ANALYSING SPATIAL DISTRIBUTION OF DAMAGING FLOODS AND MASS MOVEMENTS IN PORTUGAL FROM 1865 TO 2010 (DISASTER DATABASE): GEOGRAPHICAL FACTORS, WEATHER TYPES AND HUMAN IMPACTS

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I. INTRODUCTION

The floods and landslides events are the most common natural disasters in Portugal. Floods have been the most deadly natural disasters in Portugal during the last century, followed by earthquakes (Ramos and Reis, 2002). This reality justified the need for developing natural disaster databases, which are essential for risk management and for the implementation of effective disaster mitigation measures.

Nevertheless, until 2012, the basic information on past floods and slope mass movements which occurred in Portugal was scattered and incomplete. This situation was a limitation for establish a general framework of the floods and landslides distribution patterns in mainland Portugal.

The DISASTER database was build in the context research project "DISASTER - GIS database on hydro-geomorphologic disasters in Portugal: a tool for environmental management and emergency planning", supported by the Science and Technology Foundation (FCT), and includes all the damaging floods and mass movements events detected in mainland Portugal since 1865 (earliest dates for available newspaper records). During three years of research (2010-2012), 16 newspapers were inquired and 145344 copies of newspapers analyzed.

This database includes as hydro-geomorphological disasters any flood or landslide that, independently of the number of people, caused either casualties, injuries, or missing, evacuated or homeless people (Pereira et al, 2012). In this context, a Disaster Case is a unique hydro-geomorphological occurrence which fulfills the DISASTER 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 on 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 (Pereira et al, 2012).

So, according those criteria, the DISASTER database highlights the relationships between the occurrence of dangerous floods and landslides and the existence of vulnerable elements (e.g., people, assets, activities) that can be quantified through human and material losses. Leveraging the potentialities of this database, a characterization of flood and landslide spatial distribution in mainland Portugal is made, identifying the main flood patterns responsible for damaging occurrences and the relation with weather types, and establishing the correspondence with the characteristics of the municipalities where they occur.

II. PRESENTATION OF RESEARCH

In the 146 years (1865 to 2010) covered by DISASTER database, 1903 occurrences were detected (85% are floods), which caused 1310 human deaths, 14191 evacuated and 41844 displaced (Table I), mostly as a consequence of flash floods generated from extreme rainfall events.

	Floods	Mass movements	Total
Occurrences	1622	281	1903
Casualties	1071	239	1310
Evacuated	13372	819	14191
Homeless	40283	1561	41844

TABLE I: Number of occurrences and main impacts associated with floods and mass movements, from 1865 to 2010, in mainland Portugal (according DISASTER database).

Although it is not possible detect any clear trend over time along the period covered by the database, the spatial distribution of both phenomena reflects the influence of natural factors and the very irregular geographical distribution of the urban settlements and human activities, but concentrated essentially in the main cities – Oporto in the north coast, Coimbra in the centre coastland, and Lisbon in the south coast –, and in the main valleys, where the most part of the human activities are located, especially along Douro valley (in North, from Oporto to east) and along Tagus valley (in South, from Lisbon to northeast) (Fig. 1).

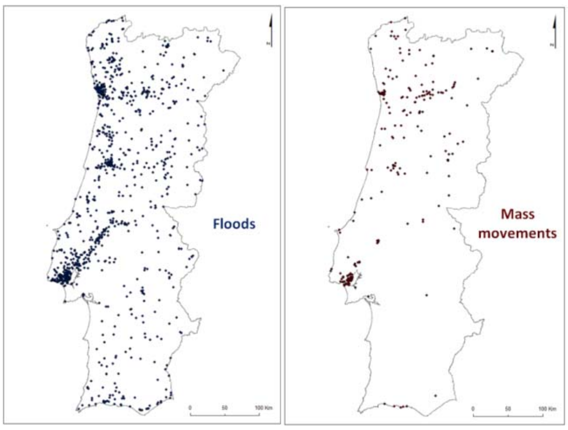

FIG. 1: Spatial distribution of floods (on the left) and mass movements (on the right) occurrences (1865 to 2010) in mainland Portugal, according to DISASTER database criteria.

The temporal distribution of the occurrences closely follows the natural rhythm of precipitation, characteristic of the Mediterranean climate (Fig. 2), with a concentration of rain from October to March. Nevertheless, the mass movements have a delay in relation to floods, since the mass centre of this phenomenon matches January and February. The reason for this delay is that the mass movements need very high water accumulation in the ground, condition that only is possibly after a few months of precipitation. Even in March, the percentage of mass movements is relatively large and doubles the percentage of floods. By the contrary, the number of floods increases drastically from October to November, and stays as a very important phenomenon until February.

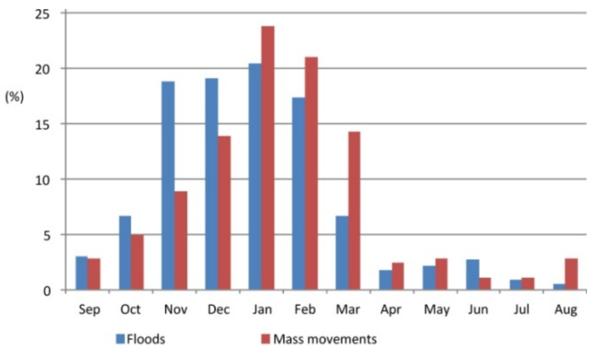

FIG. 2: Monthly frequency of floods and mass movements (1865 to 2010) in mainland Portugal (according DISASTER database).

The developments in this work followed several approaches:

- Calculation of total amount and density of flood and slope mass movements by municipality, and identification of the main patterns of the spatial distribution;
- Identification of the main impacts resulting from flood occurrences with particular emphasis for the ones related with very heavy rainfall in a severe storm context;
- Comparison between flood and mass movements by municipality and quantifying the level of association between these two phenomena;
- Identification of the most important flood patterns in mainland Portugal, with especial attention to their specific human impacts;
- Identification of the atmospheric circulation types responsible for the most damage events, and characterization of these situations.

The characterization of the natural conditions affecting each municipality, and integration with the flood and mass movement occurrences, is still going on and will not be developed in detail along this work.

Furthermore, in future research will be important to distinguish between different types of mass movements, since they are affected by distinct factors. Indeed, in the mountainous centre and north of mainland Portugal, with lithologies essentially associated to metamorphic and igneous rocks, the debris flows are very relevant, but they are almost absent from the rest of the territory. The landslides are most frequent along the centre west, associated to sedimentary rocks, and the rock falls occurs in a dispersed way, where the strong slopes come together with compact rocks.

III. RESULTS AND CONCLUSIONS

The geographical distribution of floods and mass movement according the DISASTER database criteria, as seen in Fig. 1, is highly dependent of the presence of the human settlements and activities. Therefore, these occurrences are more coincident with the municipalities where the population density is higher, so it reflects closely the distribution of the urban areas and the presence of human activities. The utilization of density of occurrences, instead of the total amount, allows eliminating the dimension of the municipality as a factor (Fig. 3).

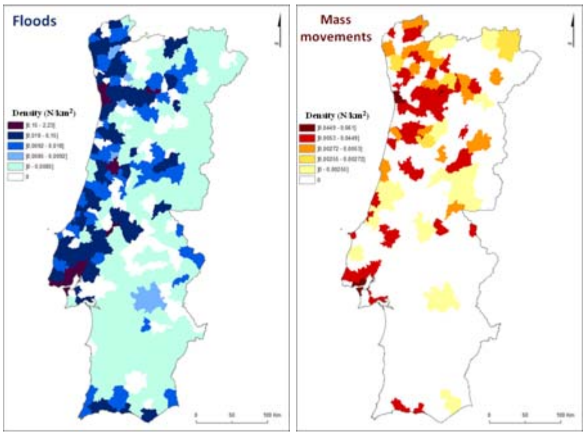

FIG. 3: Density distribution by municipality (in occurrences by km^2) of floods (on the left) and mass movements (on the right) occurrences (1865 to 2010) in mainland Portugal (according the DISASTER database criteria).

As said before, the spatial distribution of floods and mass movements reflects the influence of natural factors but are very depend of the geographical distribution of the urban settlements and human activities. These human variables helps to explain why such a different phenomena, that are conditioning by different factors, have a relatively similar distribution (r^2=0.73), when the density of floods and mass movements by municipality are compared (Fig. 4). Similar values of Pearson correlation coefficient (0.844 to 0.864) were obtained when partial samples were considered, for instance: municipalities with occurrences > 0 for both phenomena; municipalities with occurrences > 0 for at least one phenomenon; the 20 municipalities with more occurrences of floods.

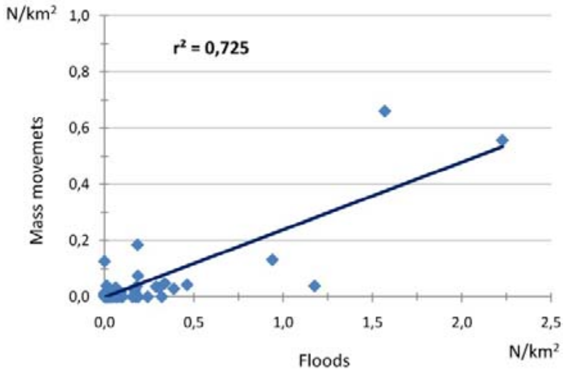

FIG. 4: Relation (coefficient of determination) of occurrence density (Number(N)/km^2) by municipality, between floods and mass movements (according DISASTER database).

The distribution of casualties associated to floods and mass movements show very different patterns (Fig. 5); the deadly floods are concentrated essentially along two areas: urban Lisbon area and Tagus river valley; Oporto urban area and Douro river valley. In the remainder territory, the occurrences are relatively dispersed, much more concentrated in the northern half and less frequent in the southern half of the country. When only the occurrences with three or more casualties are considered, it becomes evident the great concentration in Lisbon area, extending northeasterly along the right margin of the Tagus valley.

With regard to the damaging mass movements Fig. 5), much less frequent, have a more concentrated distribution, that reflects the important influence of local factors, in special the slope and lithology: Lisbon city and very near surrounding areas; Oporto city; slopes along Portuguese middle sector of Douro valley; coastal sectors, mainly in cliffs of Algarve (south coast).

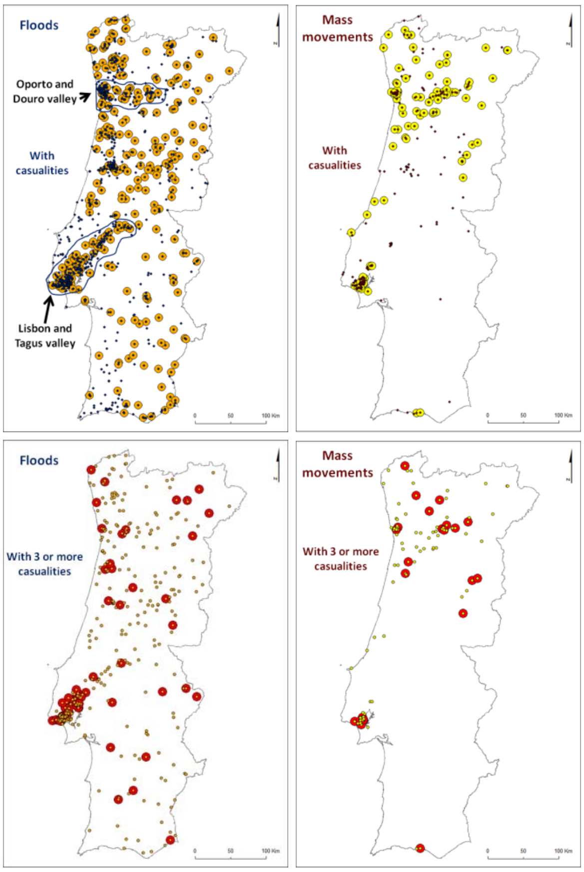

FIG. 5: Spatial distribution of deadly occurrences of floods (on the left) and mass movements (on the right) (according DISASTER database) (the two maps at the top represents occurrences with at least one casualty; the two maps below represents occurrences with three or more casualties).

Based on the analysis of all the events responsible by the occurrence of damaging flood and mass movement, from 1865 to 2010, it is possible to identify several spatial patterns, relate them with specific atmospheric circulation types, and establish a direct relation with the sort and intensity of the impacts on human life.

With respect to floods, some spatial patterns can be defined, related with different atmospheric circulation types; the most important of them can be highlighted:

- Type I: very concentrated events, along small areas (Fig. 6: A, B, C and D) or linear trajectories (Fig. 6: E and F), related with very convective depressions, that generate flash floods;
- Type II: a linear distribution along the main rivers (Fig. 6: G and H), related with very long rainfall periods caused by successive surface frontal zones, that generate progressive floods;
- Type III: mixed pattern where the floods along the main rivers occur simultaneously with located and more or less disperse flash floods (Fig. 6: I);
- Type IV: a regional spatial pattern (Fig. 6: J, K and L), more or less disperse, sometimes separated in two or three sub-regions, whose influence extends only into a part of the territory (north, centre, northwest, etc.).

The Type I distribution can be very destructive and are responsible by the most part of the human mortal victims and people injured. With the exception of sub-type with linear trajectory, these events can be characterized according the next general features (Fig. 6: A, B, C and D):

- Great intensity and destructive capacity, which arises from the intense rainfall;
- Associate to events with short duration, normally just one day, rarely more;
- Very circumscribed spatially, with areas short than 2500 km^2;
- Occur mostly in November;
- High frequency of occurrence at Lisbon Metropolitan Area;
- Created by convective depressions (active cold pools or depressions caused by the interaction between polar and tropical air masses).

The sub-type with linear trajectory can be also deadly (Fig. 6: E and F), but normally is not as dangerous as the previous sub-type because the rain doesn’t concentrate in one area only and distributes the energy along its path.

The spatial pattern Type II, include the “progressive floods” and are mainly related with the larger basins (Fig. 6: G and H), like the ones of Douro, Tagus and Guadiana. These floods results normally in a large inundated area, especially in the case that the rivers cross large alluvial plains, such as that of the Tagus River. These floods are caused by heavy rains associated with a westerly zonal circulation that may persist for weeks. As progressive (slow) floods they normally don’t have great impact in loss of human lives, but they are the main responsible for a large amount of displaced and evacuated. Nevertheless, in large but much embedded rivers, like Douro, it can generate great disturbance in the human activities.

The spatial pattern Type IV (Fig. 6: J, K and L) has similar characteristics to Type II in respect to atmospheric circulation, but affects mainly the small basins, more flash flood-prone. Thus, despite being associated to heavy precipitation generated by westerly zonal circulation, the affected catchments have short-time responses and flash floods occur. This kind of pattern appears essentially in the centre and north of mainland Portugal, most affected by the passage of weather fronts.

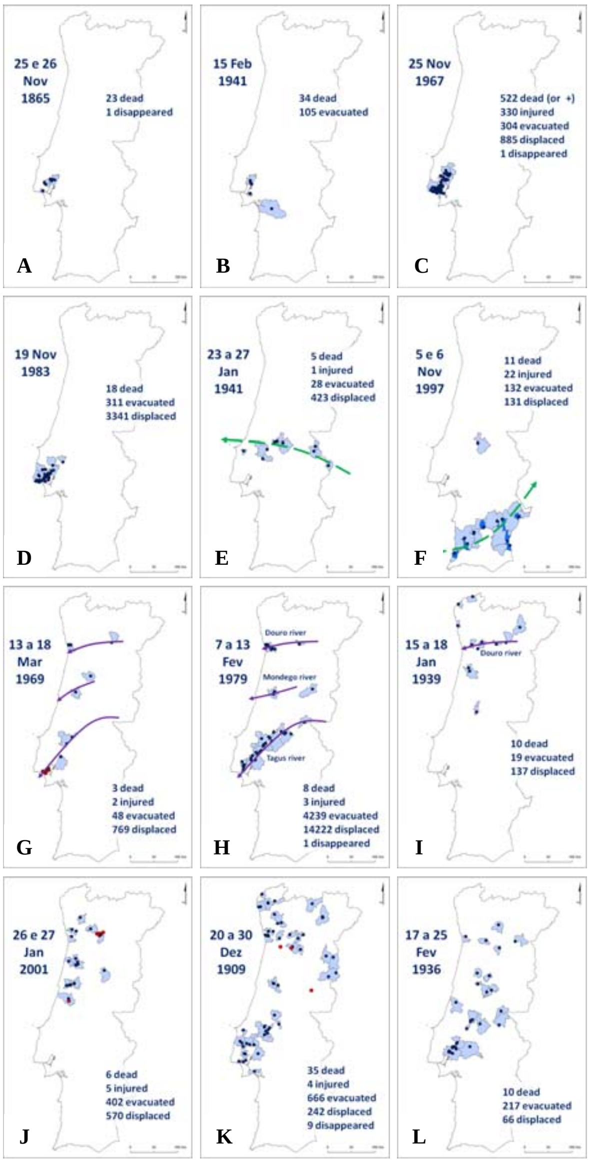

FIG. 6: Selected event patterns representatives of the main types (defined by frequency and impacts) of floods and mass movements distributions (the blue dots represent the floods; the brown dots represent the mass movements; the solid blue arrow represents the direction of the flow at the large rivers; the dashed green line represents the trajectory of the depressions).

It can be noted that the mass movements don’t occur associated to the kind of events of Type I. In fact, heavy rain intensities during October and November can generate flash floods in small catchments, but normally don’t originate mass movements, unless the ground is already saturated. So, slope mass movements are in great measure coincident with progressive floods since both phenomena need large amounts of accumulated rain.

IV. ACKNOWLEDGMENTS

This work was undertaken within the project “Disaster - GIS database on hydro-geomorphologic disasters in Portugal: a tool for environmental management and emergency Planning” (PTDC/CS-GEO/103231/2008) funded by the Portuguese Foundation for Science and Technology (FCT).

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