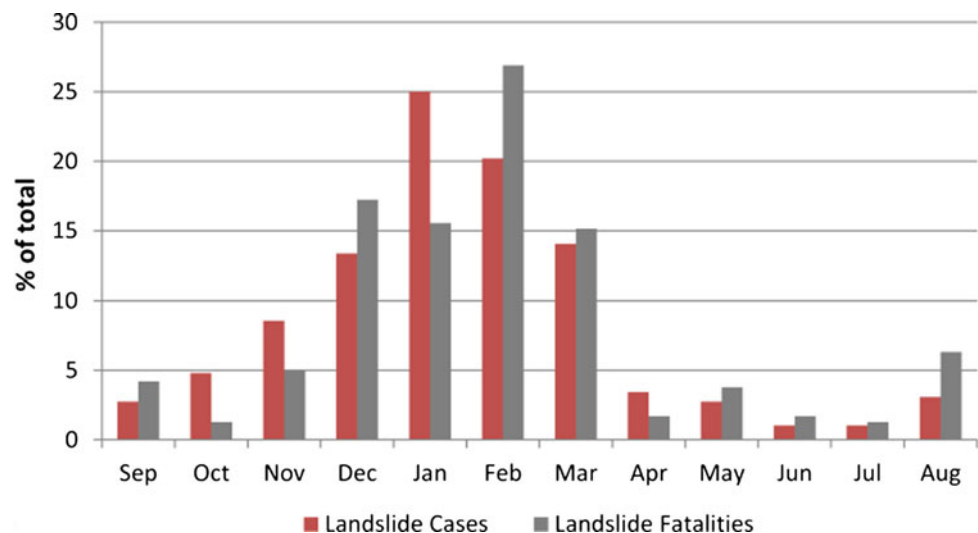
Figure 3 shows the monthly distribution of disastrous landslides cases and related fatalities occurred in Portugal during the 1865–2015 period. Landslide disaster cases and landslide fatalities distribution along the climatological year evidences a clear concentration during the autumn and the winter seasons from December to March (74.8% of landslide disaster cases and 72.6% of landslide fatalities).

Landslide occurrence depends also on the local topography, geology, and hydrologic processes acting on the slope (Zêzere et al. 2015). The monthly regional distribution of landslides that caused fatalities presents a small variation. In the North region landslide fatalities were found to be more frequent in December and February (57.7% of landslide

fatalities) and were typically associated with debris flows. In the Center region, landslide fatalities were dominant in February (36.2% of landslide fatalities) and in the Lisbon region in the later winter months (36.4% of landslide fatalities occur in March). In the South region all landslide fatalities occurred in August.

Spatial Distribution

The location of disastrous landslides and the number of fatalities generated by landslides during the period of 1865–2015 is shown in Fig. 4a, b. Landslide fatalities are almost

Fig. 3 Monthly distribution of landslide disaster cases and landslide fatalities (1865–2015)
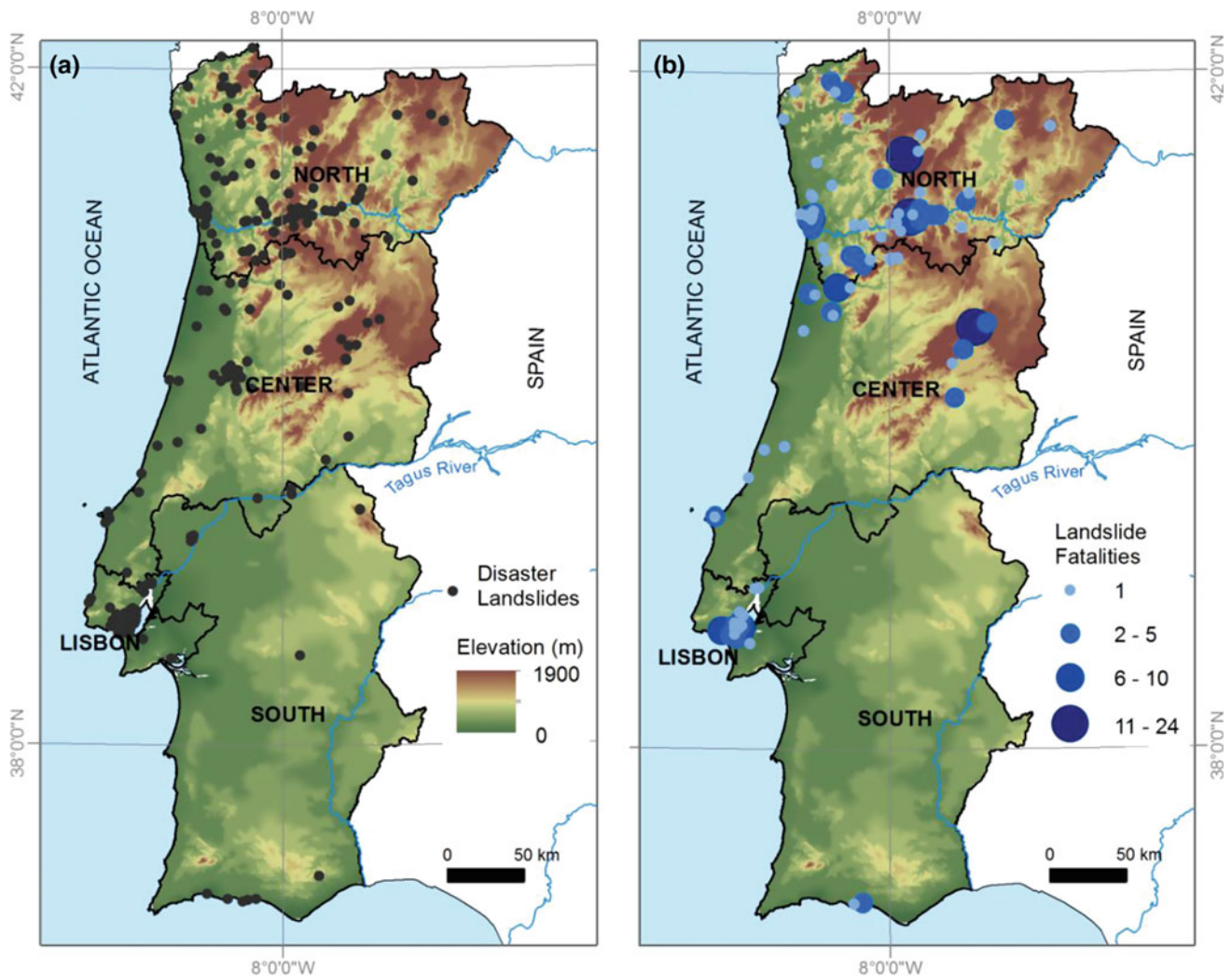
Fig. 4 Number of disaster landslides (**a**) and number of landslide fatalities (**b**) in the period 1865–2015

completely constrained northwards of the Tagus valley where geologic and geomorphologic conditions are more landslide prone than in the southern part of the country (Zêzere et al. 2014; Pereira et al. 2016). The main mortality hotspot observed in the Lisbon region is explained both by natural conditions and also by the high population numbers that increase exposure to landslide risk.

Landslide fatalities in the south region have been constrained to coastal cliffs, and have grown in number in recent years, reflecting the increasing exposure associated with careless intensive use of the coastal areas for tourism and leisure.

In Portugal, 60% of the landslide Disaster cases were related to falls, which were also associated with the highest percentage of fatalities (54%). These were followed by flows (36%). Figure 5 represents the frequency of landslide disaster cases (a) and landslide mortality (b) by landslide type for each Portuguese region.

The North region contains 41.2% of disaster landslides and more than a half of the landslide fatalities (58.4%) where the dominant fatal landslide types are falls and flows (Fig. 5). This is a mountainous region with metamorphic and granitic rocks where fatal flows and falls frequently occur (Pereira et al. 2014).

The Lisbon region is similar to the North region with respect to the number of landslide cases (33.3% of the country's total). However, the landslide mortality is lower (23.2%), reflecting the dominance of slow-moving landslides affecting clay rich sedimentary rocks and soils. The Center region registers 21% of total landslide cases, mostly of fall type, and 19.7% of landslide fatalities were generated by falls and flows that occurred in the Central Massif. The South region registered the lowest number of both landslide disaster cases and landslide fatalities which is explained by the region's low landforms.
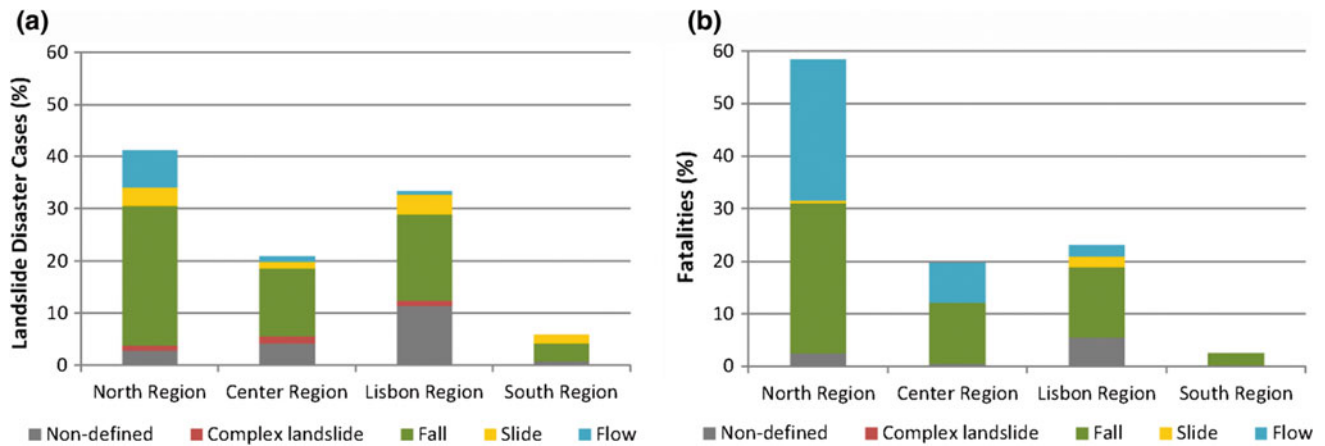
Fig. 5 Frequency of landslide disaster cases (**a**) and landslide mortality (**b**) by landslide type for each Portuguese region in the period of 1865–2015

Gender Tendencies in Mortality

The percentage of landslide fatalities per regions and gender is summarized in Table 3. Newspapers did not provide information on gender for 19.3% of landslide fatalities in Portugal. For cases where the gender of the victim is known, it is clear that disaster landslides generated more male victims. Indeed, the number of documented male fatalities is more than double of the equivalent for female fatalities (67.7% for males and 32.2% of female fatalities in the country). The dominance of male fatalities is also observed in all regions, except in the South region (Table 3).

Figure 6 represents the percentage of total fatalities per region and gender and periods in order to verify if there are different gender trends among regions and periods.

Excluding the South region where female fatalities were dominant in the most recent analyzed period (1970–2015), in the other regions male fatalities are predominantly dominants in spatial and temporal terms. The period of 1865–1934 concentrates the highest percentage of landslide fatalities with gender not reported due to the limited number of newspapers available and reports about the gender of the victims.

Male fatalities were more frequent in the period of 1935–1969 in the North, Center and Lisbon regions. In the last period (1970–2015) the prevalence of male fatalities is still very important in the North region. The other regions registered a decrease in the percentage of landslide fatalities but male fatalities are still dominant.

Also frequency of landslide fatalities per gender and period does not evidence any particular trend for each Portuguese region, not allowing for any conclusions to be made regarding territorial inequalities and differentiation on gender mortality in Portugal.

Landslide fatalities were also aggregated according to the circumstances surrounding the fatality and periods (Fig. 7).

In Portugal 49.2% of total landslide fatalities occurred inside buildings, from which 32.8% occurred in the North region. Landslide fatalities that occurred outdoors correspond to 31.9% of total fatalities.

In the period of 1865–1934 fatalities that occurred inside buildings were the most frequent in the North and Center regions (14.3 and 8.8%, of total fatalities, respectively). In the period 1935–1969 mortality occurred outdoors was more frequent in the North and Lisbon regions while in the Center region mortality inside vehicles was more frequent.
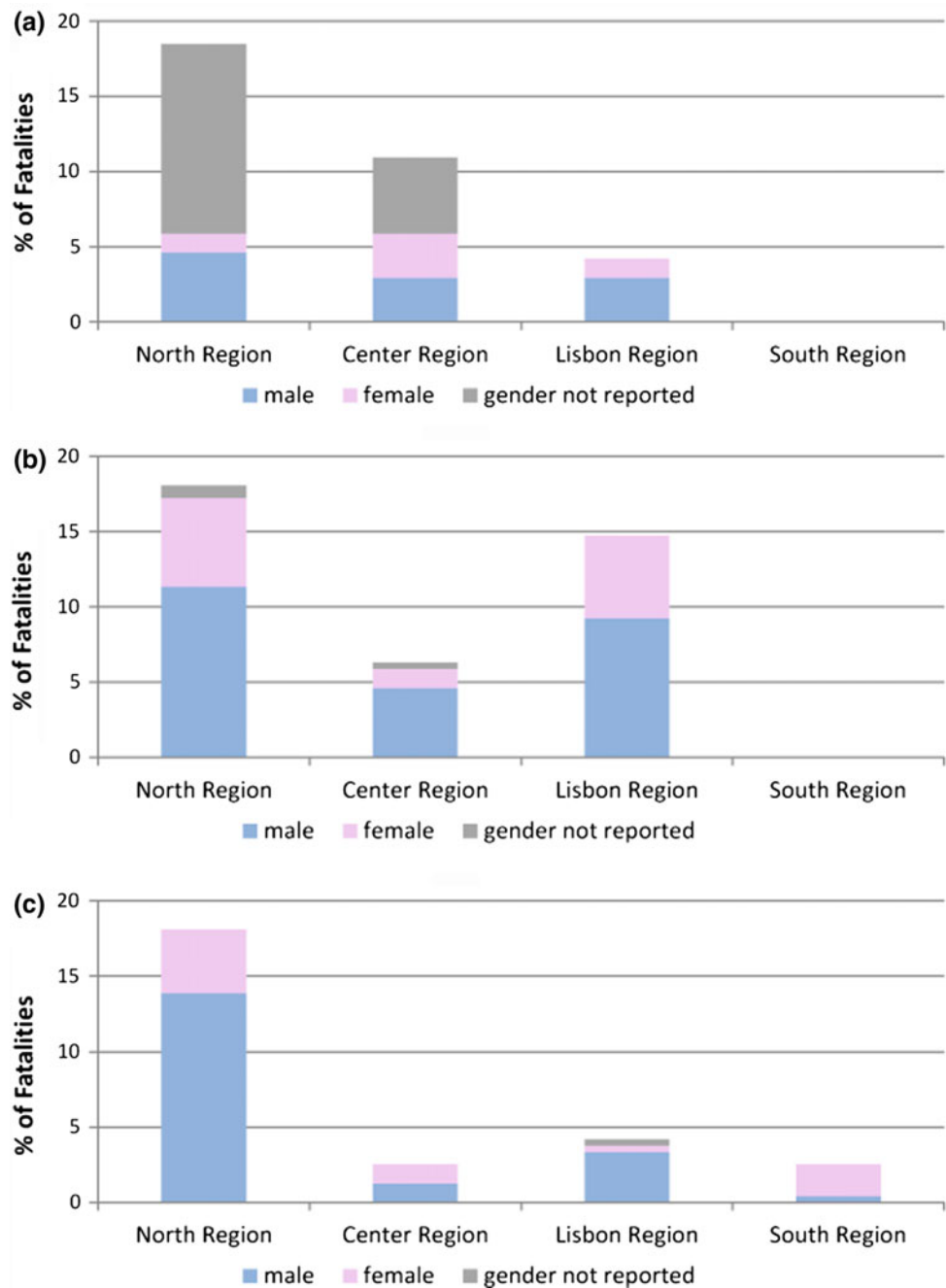
In the last period (1970–2015) North region still stands out with the highest frequency of total fatalities inside buildings and inside vehicles (10.9 and 5.9%, respectively). In the North region fatalities occurring inside vehicles have been increasing in time while fatalities occurring outdoors registered a slightly decrease and inside buildings remain stable.

Table 3 Percentage of landslide fatalities per regions and gender

	% M	% F	% NR
North region	54.6	20.8	24.6
Center region	44.7	27.7	27.7
Lisbon region	67.3	30.9	1.8
South region	16.7	83.3	0.0
Portugal	54.6	26.1	19.3

Note M male; *F* female; *NR* gender not reported

Fig. 6 Percentage of total fatalities per region and gender and periods **a** 1865–1934; **b** 1935–1969; **c** 1970–2015

Individual and Societal Risk

The mean annual average mortality rate for landslides per regions was computed for time periods defined by the dates of population census (Fig. 8a). Landslide mortality rates reached three maximums, one in the decade of 1901–1911 that includes a debris flow that occurred at Peso da Régua and caused 24 fatalities in 1904 (Pereira et al. 2016). Moreover, the mortality rate peak ($0.150/10^5$ inhabitants) is also a consequence of the low number of exposed population at that time (17.3×10^5 inhabitants in the North region).

The second peak of mortality occurred in the decade of 1921–1930 in the Lisbon region ($0.079/10^5$ inhabitants). Other landslide mortality peak ($0.078/10^5$ inhabitants) was registered in 1981 again in the North region, as a consequence of a debris flow that caused 15 fatalities at Cabeceiras de Basto (Pereira et al. 2016).

Landslide mortality rates in the North region registered an important decrease since the 1982–1991 decade while in the
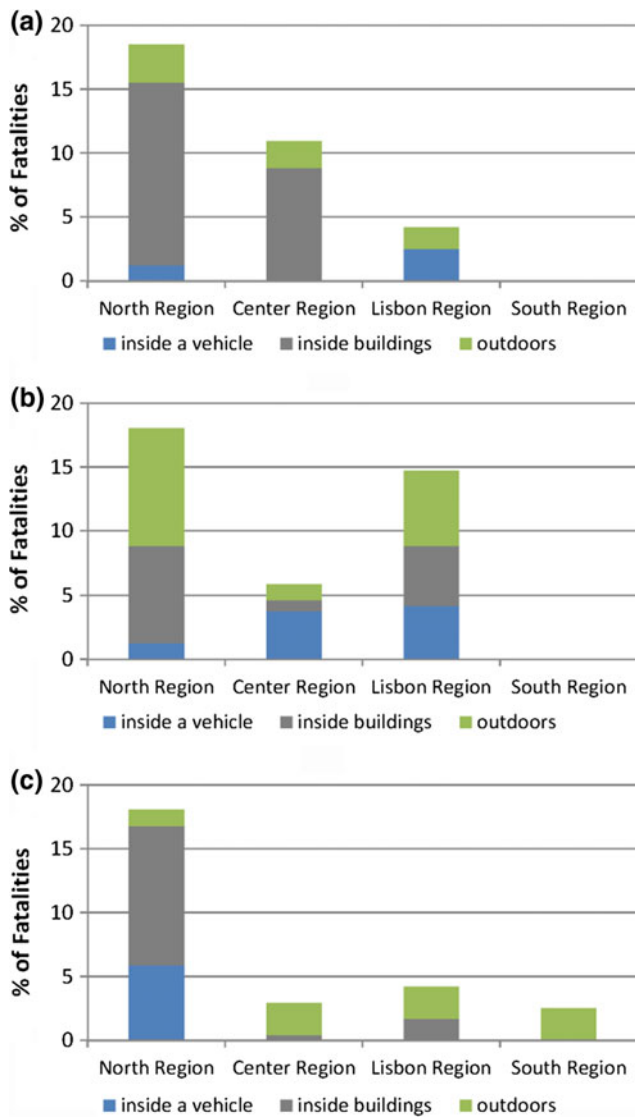
Fig. 7 Percentage of total fatalities per region according to the circumstances related to the fatality and periods **a** 1865–1934; **b** 1935–1969; **c** 1970–2015

Lisbon region this decrease started two decades earlier (1961–1971).

According to Pereira et al. (2016) the landslide mortality rate shows a slight upward trend in the Portuguese regions, except in the Center region where a slight decrease is observed.

Figure 8b shows the curves of frequency against consequences for landslides that caused deaths in Portugal (1865–2015). F-N curves for landslides that caused deaths in Portugal were described by Zêzere et al. (2014) and compared with similar curves obtained for other countries.

In Portugal the annual frequency of fatal landslides is highest in the North region (Fig. 8b) and lowest in the south region where the maximum annual number of fatalities is

below 10. Taking into account these results and according to the most commonly used risk acceptable criteria (Fell et al. 2005) the societal risk in Portugal is considered unacceptable for landslides.

Conclusions

Landslide societal risk in Portugal was based on an updated version of the Disaster database until the year 2015 and updates the work developed by Pereira et al. (2016) about landslide fatalities. The Disaster database was built under the assumption that social consequences (specially fatalities) of landslides are relevant enough to be reported by newspapers, which were used as a data source (Pereira et al. 2016). Also information about the mortality, i.e., time, place, loss description (how many, who, how, and what) and the description of the surrounding environments in which the fatality occurred was provided by the newspaper reports.

This work shows a more detailed vision of the temporal and spatial distribution of landslide fatalities when compared with the results of other studies (e.g. Haque et al. 2016) that did not used detailed data on damaging landslides for such a long time as the Disaster database.

The temporal trends of disaster landslides and corresponding fatalities demonstrate the absence of any exponential growth with time (151 years) in Portugal.

The temporal trend of landslide mortality rate in Portugal did not show a decrease. Despite the increasing quality of the building environment observed in the last decades due to the adoption and use of building construction techniques and codes most of fatalities occurred inside buildings. These buildings improvements are not enough to resist very rapid landslides such as falls and flows. Even today these incidents are frequent because buildings are often located on hazardous slopes. In the last 151 years, falls and flows were responsible for the majority of fatalities associated with landslides in Portugal.

Spatial distribution of landslide mortality can be related to factors other than climate, such as the unequal distribution of predisposing conditions to landslide occurrence (geomorphologic and hydrologic), changes on land use and population exposure to landslide hazard and the evolution of social vulnerability (Pereira et al. 2016).

Gender distribution of landslide fatalities showed that landslide victims are mostly male, which are more than double the number of female victims. It is apparent that males are more exposed to disastrous landslides in Portugal, which can be explained by cultural reasons, related to the social role of the breadwinner that exposes men to hazardous occupations and men often assume risk behaviors outdoors and act with a false sense of security when are driving vehicles.
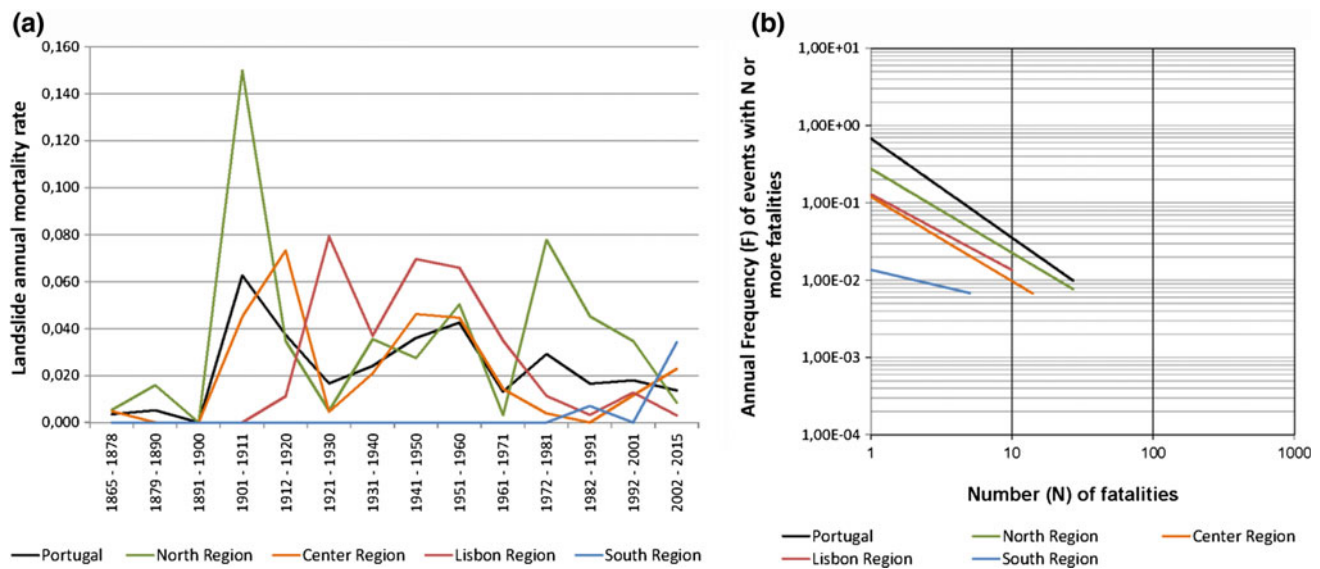
Fig. 8 Mean annual mortality rates per time period adjusted to population census (**a**) and frequency versus consequences (**b**) for landslide cases that caused fatalities in Portugal per region

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