CO-022

EXAMPLES OF NATURAL RISK ANALYSIS FROM SPATIAL DATA INFRASTRUCTURES

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ABSTRACT

Natural hazards and risks analyses are based on the overlapping of geographical information layers to produce different level maps (susceptibility, hazard, elements at risk, vulnerability and risk), depending on the used or available data. In this way, natural hazard analyses had got a great development with the rise and use of Geographical Information Systems. Because of it, Spatial Data Infrastructures, as an extended concept of GIS, are a new step in natural hazard analyses in various ways, such as the availability of web data, the production of environmental information and the presence of metadata. In this work, we discuss these questions and we study the possibility to make natural risk maps from SDI and web databases (Spanish central SDI, Cadastral, Regional Governments, Geological Institute, Andalusian Environmental Network, Weathering Agency and Statistical Institute). In the second place, we propose different examples of methodologies to natural risk analysis such as landsides susceptibility and hazard, seismic hazard and burns hazard. We conclude that there are a good variety and quality of basic and thematic data related to natural hazards in Spain; however, most of them are in web map services (WMS), being necessary to have data in web feature and web coverage services (WFS and WCS) to make the analyses with a great guarantee.

INTRODUCTION

Natural risks are defined as the expected damages or losses as a consequence of the occurrence of a danger (process or phenomenon) over a good to be preserved, that can be the human life, economic goods or environment (Ayala, 2002). They are an increasing importance fact in the global world, because in the 20th century more than 4,5 millions people died and 200 million were damaged by natural risks; additionally, economic losses are uncountable; for instance, in Spain, total losses between 30 and 50 billion € are estimated (González, 1988).

Then, a risk management is necessary to eliminate or at least mitigate their effects. Risk management involves two types of actions: structural and non-structural actions (Ayala, 1978, 2002). Among them, one of the most effective is risk analysis because allows know risk causes and value their consequences. Risk quantitative analysis or evaluation must take in account social, economic and environmental aspects and usually are estimated from its components by means the general equation of risk (Varnes, 1984), adopted by the United Nations Disaster Relief Organization (UNDRO):

$$R=\sum 〚Pi*Ei*Vi〛$$

Where R is the risk, and P (hazard), E (exposure) and V (Vulnerability), its components.

Because of natural risks are a spatial phenomena, the analysis must be also spatial or cartographic. In this sense, risk cartography has been one of the most used tools to risk mitigation because clearly highlights zones with elements at risk, as a basis to other actions such as regional planning, post-disaster management or structural actions (Olcina, 2002).

Nowadays, analyses are based in overlapping of geographic information layers of different sources in Geographical Information Systems (GIS) to build several level maps or models (susceptibility, hazard, exposure, vulnerability and risk), depending on the used information. Generalized use of GIS from 1980 years was a big step to thematic and environmental cartography because they allowed more advanced analysis and data modeling techniques. Meanwhile, the rise of Spatial Data Infrastructures emphasizes the relevance of environmental data and maps and integrates them with general or topographic maps. Initiatives such as INSPIRE (European Union) or national and regional SDI highlight the importance of geographical information in current society and lead politics, technologies and standards to integrate coherently geographic information of different themes. SDI allow the availability of updated information layers in the web, impulse the production of new sets of data and maps, and ensure the presence of metadata to inform about data and subsequent analysis quality. However, SDI must not be restricted to data storage, visualization and exchange, but must to give services, as the major novelty regards to conventional cartography. Data can be used in different ways depending on the applied services.

The simplest ways are the visualization through Web Map Services (WMS) in SDI web sites, virtual globes (Google Earth, Bing Maps …) or being introduced in GIS connected to these services. In these cases, analyses are limited to basic queries, but data digitalization with GIS tools can be also made. To more advanced and less restricted analysis (overlapping information layers or neighborhood operations), SDI use to provide downloading systems of different data formats, from pdf or image files (JPEG, TIFF…) to vector files (SHP, DXF, DWG …); but in a more appropriate way, SDI also develop web file services (WFS) to work with vector data layers and web coverage services (WCS) to work with raster data layers. In these cases, SDI connections from a GIS allow work in a similar way to a conventional GIS but without physical data in the computer. The next step is the development of web processes services (WPS) with a wide application in natural risks studies.

In this work, we discuss about the possibilities to make risks analyses from SDI, evaluating different initiatives and databases available in the web.

NATURAL HAZARD MAPS AND INFORMATION LAYERS

As we previously said, risk evaluation from its components leads to maps or models of a different level depending on the available information.

Susceptibility and hazard

The first level, hazard, can be defined as the probability of a potentially risk phenomenon to happen with a given intensity in a given place and time. Some concepts such as phenomenon intensity, return period (number of years considered to evaluation) or annual probability (inverse of return period) to exceed a high intensity, must be defined to establish with accuracy the hazard degree (Ayala, 2002).

For this reason, the concept of susceptibility or spatial probability arises, that often is all that can be determined with available data, although supposes a lower information level than hazard. According to Brabb (1984) in the field of slope movements, susceptibility is the probability or possibility that a risk phenomenon occurs in a specific zone and in unknown future, based on the correlation between the process determinant factors and the spatial distribution of past events. Nevertheless, this simple susceptibility mapping is an effective tool to regional planning, because it shows to planners and decision makers the location in which a potentially risk process have occurred o can occur.

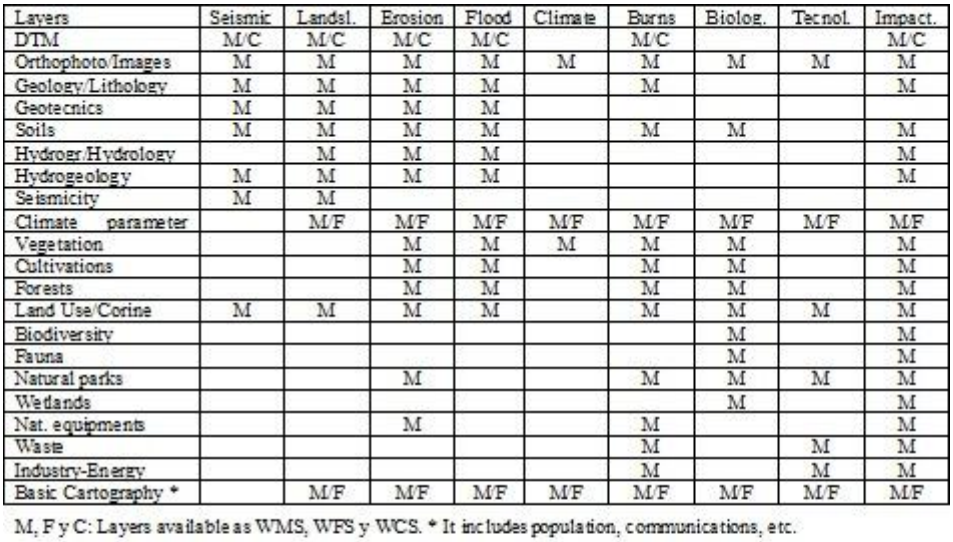
Information layers necessary to produce susceptibility and hazard maps are the past phenomenon inventories and the determinant factors maps. Useful data to susceptibility and hazard analysis of the most important processes are shown in table 1.

Geological processes can be well modeled because geological information in SDI is quite extensive and reliable; in addition there are digital terrain models (DTM), basic information, soils maps, orthophotography and satellite images of different resolutions and dates; in some cases, there are specific inventories and even susceptibility maps. Climate data are usually in non-cartographic databases of weathering and environmental services, although easily convertible to cartographic layers. Burns are other well-documented processes with abundant climatic and vegetation information as well as orthophotography and images catalogs; in this case, there are SDI that even incorporate susceptibility and hazard maps. Biological information concerns about vegetation, fauna, biodiversity, natural parks and satellite images. Finally, regarding to technological risk there information about wastes, industries and energetic plants, population and satellite images.

To hazard determination it is necessary to date the events with accuracy or at least to know the frequency of the processes or their triggering factors. Dating techniques are usually based on historical recording, field observations, radioactive isotopes, or for the last years, historical photography and satellite images. From these studies, the return period or annual probability of a high intensity event can be calculated (Ayala, 2002). Because of spatial distribution of hazard, it can be expressed by means hazard maps.

In SDI, hazard information is based in historical recording such as seismicity or climatic parameters as well as historical cartographies. In Spain, sets of aerial photography are available since 1956 (USA flight), although most of images are taken in the last years; the same for satellite images since 1990 years.

Table 1.Useful information layers to susceptibility and hazard maps.



Layers	Seismic	Landsl.	Erosion	Flood	Climate	Burns	Biolog.	Tecnol.	Impact.
DTM	M/C	M/C	M/C	M/C		M/C			M/C
Orthophoto/Images	M	M	M	M	M	M	M	M	M
Geology/Lithology	M	M	M	M		M			M
Geotecnics	M	M	M	M					
Soils	M	M	M	M		M	M		M
Hydrogr./Hydrology		M	M	M					M
Hydrogeology	M	M	M	M					M
Seismicity	M	M							
Climate parameter		M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F
Vegetation			M	M	M	M	M		M
Cultivations			M	M		M	M		M
Forests			M	M		M	M		M
Land Use/Corine	M	M	M	M		M	M	M	M
Biodiversity							M		M
Fauna							M		M
Natural parks			M			M	M	M	M
Wetlands							M		M
Nat. equipments			M			M			M
Waste						M		M	M
Industry-Energy						M		M	M
Basic Cartography *		M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F

M, F y C: Layers available as WMS, WFS y WCS. * It includes population, communications, etc.

Exposure and valuation

Elements at risk are the whole of goods to preserve that can be damaged by a risk process action; these goods are exposed to phenomena because of their spatial-temporal location. Once that goods exposure has been determined, the next step is their valuation in economic, social and environmental terms with the objective of society and decision makers aware of these processes importance.

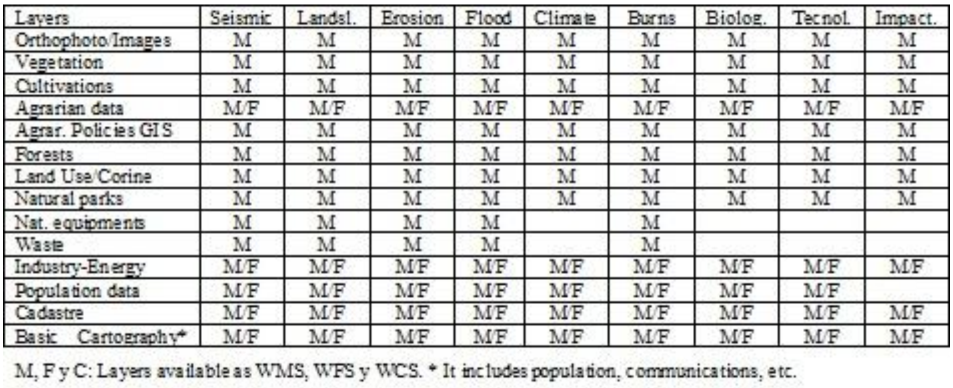
The determination of elements at risk exposure is quite simple by means cartographic and GIS techniques, overlapping information layers corresponding to hazard maps and elements inventories. These elements are present in topographic or general maps (roads network, population, constructions, buildings, cultural elements, land uses, etc.) and thematic maps (agriculture, forestry, mining, touristic, population, etc.). In this sense, cadastral, environmental and agrarian maps have interest information.

Most cases, the valuation of element at risk is limited to general studies or qualitative approaches, especially of economic component. However, other aspects must be considered: social valuation, directly determined as the number of people exposed to risk; environmental valuation from environmental inventories and maps; and finally, including –not going through- economic valuation can be estimated from different inputs. Agrarian valuation deals about cultivations and forests; real-estate market is related to land and edifications; insurance companies work with estimation of damage to people and their goods.

In this way, cadastral cartography and valuation can be a first-line tool to quantitative estimation of element at risk, and subsequently estimation of risks. Cadastral valuation presents a high resolution allowing its use in large scales (risk mapping in urban zones and municipalities); to use them in lower scales, must be generalized. Besides, they covers a wide range of land elements (private and public buildings, urban and rural, etc.), but they do not reach other elements such as civil works, personal properties, public facilities, that have to be deduced from other sources. Nevertheless, most cases of risk maps, a detail inventory as cadastral one is not required, and the valuation must be obtained from more general data such as cultivation maps or statistical data.

In SDI, there is good quality information about these topics but lower than for inventories and determinant factors (susceptibility and hazard), previously discussed (table 2). Population data is available in layers of general maps and in statistical databases (for instance, National Statistic Institute of Spain); cadastral data are present in national SDI, as well as property registration and census data. Rural edifications and parcels can be obtained from thematic layers about vegetation, cultivations and forests combined with agrarian statistics, or from rural cadastre.

Table 2. Useful information layers to elements and risk exposure and valuation maps.



Layers	Seismic	Landsl.	Erosion	Flood	Climate	Burns	Biolog.	Tecnol.	Impact.
Orthophoto/Images	M	M	M	M	M	M	M	M	M
Vegetation	M	M	M	M	M	M	M	M	M
Cultivations	M	M	M	M	M	M	M	M	M
Agrarian data	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F
Agrar. Policies GIS	M	M	M	M	M	M	M	M	M
Forests	M	M	M	M	M	M	M	M	M
Land Use/Corine	M	M	M	M	M	M	M	M	M
Natural parks	M	M	M	M	M	M	M	M	M
Nat. equipments	M	M	M	M		M			
Waste	M	M	M	M		M			
Industry-Energy	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F
Population data	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F	
Cadastre	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F
Basic Cartography*	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F

M, F y C: Layers available as WMS, WFS y WCS. * It includes population, communications, etc.

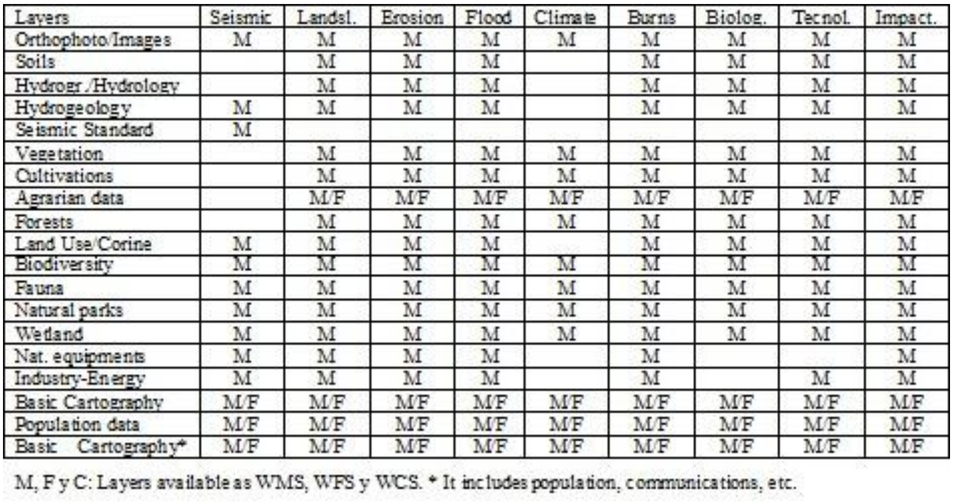
Vulnerability

Vulnerability is the degree of expected losses by the occurrence of a phenomenon of a given intensity; it depends on the intensity but also on the protection measurements.

In this case, there are studies focusing in some phenomenon such as seismic events and goods such as edifications and other structures. Vulnerability have to be valued by professionals of edifications or exploitations (engineers or architects), but also can intervene other professionals of health, cultural or natural heritage, etc. Vulnerability is perhaps the risk component less developed because there are not enough studies and reliable data, with the exception of seismic standard (Martin, 2002). The way to incorporate vulnerability data is through a quantitative layer in a 0-1 scale for each considered phenomenon.

In SDI, available information allows estimate vulnerability by experts in different elements at risk affected by processes. In some cases, there is relevant information such as seismic standard to determine the vulnerability of edifications to seismic events of a given intensity (table 3).

Table 3. Useful information layers to vulnerability maps.



Layers	Seismic	Landsl.	Erosion	Flood	Climate	Burns	Biolog.	Tecnol.	Impact.
Orthophoto/Images	M	M	M	M	M	M	M	M	M
Soils		M	M	M		M	M	M	M
Hydrogr./Hydrology		M	M	M		M	M	M	M
Hydrogeology	M	M	M	M		M	M	M	M
Seismic Standard	M								
Vegetation		M	M	M	M	M	M	M	M
Cultivations		M	M	M	M	M	M	M	M
Agrarian data		M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F
Forests		M	M	M	M	M	M	M	M
Land Use/Corine	M	M	M	M		M	M	M	M
Biodiversity	M	M	M	M	M	M	M	M	M
Fauna	M	M	M	M	M	M	M	M	M
Natural parks	M	M	M	M	M	M	M	M	M
Wetland	M	M	M	M	M	M	M	M	M
Nat. equipments	M	M	M	M		M			M
Industry-Energy	M	M	M	M		M		M	M
Basic Cartography	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F
Population data	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F
Basic Cartography*	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F	M/F

M, F y C: Layers available as WMS, WFS y WCS. * It includes population, communications, etc.

Risk

Risk can be defined as the sum of products of hazard, exposure and vulnerability, calculated to each of elements at risk. If in a zone more than one process intervenes, the obtained results of risk for each one will be summed.

Risk calculation from its factors is a GIS overlaying operation, once that these factors have been modeled.

EXAMPLES

Landslides

The general methodology to obtain risk maps on landslides (Chacón et al., 1994) is shown in figure 1.

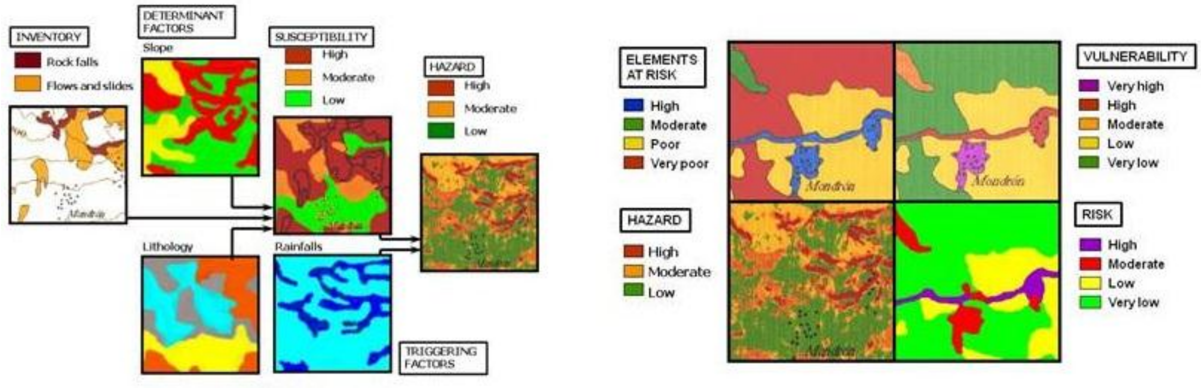


Figure 1. Methodology for landslide risks maps.

To this work, we present the example of susceptibility and hazard mapping of a basin located in the South of Granada province (Spain) at a 1:200.000 scale. The methodology to elaborate susceptibility maps are summarized in the following steps:

1. Landslides inventory and database.
2. Determinant factors analysis by means of cross correlations with inventory.
3. Susceptibility modeling by GIS overlapping of factors layers.

In this work the inventory is own elaborated; although in Spanish SDI there is some information about landslides, this is at very low scale and precision.

Regarding to determinant factors, DTM of 25 m resolution is obtained from central SDI (National Geographic Institute-IGN). Although it is possible to work on-line, by means WCS services, finally we have decided download data in ASCII format. These files have been converted to raster format and then derived models such as slope, exposure and curvature have been obtained.

Geological, geomorphological, geotechnical and soils information is also available at a several scales as WMS in Geological and Mining Institute (IGME) or Environmental Information Network of Andalousia (REDIAM), but we prefer download it. In this way the geological map at 1:400000 scale has been obtained from the last service.

Hydrographic information is available as WMS and WFS and also downloadable from central SDI; this layer is not used in the analysis because this information is related with curvature. Weathering information is present in some regional SDI (for instance REDIAM), but over all in databases such as those in National Weathering Agency (AEM); from these services annual average precipitation has been obtained.

Factor analysis is shown in table 4. Rock falls appear conditioned by slope, curvature, lithology and precipitations; rock and earth slides are conditioned by height, slope, curvature and lithology; earth flows are conditioned by height, curvature and lithology; and finally, debris flows are conditioned by slopes, curvature and lithology.

Table 4. Factor analysis.

Factors	Rock falls	Slides	Debris flows	Earth flows
Height	0,451	**0,515**	0,190	**0,813**
Slope	**0,795**	**0,481**	**0,465**	0,382
Aspect	0,253	0,110	0,066	0,274
Curvature	**0,534**	**0,554**	**0,568**	**0,493**
Lithology	**0,615**	**0,597**	**0,545**	**0,992**
Rainfalls	**0,482**	0,392	0,183	**0,606**

From this analysis, susceptibility is modeled by overlapping of determinant factor that present a higher correlation in each landslide typology. Of all existing methodologies, matrix approach has been used, because it is a methodology very adequate to low-medium scales (Chacon et al, 1994, 2007). In this approach, susceptibility is defined as the percentage occupied by rupture zones in each possible combination of factors. This value is assigned to each point and the susceptibility map is obtained classifying in five intervals (0-1%: very low; 1-5%: low; 5-10%: moderate; 10-25%: high; >25%: very high). The susceptibility map for rock and earth slides of studied zone is shown in figure 2.

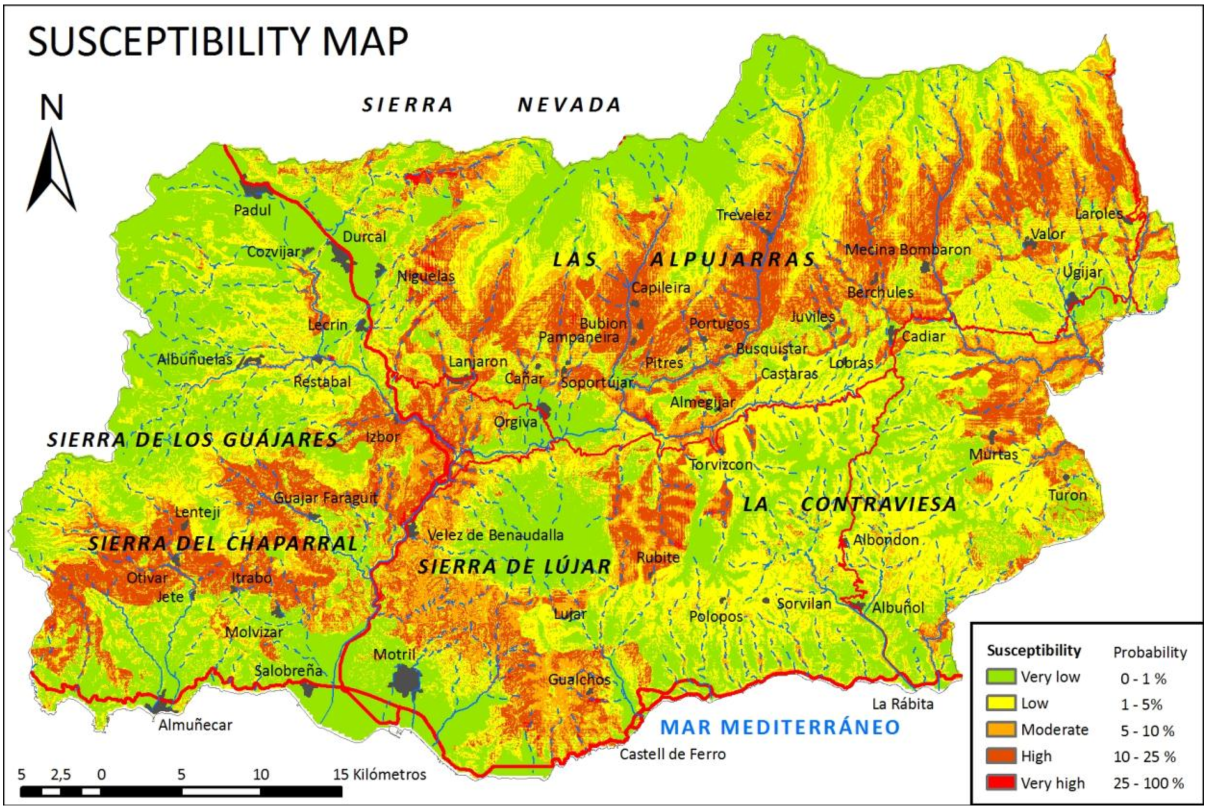


Figure 2. Rock and earth slides susceptibility map.

Hazard maps are derived from knowledge of frequency of risks processes and then dating of these events are necessary. In some processes such as earthquakes and floods with a sudden occurrence or confined to a few hours-days, dating is enough accurate by means historical record or other techniques. In landslides, accurate dating of an event by means radioactive isotopes in scarps (cosmogenic) or in boreholes (buried organic matter) usually is not enough, because these processes are usually diachronic. Diachroneity is related to duration of phenomena (Chacón et al., 2010); 12 degrees of diachroneity are defined, from sudden movements to those developed during hours, days, months, years and thousands of years. This is an interesting concept because there are some movements that present a slow and irregular evolution, alternating moments of lower or higher activity that must be taken in account in the susceptibility modeling. Then, dating techniques must aim to detect this activity; the more appropriate are dendrochronology for intervals of 10 to 1000 years or the use of historic aerial photography, satellite images or landslide monitoring to more recent times. In Spanish SDI is available historic photography since “USA flight” and satellite images.

From the diachroneity and activity of some typical movements, return period of landslides of an area can be determined and then the susceptibility for these periods, following the previously described methodology. Annual hazard or probability (Ayala, 2002) for each return period can be calculated multiplying susceptibility by the inverse of periods or frequency (Pa=S*1/T). Finally, global annual probability is obtained determining the maximum value of probability of all the considered periods. To a period of n years, hazard is calculated by the formula Pn= (1-(1-Pa)n).

In this work, landslides dating are estimated approximately. Susceptibility maps for return periods of 100, 1000 and 10000 years, have been made from partial landslides inventories in which the movements have been included according a geomorphologic criterion; in the case of 10000 years all the landslides have been included; in the case of 1000 years, movements considered as relicts (denudated landscape) are excluded for the analysis; in the case of 100 years, movements considered as dormants (intact landscape but without recent evidences) are also excluded.

However, in the case of landslides with return periods of 10 years, other criterion has taken in account, based on the rainfall frequency that is considered as the main triggering factor of natural landslides in the study area with seismic activity whose return period is very large. From available data of precipitation in REDIAM and National Weathering Agency for a large network of weather stations in a wide time interval (1940-2010), 5 to 7 rainy events are found in the last 70 years, similar to those at 1996/97 and 2009/10 in which an important landslide activity took place. These periods of 10-15 years appear to have a high correlation with negative index of Atlantic North Oscillation (Trigo et al., 2002). Because of a landslide inventory related to 1996/97 rainy event was made, this can be used to elaborate a susceptibility map of 10 years of return period. Combining the different return period susceptibility maps the annual hazard map is obtained (figure 3 shows this maps to rock and earth slides).

The next step is the exposure and valuation of elements at risk maps. The first element at risk for landslides is population, available at different scales as information layers in WMS and WFS services in central and regional SDI, with data from statistical institutes and Cadastre. The second data set are road and railway networks, constructions and buildings that can be obtained also as SDI layers. The third data set is land uses available as information layers in general and thematic SDI. To the valuation of population can be necessary to have data from insurance companies, what is difficult. The detailed valuation of urban and rural private terrains is more likely but other such as valuation of public buildings and civil works is more difficult. To a lower detailed valuation of these elements such as cultivations can be used other type of studies such as agrarian valuations.

Vulnerability is the component more difficult to obtain from SDI data. There is virtually none information of these topics, and the valuation only can be addressed from professional studies of engineering and architecture and even of health. For these reasons, in this general and preliminary work, exposure and vulnerability maps are not elaborated, until the studies will be more advanced.

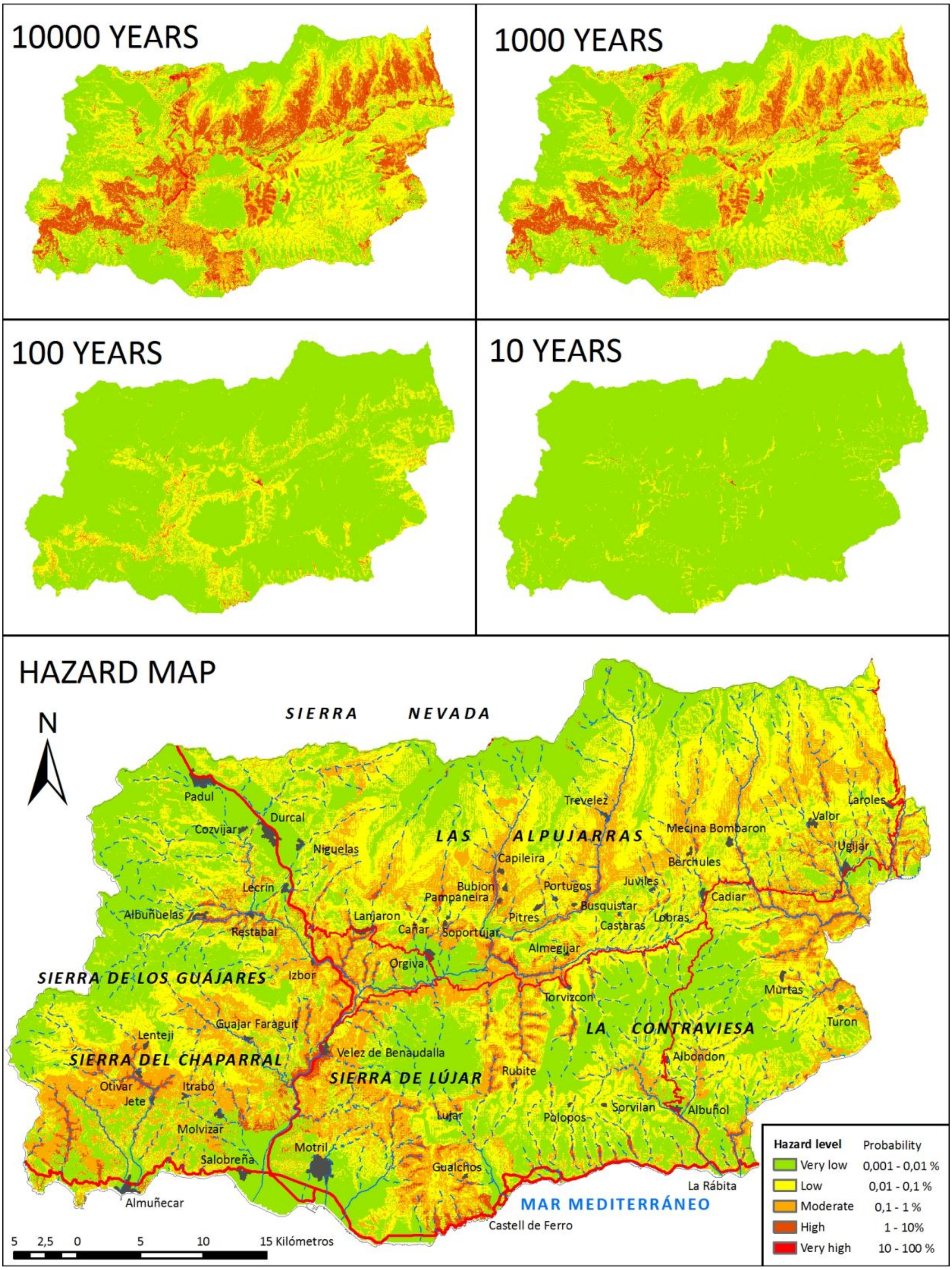


Figure 3. Rock and earth slides hazard map.

Seismic risk

In seismic risk, hazard or probability that an earthquake higher than a given intensity happens in a zone and in a return period is calculated through deterministic or probabilistic methodologies from seismicity of that zone, seismic attenuation by the distance and terrain, and local factors.

The seismicity is estimated from parameters such as magnitude, intensity or acceleration produced in terrain by an earthquake in a return period in the considered zone. The attenuation of the intensity or acceleration is obtained using empirical formulas in function of distance and terrain characteristics. From them, regional hazard or seismic macrozonation maps are determined.

To elaborate detailed maps, it is necessary to consider local factors related to geology (lithological types and depth of superficial formations), hydrogeological (water table depth) and topographic. Taking in account these factors, seismic microzonation maps are obtained as expression of hazard.

Once the seismic hazard has been determined, vulnerability can be calculated from response spectra of different types of structures to a particular intensity or acceleration; in Spain, that is reflected in documents called seismic-resistant standards (until now two standards have been redacted, to edifications and to large bridges). These responses can be expressed in vulnerability maps that combine hazard and structures types. Nevertheless, vulnerability maps must take in account other element at risk such as people (its vulnerability can be determined from structures vulnerability) and other goods (cultivations, etc.). Regarding to exposure and valuation of elements, the used methodologies are similar to those presented in other risk processes.

Burns

Burns are other processes in which risk studies are more advanced. As in previous cases, most of analyses are about hazards, for what many approaches have been developed. Given the nature of these processes whose triggering factors can be changed in a continuous way, the more interesting are those maps with a daily period.

To these maps, two types of factors are considered: permanent and variable factors. The first factors allow elaborate susceptibility maps and even annual or multiannual hazard maps. If the second factors are considered, daily hazard maps can be obtained; in this case, it is necessary to have GIS applications that calculate maps in an automatic and fast way and, at the same time, warning systems and civil protection teams who act immediately.

Permanent factors are height, slope, aspect (DTM derivatives), land uses and vegetation types. From these basic data, other more complex factors can be elaborated, such as fuel models, flammability modes and vegetation charges obtained from interpretation of aerial photographs and satellite images, according to available methodologies. Finally, other information about past burns obtained from historical record and photography sets can be incorporated in the models.

Variable factors are weather conditions estimated to a given time (weather forecast) and the state of vegetation that can be determined also from weather conditions of previous day and from vegetation indexes in satellite images.

CONCLUSIONS

Natural risks analyses are based on the overlapping of information layers of difference sources to produce maps or models at a several level. Until now, overlapping was being made in GIS, with data stored in the computer memories. The rise of SDI in the last years has produced a paradigm change in Cartography, gaining in importance the concept of shared information for what it is necessary to establish policies and institutional agreements, and to develop technologies and standards to make possible data interchanges; at the same time, the emphasis has shift from data to services.

There are some advances and initiatives at different scales: world scale, European scale such as INSPIRE, and national scales; in Spain, a great development in SDI has taken place with the central and institutional SDI (IDE-E and IDEAGE), as well as regional and local SDI. We can state that there is enough information to make possible natural risk studies in which diverse and quality information is necessary; these information are basic and thematic cartography layers, DTM, satellite images and orthophotography.

However, most of information is nowadays in WMS to only visualization and simples queries, although it would be necessary in the future that information were available at WFS and WCS to vector and raster data, respectively, to can work with a lower restrictions. Besides, these services must improve to be able work on-line and not have to download data in the computer memory. Nevertheless, the access to updated information even through WMS can be considered a great advance. In these sense, some risk studies such us those related to landslide susceptibility and hazard, seismic hazard and burns hazards can be addressed successfully with GIS and SDI technologies.

Other future guidelines are the availability of historic information to make temporary analyses. A next step is the publication of research results in SDI services as information layers available to both scientific and general community.

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