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The geological multi-hazard map of Catalonia. A user-friendly tool for land use planning and management risk

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ABSTRACT: The Geological Hazard Prevention Map of Catalonia 1:25,000 (MPRG25M) developed by the Cartographic and Geological Institute of Catalonia (ICGC) is a multi-hazard map, which includes the representation of natural hazards evidence, phenomena and susceptibility generated by external and internal geodynamics. The MPRG25M is conceived to be used for land use planning and risk management by the competent authorities. The main challenge of the map is the graphic representation for the easy reading of the overlapping hazard of the danger of different phenomena. The map is intended to enable government and individuals to have an overview of the territory identifying areas where it is advisable to carry out detailed studies for planning purposes. Nowadays the Geological Hazard Information System of Catalonia (SIRGC) is being implemented. This database incorporates all the information from the MPRG25M project.

1 INTRODUCTION

The Parliament of Catalonia approved, by Law 2/2014, the creation of the Cartographic and Geological Institute of Catalonia (ICGC) before Geological Institute of Catalonia (IGC), assigned to the Ministry of Land and Sustainability (TES) of the Catalonian Government. One of the functions of the ICGC is to "study and assess geological hazards, including snow avalanches, to propose measures to develop hazard forecast, prevention and mitigation and to give support to other agencies competent in land and urban planning, and in emergency management". Therefore, the ICGC is in charge of making official geological hazard maps for such a purpose. These maps comply with the Catalan Urban Law (1/2005), which defines that in those places where a risk exists, building is not allowed.

In Catalonia, the main phenomena that have and could occur in the future are those generated by external geodynamics, such as floods (fluvial and coastal), slides, falls, hyperconcentrated and debris flows, collapses and snow avalanches, and by internal geodynamics, such as earthquakes.

The high density of urban development and infrastructures in Catalonia requires geo-thematic information for planning. As a component of the Geoworks of the ICGC, the strategic program aimed at acquiring, elaborating, integrating and disseminating the basic geological, pedological and geothematic information concerning the whole of the territory in the suitable scales for the land and urban planning.

The geological multi-hazard map of Catalonia is an essential part of this information. Despite some tests have been carried on at regional scale (Mountain Regions Hazard Map 1:50,000 [DGPAT, 1985], Risk Prevention Map of Catalonia 1:50,000 [ICC, 2003]), in 2006 the Catalan government made a strong commitment to produce the Geological Hazard Prevention Map of Catalonia (Oller et al, 2011) mapped at a greater detailed scale.

The MPRG25M is a 1:25,000 scale map where whole of the Catalan territory will be zoned according to geological hazard. The purpose of this tool is to support urban, road and infrastructure planning. The map is intended to enable government and individuals to have an overview of the territory, with respect to geological hazards, identifying areas where it is advisable to do detailed studies for planning purpose. The main challenge of the map is the graphic representation for the easy reading of the overlapping hazards of different phenomena.

At the same time a database is being implemented. It will incorporate all the information coming from these maps. Nowadays the Geological Hazard Information System of Catalonia (SIRGC) is being implemented and designed according to European guidelines INSPIRE (Infrastructure for Spatial Information in the European Community).

2 THE GEOLOGICAL HAZARD PREVENTION MAP OF CATALONIA 1:25,000 (MPRG25M)

The MPRG25M includes the representation of activeity evidence, phenomena, susceptibility and level hazard of geological processes considered. These are the processes generated by external geodynamics (such as slope, torrential, snow, coastal and flood dynamics) and internal (seismic) geodynamics. The information is displayed by different maps on each published sheet. The main map (Fig. 1) is presented on a scale of 1:25,000, and includes landslide, snow avalanche and flood hazard. Hazard level is qualitatively classified as high (red), medium (orange) and low (yellow). The methods used to analyse hazards basically consist of geomorphological, spatial and statistical analysis.

Several complementary maps on a 1:100,000 scale shown hazard level caused by each phenomenon individually in order to facilitate the reading and understanding of the mapped phenomena. Two additional maps for flooding and seismic hazards, represented on a 1:50,000 scale, are added to the sheet.

For hazard evaluation, maximum homogeneity and reproducibility in the mapping procedure is intended, in order to extrapolate it to the entire territory. It consists of a geomorphological approach complemented with GIS analysis and statistical modelling. In this process we obtained, for each different phenomenon, the following parameters:

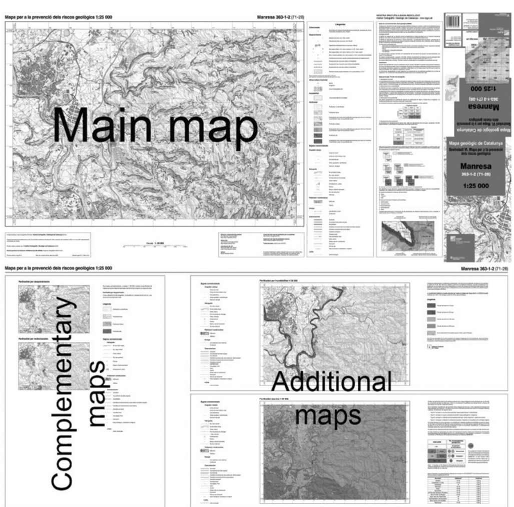

Figure 1. Outline sheet. It shows the distribution of the different maps. Example of Manresa (71–28) sheet, published in 2014. Downloadable at www.icgc.cat.

susceptibility, frequency, magnitude, and hazard level. Of course, expertise is important throughout the entire process. The procedure followed in the main map consists of three steps: catalogue of phenomena and activity evidences, susceptibility determination, and hazard determination.

The catalogue of phenomena and activity evidence is the base of the further susceptibility and hazard analysis. It consists of a geomorphologic approach and it comprises the following 4 phases. (1) Bibliographic and cartographic search which consists of collecting the information available in archives and databases. (2) Photointerpretation carried out on vertical aerial photos of flights from different years since 1945. The observation of the topography and the vegetation allows the identification of areas with signs of instability coming from the identification and characterization of events that occurred recently or in the past, and from activity indicators. (3) Field survey which consists in checking and contrasting on the field, the elements identified in the previous phases. Field analysis allows a better approach and understanding, and therefore identifying signs and phenomena not observable through the photointerpretation. (4) Population inquiries, the goal of this stage is to complement the information obtained in the earlier stages, especially in aspects such as the intensity and frequency. It is done through a survey of witnesses who live and/or work in the study areas.

In a second step, areas susceptible to be affected by the phenomena are identified from the starting zone to the maximum extent determinable at the scale of work. Their limits are drawn taking into account the catalogue of phenomena, geomorphological indicators of activity, and from the identification of favourable lithologies and morphologies of the terrain. This phase includes the completion of GIS and statistical analysis to support the determination of the starting and run-out zone.

Finally, hazard is estimated on the basis of the analysis of the magnitude and frequency of the observed or potential phenomena. Hazard from each phenomenon is analyzed individually. Susceptibility areas are classified according to hazard matrix represented in Fig. 2. Hazard zones are represented as follows: in white, areas where no hazard was detected; in yellow, zones with low hazard; in orange, medium hazard zones and in red, areas with high hazard.

In order to assess equivalent hazard for each phenomena considered in the MPRG25M, we used a systematic and homogeneous methodology throughout the territory, based on the frequency and magnitude of each phenomenon. The same frequency values were used for all phenomena, but magnitude values were adapted to each of them.

		FREQUENCY		
		Low	Medium	High
MAGNITUDE	Low	**Low**	**Low**	**Low**
	Medium	**Low**	**Medium**	**Medium**
	High	**Medium**	**High**	**High**

Figure 2. Hazard matrix (based on Altimir *et al,* 2001).

	PREVENTION	
HAZARD	**DETAILED STUDIES**	**HAZARD MANAGEMENT**
Not observed	-----	-----
Low	**Recomendable**	**Necessary in certain cases**
Medium	**Indispensable**	**Necessary in many cases**
High	**Indispensable**	**Necessary in most of the cases**

Figure 3. Prevention recommendations.

The frequency limits are 50 and 500 years; the limit of 50 years (high-medium frequency) is based on the return period of the rains that produced great widespread river flooding and landslides, which is between 40 and 70 years (Corominas et al., 2010). To set the boundary for low-middle frequency (return period of 500 years) we used a logarithmic scale, because it minimizes the uncertainty in its assessment in the absence of many historical records exceeding 100 years.

The magnitude is determined based on the dimensions and expected energy, whereas the frequency is determined from inventory of phenomena and their activity indicators.

Each hazard level contains some considerations for prevention (Fig. 3). These considerations inform about the need for further detailed studies and advise about the use of corrective measures.

3 A USER-FRIENDLY TOOL FOR LAND USE PLANNING AND MANAGEMENT RISK

The main challenge of the map is to easily present the overlapping hazard of different phenomena. A methodology identifying that this overlap exists has been established with this objective in mind. It indicates what the maximum overlapped hazard is, but in any case, without obtaining new hazard values. Multi-hazard zones are represented as follows (Fig. 4).: areas where no hazard was detected (white), areas with one phenomena with low hazard (yellow), zones with two or more phenomenon with low hazard (dark yellow), areas with one phenomena with medium hazard (orange), areas with two or more phenomena which the highest hazard is medium (dark orange), areas with one phenomena with high hazard (red), and areas with two or more phenomena which the highest hazard is high (dark red).

It has created an epigraph which identifies the level of hazard and the type of phenomenon it belongs. It's useful especially in overlapped hazard areas (Fig. 5). This epigraph consists of two characters, the first, in capital letters, indicates the value of hazard (A for high hazard, M for medium hazard and B for low hazard), and the second, in

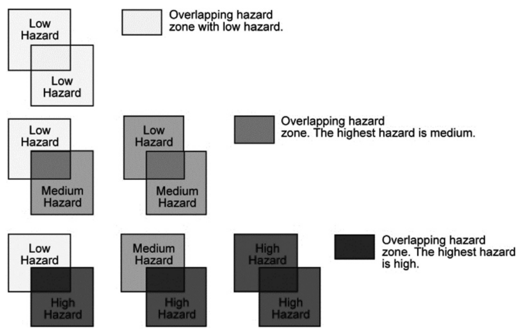

Figure 4. Multi-hazard representation.

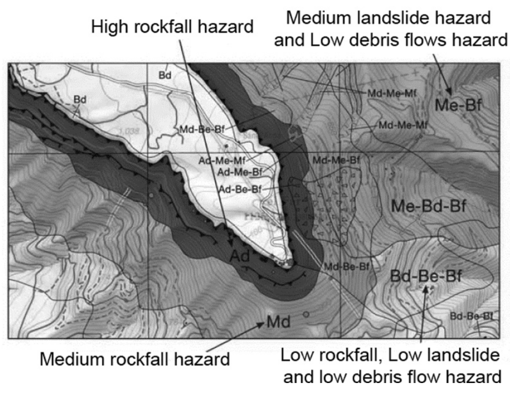

Figure 5. Example of multi-hazard representation. The epigraph shows three types of information: the number of overlapping events, their types and the hazard level of each.

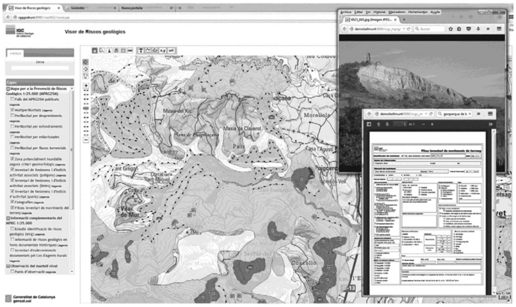

Figure 6. The MPRG25M Internet viewer "Geoindex".

lower case letters, indicates the type of phenomena (d for rockfall, s for slides, x for hyperconcentrated and debris flows, a for avalanches and f for subsidence and collapses).

The more overlapping phenomena are, the longer the epigraph will be.

3.1 *The MPRG25M products*

Different ways to distribute the MPRG25M have been developed with two main objectives. First, the information must be used for the maximum number of end-users. Secondly, the information must respond efficiently the requirements from the authorities and society in general. With these objectives the MPRG25M is distributed in 4 different formats: traditional paper, GeoPDF, ArcGis shape file format (ICGCa 2015) and Internet viewer "Geoindex" (Fig. 6) (ICGCb 2015).

4 CONCLUSIONS

The target of the MPRG25M is to give an overview of the territory at 1:25,000 scale, with respect to geological hazards, identifying areas where it is advisable to carry out detailed studies in case of urban or infrastructure planning.

Has been established a methodology that easily shows hazard areas with different overlapped phenomena. These areas can be identified by the color and the epigraph. The color shows that overlapped exist and the epigraph shows the level of hazard and the type of phenomena.

The MPRG25M It is distributed in 4 different products to be used for the maximum number of end-users.

Geohazard information is dynamic. For this reason, a database is being implemented. It will incorporate all the information obtained for the elaboration of these maps, and information coming from the geohazard surveillance service of the ICGC. Nowadays the Geological Hazard Information System of Catalonia (SIRGC) is being implemented and designing according to European guidelines INSPIRE (Infrastructure for Spatial Information in the European Community).

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