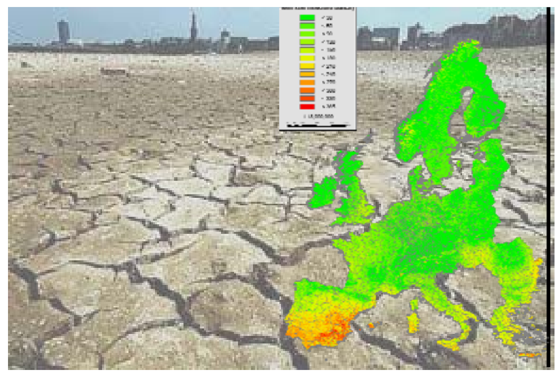
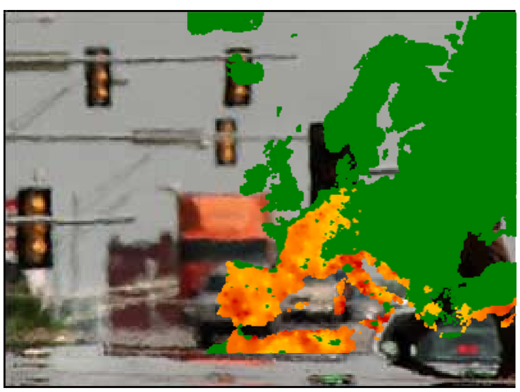
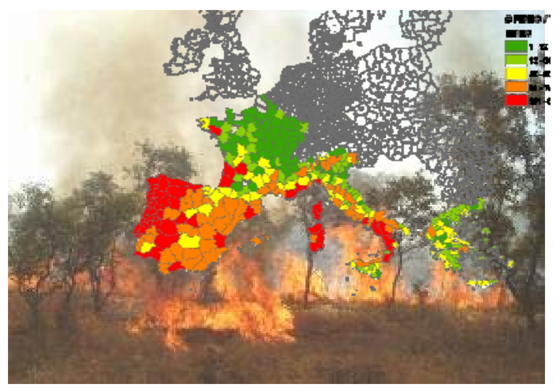
Towards an European integrated map of risk from weather driven events

A contribution to the evaluation of territorial cohesion in Europe







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Towards an European integrated map of risk from weather driven events

A contribution to the evaluation of territorial cohesion in Europe

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1 INTRODUCTION

The last couple of decades have experienced a significant increase of impacts of events driven by extreme weather conditions.

There are several concurrent causes for this trend, which is confirmed at both global and European levels. From one side, it is now widely accepted in the scientific community that there is an increased frequency of extreme events due to on-going climate transformations (IPCC, 2001). From the other side, uncontrolled developments have originated an increased exposure of assets which in turn results in higher impacts when the extreme event occurs (EEA, 2004).

In the frame of an analysis of the cohesion of the European Union, it has to be evidenced that natural hazards can well be considered elements of territorial disparities (i.e. of causes that threat the harmonised and sustainable growth across the continent) because consequences of extreme events (e.g. floods, forest fires, droughts and heat-waves) and plans to reduce exposures (for instance intensive actions such as dykes or fire-breakers, or zoning regulation measures) have an impact on the socio-economic growth of the concerned region. Both direct and indirect impacts have to be considered in quantitative and qualitative manners to evaluate regional variations in vulnerabilities and define sustainable remedial strategies.

The Joint Research Centre (JRC) is active since several years in the field of forecasting and prevention of natural hazards such as floods, forest fires and droughts. The issue of heat-waves is the subject of an activity recently started.

This technical note aims to present the status of progresses of the work carried out at the Land Management Unit (LMU) of the Institute for Environment and Sustainability (IES) in the field of risk and vulnerability analysis for weather-driven natural hazards. The work is performed in the frame of the overall JRC's mission, with the specific objective to contribute to the understanding of territorial features linked to extreme events and to propose solutions and policy-options for sustainable regional development in the context of the European cohesion. These activities also contribute to the overall EU policy on climate change, in the specific sectors of 'Adaptation to extreme events induced by climate change'.

The main foci of the work carried out concern flood, forest fire, drought and heat-waves. Following varied periods of hazard assessment and risk evaluation in those fields the corresponding products have now matured to a degree, which allows for the first time integrating the results to present risk mapping caused by those extreme weather events.

2 METHODOLOGICAL BACKGROUND

The framework for the activities of the Land Management Unit of IES is developed in the context of research and policy support related to evaluation of risks caused by extreme weather events.

Two considerations are at the basis of the work and of this note:

1. The evaluation of the potential impacts of extreme events has a fundamental role in the definition of integrated strategies for sustainable development at global, continental and regional scale, since policies for hazard mitigation can be more effective when consistently embedded within broader strategies designed to make national and regional development paths more sustainable.
2. The territorial (or spatial) dimension is the ‘key’ to integrate and to assimilate the large variety of available information needed to formulate scenarios of evolution of complex dynamic systems by mean of prediction and simulation models. Any ecological or human-induced process is by nature “territorial”, since it takes place at certain point on Earth and extends its influence over a specific a region (a municipality, a country, a catchment, a trans-boundary area, a continent or the whole world) which might in turn have internal spatial heterogeneity or differences.

The aims are to:

- improve understanding and prediction of extreme weather events;
- quantify impacts at continental, regional, and local levels;
- analyse adaptation and mitigation activities (i.e. strategies to prevent and reduce impacts and damages);
- integrate all aspects related to hazards’ response into wider strategies for sustainable development;

The adopted approach is based on two basic steps:

1. monitoring and understanding (includes risk analysis, damage assessment, etc.);
2. management and preparedness (include modelling and scenario preparation).

The first step entails the adoptions of methods for observation and analysis of the status of the risk over European areas subject to specific hazards driven by extreme weather events for the following core areas:

- forest policies in the EU and MS (Forest Focus);
- forest fires;
- floods, droughts and heat-waves;
- EU areas with increasing vulnerability to natural hazards due to anthropogenic changes in the context of regional development.

It is important to note that the definition of 'hazards driven by extreme weather events' does not imply necessarily events happening in a short span of time. In the context of this note, extreme events are categorized in the following two typologies:

- large or medium scale persistent anomalies like heat-waves , drought periods , or
- "small" scale events such as heavy rain.

In turn, also the impacts of these events might be distributed along the time in various ways; for example, the modification induced in the plant phenology is the result of a long and constant increase in the temperature, although some consequences could be fairly abrupt (e.g. modification of land use and landscape with consequent hazard of mudslides).

The analysis of impacts from weather driven extreme events is centred around the concept of 'risk' which is defined as the resulting combination of hazard, exposure and vulnerability (Barredo, 2004; Kron, 2002).

More on definitions of risk, hazards, exposure and vulnerability and on the way in which risk maps are produced is given in Section 2.5.

The second phase concerns the actual integration of methods for the evaluation of mitigation strategies. It is based on an integrated modelling concept which serves firstly to assimilate and integrate the thematic information collected in the previous step and then to evaluate scenarios of future evolutions to manage and get prepared for extreme weather events.

In terms of measures to be considered, a wide range of temporal and spatial scales are dealt with, depending on the type of measure/issue. Measures can be 'structural', i.e. based on engineering infrastructures, or 'non-structural', i.e. based on institutional or non-infrastructural instruments. A not exhaustive list of examples of measures is presented in ***Table 1*** for the four hazards being dealt with in this note. As always the case, the highest efficiency is reached when the two typologies of measures are integrated (Petry, 2002 for flood prevention).

Table 1: Examples of measures to be considered for mitigation

<table>
<tr><th>Structural</th><th>Non Structural</th></tr>
<tr><td><u>Extensive</u>
– Reshaping of land surface
– Protection from erosion
– Forest practices
– Urban and construction works</td><td><u>Flood / Fire / Heat Defence</u>
– Forecasting; Warning; Alert
– Flood/Fire/Heat -proofing building
– Evacuation & Relocation</td></tr>
<tr><td rowspan="2"><u>Intensive</u>
– Levees, dikes, floodwalls
– Fire-breakers
– Dams and reservoirs
– Flood-ways and diversion works
– Polders, fills, Drainage works
– Green planning</td><td><u>Legislation & Regulation</u>
– Zoning, Coding
– Water and power management plans
– Health and education services</td></tr>
<tr><td><u>Insurance</u>
– Governmental, Private, Mixed</td></tr>
</table>

Measures and instruments can also be grouped according to their sectorial domain and to the time scale of application. A non-exclusive set of examples is show in ***Table 2***.

Table 2: Measures and instruments according to their sectorial domain and to the time scale of application

<table>
<tr><th>>10 years</th><th>5 years</th><th>1-2 years</th><th>3-30 days</th><th>Few hours</th></tr>
<tr><td></td><td></td><td></td><td></td><td>Alert</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Early Warning</td></tr>
<tr><td></td><td></td><td></td><td>Forecast</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Regulatory plans</td><td></td></tr>
<tr><td colspan="3">Spatial Planning</td><td></td><td></td></tr>
<tr><td colspan="2">Forest management</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Land Management</td><td></td></tr>
</table>

The integrated modelling framework, subject of research and development at the LMU, aims to evaluate the impact of adaptation measures by simulating their application in specific development contexts. This part of work is not the main subject of this report.

2.1 ACTIVITIES ON FLOOD

The activity on flood, prevention and mitigation is based on the hydrological model LISFLOOD (De Roo *et al*., 2000) adapted for scenario modelling, flood forecasting and flood plain inundation modelling.

The LISFLOOD model is a physically based hydrological rainfall-runoff model that is embedded in a dynamical GIS environment. LISFLOOD has been specifically developed as a flexible tool to simulate hydrological processes on a wide range of spatial and temporal scales. The spatial scales range from grid sizes of around 100 m for catchments of the size of a few hundred square kilometres, to 5,000 m for the whole of Europe.

Numerous outputs are available from the LISFLOOD and include soil moisture contents in each grid cell, predicted flow and stage hydrographs for any point on the drainage network, flood source areas and estimates of groundwater recharge. These outputs are used to compile EU flood maps of hazard.

The LISFLOOD model comprises the modelling of vegetation, soils, groundwater, snow cover, runoff generation, and stream routing in major European rivers. Basic pan-European datasets applied for modelling with LISFLOOD in various spatial resolutions include the European Soils Map and the CORINE land cover classification.

The LISFLOOD model is the core of the European Flood Alert System (EFAS, http://efas.jrc.it) which is also based on various static datasets, meteorological forecast data reception from the European Centre for Medium-Range Weather Forecast (ECMWF) and National Weather Services (e.g. DWD), and a suitable technical infrastructure to manage and process data and run the model several times daily for different forecasts. EFAS is currently operated in a pre-operational mode at the JRC and provides the following products:

- forecasted river discharges across Europe;
- early flood alerts between 3-8 days in advance;
- translation of meteorological forecast uncertainty into flood risk;
- a comparison of flood risk using different meteorological forecasts.

LISFLOOD is also being adopted to produce drought forecasts.

2.2 ACTIVITIES ON FOREST FIRE

The activities related to forest fires are divided in pre- and post- fire analysis. Pre-fire activities concentrate in the evaluation of forest fire risk through the so-called dynamic indices that take into account the climatic variability and the long-term fire risk indices that look at historical perspectives of fire frequency and burned areas. Post-fire activities are focusing on the mapping of burnt areas from satellite imagery and the follow-up of those areas affected by forest fires.

Hence, these specific activities comprise the following topics:

- Fire Risk Evaluation
- Burnt area mapping and forest fire damage assessment
- Post-fire risk analysis to evaluate burnt areas that may suffer further damage such as soil loss and landslides
- Evaluation of forest fire emission
- Follow-up of vegetation regeneration in burnt areas

The exposure to forest fire is evaluated at JRC by mean of ‘indicators of risks’.

The information is available at the European Forest Fire Information System (EFFIS) web-site (http://inforest.jrc.it/effis).

Yearly bulletins on the fire campaigns in each country and the overall UE are produced and available in internet (http://inforest.jrc.it/publications).

2.3 ACTIVITIES ON DROUGHT

Droughts have been recognized as a major natural hazard throughout Europe, and have created large damages to natural vegetation, agriculture, and society. The drought of 2003 in central Europe has been responsible for an estimated economic damage of more than 12 billion Euro (Munich Re, 2004). In 2005, in southern Portugal and Spain a new drought situation has developed that poses a already severe challenge to agriculture and might affect water supply to households and industry in the near future as well (European Parliament, 2005). Moreover, studies on regional climate change are predicting a considerably higher probability for the occurrence of drought situations throughout Europe during the next decades, as the climate moves towards increased air temperatures, a modified distribution of rainfall with dryer summers and wetter winters, and especially towards a higher variability with consequently higher chances of extreme climatic events (Meehl and Tebaldi, 2004; Schaer *et al*., 2004). Due to the increased need for consistent and timely information on droughts on the European scale, LMU is performing a feasibility study as to how far the current system for flood forecasting can be adapted for drought forecasting, detection, and monitoring.

Drought studies commonly focus on the disciplinary view to characteristics of this hazard, i.e. the perspectives of meteorological, hydrological, or agricultural droughts. However, only the comprehensive image of drought from all these perspectives together will allow for a thorough evaluation of a potential drought situation. This approach has been already followed successfully in the frame of the U.S. and the North American Drought Monitor (Svoboda *et al*., 2002).

While the existing datasets and infrastructure set up in the framework of EFAS are a good starting point, the LISFLOOD model has to be examined carefully as to how far the spatio-temporal characteristics of droughts in Europe can be addressed with.

While meteorological droughts can be addressed by various available meteorological data products on precipitation, hydrological drought is described usually by the analysis of stream-flow data. Here, after careful calibration, the hydrological model LISFLOOD might contribute to a forecasting of low flows by predicting discharge as it is already being doing for the prediction of flood events in major pan-European catchment areas.

Soil moisture drought and water stress of vegetation as the more general view of an agricultural drought are more difficult to address, as both phenomena show a high variability in space and time and are difficult to measure directly. Remote sensing data can help to characterise the state of vegetation and soil moisture content (e.g. Parde *et al*., 2003; Wigneron *et al*.,2003), but need additional information for calibration and validation especially for the latter parameter (Wagner *et al*. 1999). Here, the continuous modelling with LISFLOOD within EFAS can contribute to a comprehensive, spatially distributed image of the surface moisture distribution in Europe.

2.4 ACTIVITIES ON HEAT-WAVES

Amongst the data which are dealt with in the previously described activities, the meteorological ones are particularly significant. Their central position is not due to any specific meteorological scope of the actions, but because data such as temperature, precipitation, wind, humidity, etc. form the basis of many computational algorithms.

The covered range of ‘weather driven hazards’ is already quite wide, but still does not cover an aspect, which has been (unfortunately) much felt in Europe in the last couple of years. It is the temperature extreme referred to as ‘heat-wave’.

Heat-wave is the current subject of a focused feasibility study.

According to the common terminology defined in section 2.5, the following applies for the heat wave case:

a) Hazard

The heat-wave hazard is defined by meteorological indicators. The indicators linked most directly with meteorological data are based on temperature or a combination of temperature and humidity:

- *Temperature indicators*

  Use a single parameter and a threshold value to define conditions, e.g.

  - maximum day time temperature
  - minimum temperature at night
  - days of average temperature above threshold

- *Temperature & Humidity indicators*

  Combine the effects of temperature and relative humidity on the ability of the body to reduce internal temperature through evaporation from sweat. Specific formulas are adopted to compute these indices, e.g.

  - ‘Heat Index’ or ‘Apparent Temperature’
  - HUMIDEX

It is worth specifying that the study is not looking into the characteristics of the source data indicating the hazard as such (i.e. the temperature) and therefore will not engage in any specify meteorological study.

b) Exposure

Exposure is the measure of the values/humans that are present at the location involved. This is typically expressed by statistics on population, socio-economic data on sectorial activities and infrastructure. The feasibility will identify which are the effects most exposed to heat-waves.

c) Vulnerability

Vulnerability is the lack (or loss) of resistance to the extreme event. It is therefore the indication of the value of measures taken (or to be taken) to mitigate the effects of the extreme event. Examples of mitigation measure for heat-wave are:

- *Urban Planning*
  - Maintain or create green belts around urban areas.
  - Maintain or create inner-city parks and gardens.
- *Facilities and Infrastructure*
  - Increase nursing and elderly home beds.
  - Advance emergency health care services.
  - Install air-conditioning in bedrooms and improve building insulation.

2.5 ACTIVITIES ON INTEGRATED RISK ANALYSIS

The perception of risk is based on the evaluation of the likelihood of a hazardous event occurring, with an assessment of its impact. Keeping in due consideration the rapid changes of meteo-climatic conditions, vulnerability to natural hazards has also increased due to growing urban populations, spread of building activities in hazard-prone areas, environmental degradation, and neglect of threats posed by changing climate in planning, land management and preparedness activities. Environmental disasters in many cases are partially or completely induced and aggravated by incorrect human usage of natural resources (Dilley *et a*l., 2005).

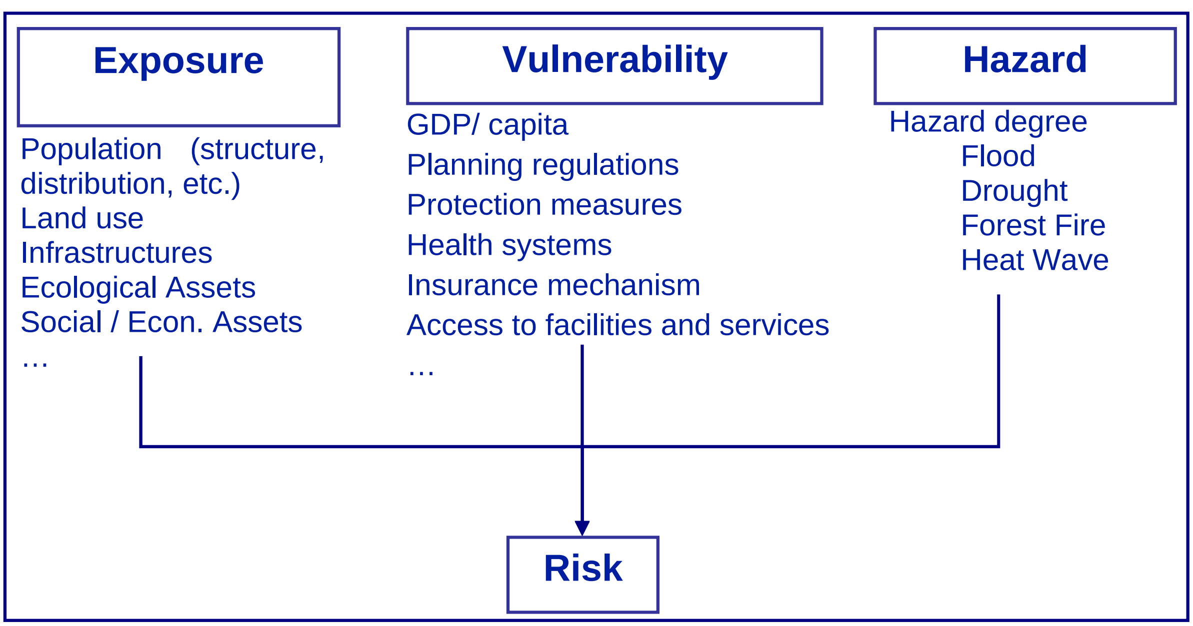
The first step towards the definition of a strategy for the prevention of natural disaster is the evaluation of the risk (Barredo, 2004).

Three components determine the “risk” i.e.: hazard, vulnerability and exposure (see ***Table 3***). The term “risk” has been defined in several ways in the natural hazard literature. In this report we use the definitions proposed by Kron (2002):

- Hazard: the threatening natural event including its probability/magnitude of occurrence;
- Exposure: the values/humans that are present at the location involved;
- Vulnerability: the lack (or loose) of resistance to damaging/destructive forces.

Hence, based on mathematical calculations, risk is the product of hazard, exposure and vulnerability.

Table 3: Components determining risk



Based on this definition, the risk may be decreased by reducing the size of any one or more of the three contributing variables - the hazard, the elements exposed and/or their vulnerability. The reduction of any one of the three factors to zero would consequently eliminate the risk.

The key feature in the proposed methodology is that exposure and vulnerability are specific for each type of hazard (Dilley *et al*., 2005), although we have to be aware that the term risk is understood in different ways by different people. For instance risk is understood differently in the fields of floods and forest fires (Barredo *et al*., 2005b). A further characteristic is that all three components can change over time. It is therefore possible to configure risk-scenarios by modifying the hazard (e.g. as consequence of climate change), the exposure (e.g. as result of regional development policies) and/or the vulnerability (e.g. as outcome of adaptation measures).

The three components that determine the risk have to be represented by using available geo-referenced datasets in order to be able to produce a risk layer. Spatial analysis techniques using GIS are probably the only way to deal with the huge volume of data necessary for the assessment of large regions. To this end, data availability has to be taken into account in order to achieve a realistic representation of risk and its three components (Barredo *et al*., 2005b).

Based on mathematical calculations including return period probabilities for each location risk can be seen as the product of hazard, exposure and vulnerability. However in practice this kind of analytical calculation for assessing risk are seldom possible, mostly in the case of very large study areas. This is because the available data is usually very thin (Kron, 2002). Instead simplified procedures are usually applied and a number of assumptions have to be made in order to produce, for instance, flood risk index maps (Barredo *et al*., 2005b).

Key inputs for risk analysis are the maps of hazards for flood, forest-fire, drought and heat-wave, generated as output of the activities previously described.

2.6 ACTIVITIES ON HAZARDS MITIGATION

The activity on hazards' mitigation is based on the merging of the LIFSLOOD model with the MOLAND (Lavalle *et al*., 2004) urban and regional growth model to evaluate spatial planning policies and measure for natural risks reduction.

Once the risk levels have been defined, the combination of the LISFLOOD and MOLAND modelling capabilities allows to suggest (or identify) both structural and non-structural nature to be implemented in the frame of spatial planning policies. In this context, the analysis of urban areas and their developments assume particular relevance because of their complex relationships with factors related to floods, such as increased water runoff and stream flashiness, loss of natural flood retardation and others. Inappropriate regional and urban planning can exacerbate the negative effects of extreme hydrological processes. On the other hand, good land management and planning practices, including appropriate land use and development control in flood-prone areas, represent suitable non-structural solutions to minimise flood damages. The overall effects of these measures in terms of both sustainable development and flood defence can be quantified with the proposed combined modelling approach.

Spatial planning and land management provide various tools to prevent natural hazards. The prevention of catastrophes in general is a consideration of spatial planning and land management on the regional and local level. Because of significant consequences of environmental disasters a more active role of planning and land management with proper integration of various public and private interests is necessary to support a sustainable settlement development and a sustainable land use.

The analysis of the interrelation between environmental catastrophes and regional development will enable to point out the strategies and instruments of spatial planning and land management to support the prevention hazards. The MOLAND land use prediction model allows the evaluation of alternative spatial planning and policy scenarios Based on these scenarios, and on the actual land use types at the start of the forecasting period, the model then predicts the likely future development of land use, for each year over the next ten/twenty-five years. In order to compare the alternative predicted land use maps produced by the model, in terms of the long-term sustainability of the input land use planning and management parameters, various indicators – including those describing landscape fragmentation – are computed and analysed. Predicted land use maps are therefore used as input for other models (e.g. LISFLOOD) and, vice versa, flood risk maps and burn areas maps are used to develop scenarios of land use for risk minimisation.

Results and examples for hazard mitigation are not presented in this report.

3 HAZARD AND RISK MAPS FOR FLOODS, DROUGHTS, FOREST FIRES AND HEAT WAVES

3.1 FLOODS

The products related to flood hazard and risk are so far the most advanced because of the level of maturity of the activity at the JRC.

Figure 1 shows the approach followed for the definition of the flood risk index (Barredo *et al*., 2005a).

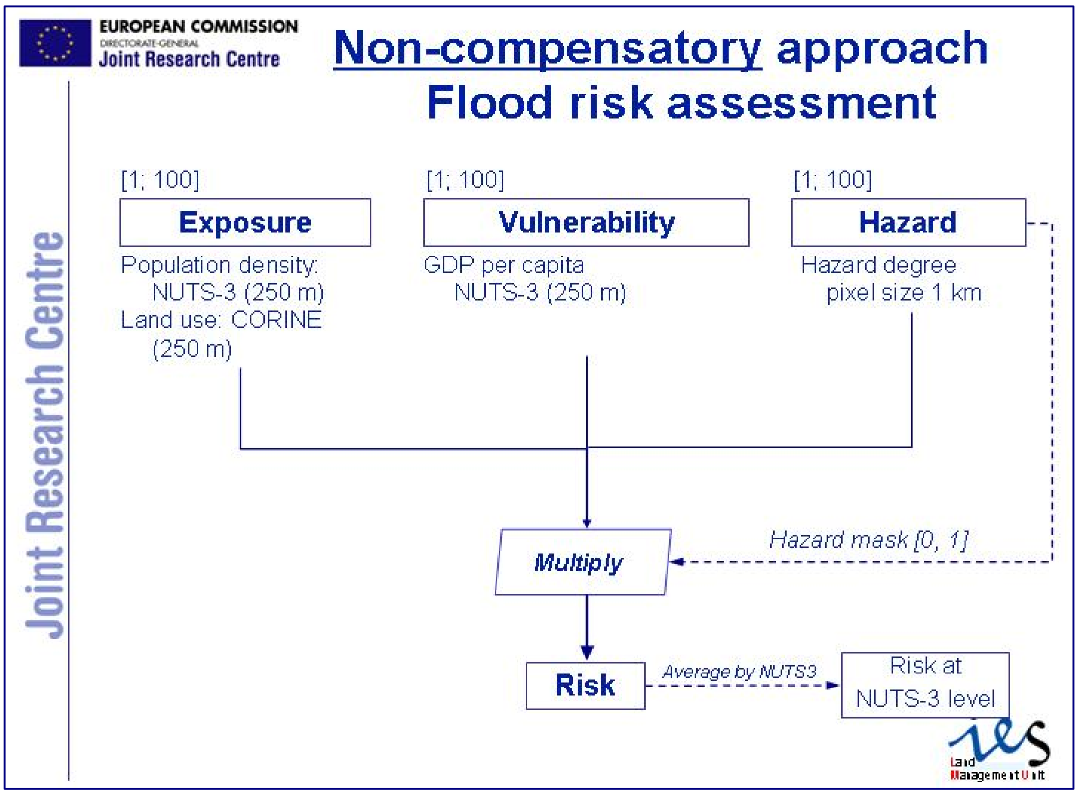


Figure 1. Flood risk assessment: methodological approach.

The hazard map (see Figure 2) used in this analysis is obtained using a 1 km grid digital elevation model and the 1 km European flow network developed at JRC (Barredo *et al*., 2005). An algorithm has been developed to find the elevation difference between a specific grid-cell and its closest neighbouring grid-cell containing a river, while respecting the catchment tree-structure: in this way a grid cell can never be linked to a river in another (sub)-catchment. For the moment extreme waterlevels have been estimated using a simple function based on upstream catchment size. Higher resolution DEMs (250 m and 90 m grid size) and calculation of extreme water levels using the LISFLOOD model are being currently implemented. More information about the LISFLOOD model can be found at http://natural-hazards.jrc.it/.

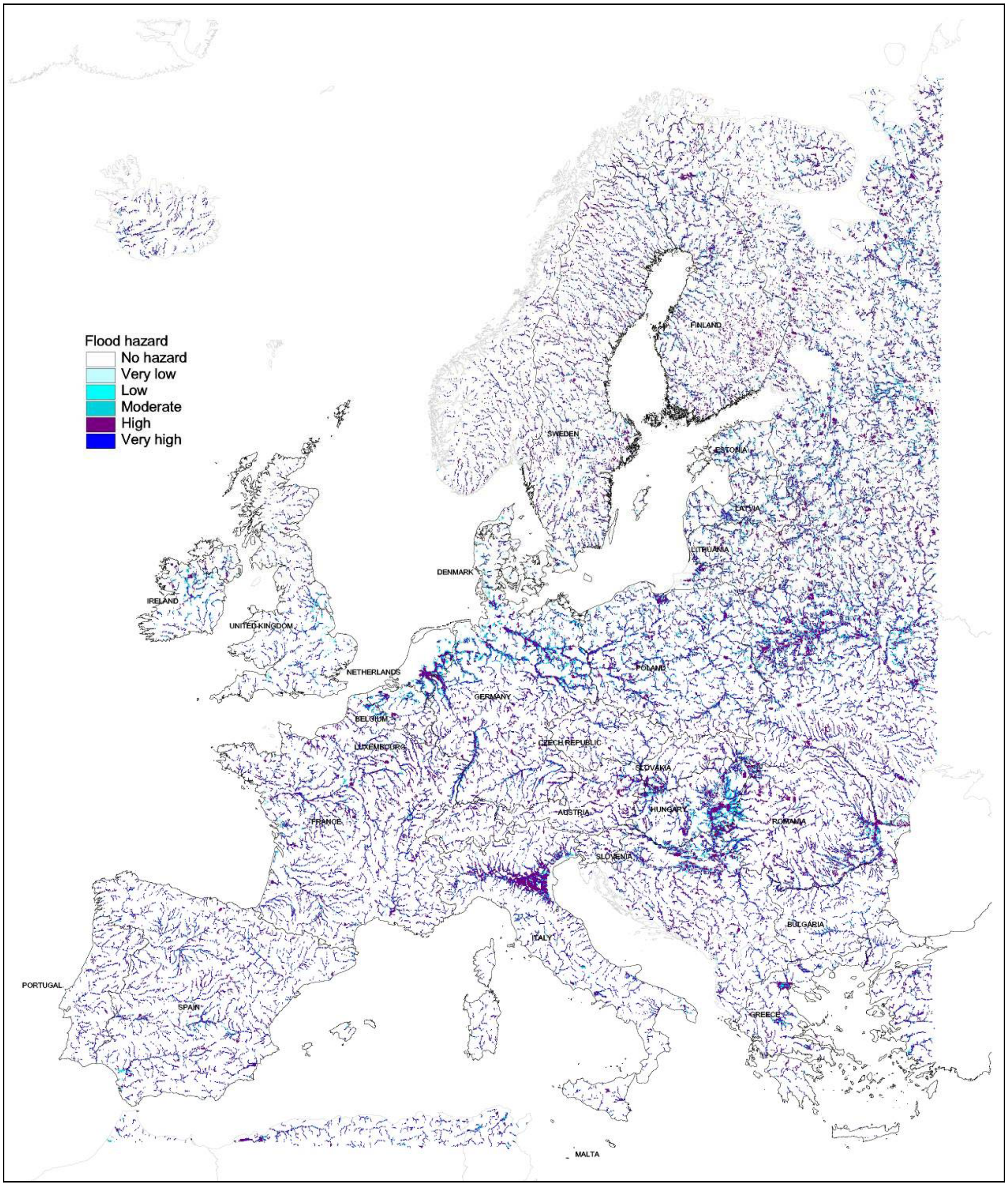


Figure 2: Flood hazard map

The exposure factor has been produced by merging the effect of population density and land use potential cost of damage due to a flood.

In the case of population the assumption is obvious. The number of people in danger is one of the basic indicators for flood exposure. On the other hand, the land use type serves for measuring the economic damage as result of a potential flood (including flood depth).

The land use potential damage due to floods has been produced by using the approach developed by Van der Sande (2001). In this approach each CORINE land use class is assessed on the basis of the monetary cost of several water depth scenarios.

Several assumptions have to be considered for this assessment:

- Damage is related only to water depth. However there are a number of other factors that contribute to increase damage e.g. water velocity, duration, sediment amount, etc.
- Price level of 1995, generalized for the whole of Europe
- Cars are not taken into account of the damage assessment.

The variability of average damage per land use class in CORINE is considerable. Moreover, important differences can be observed among MS.

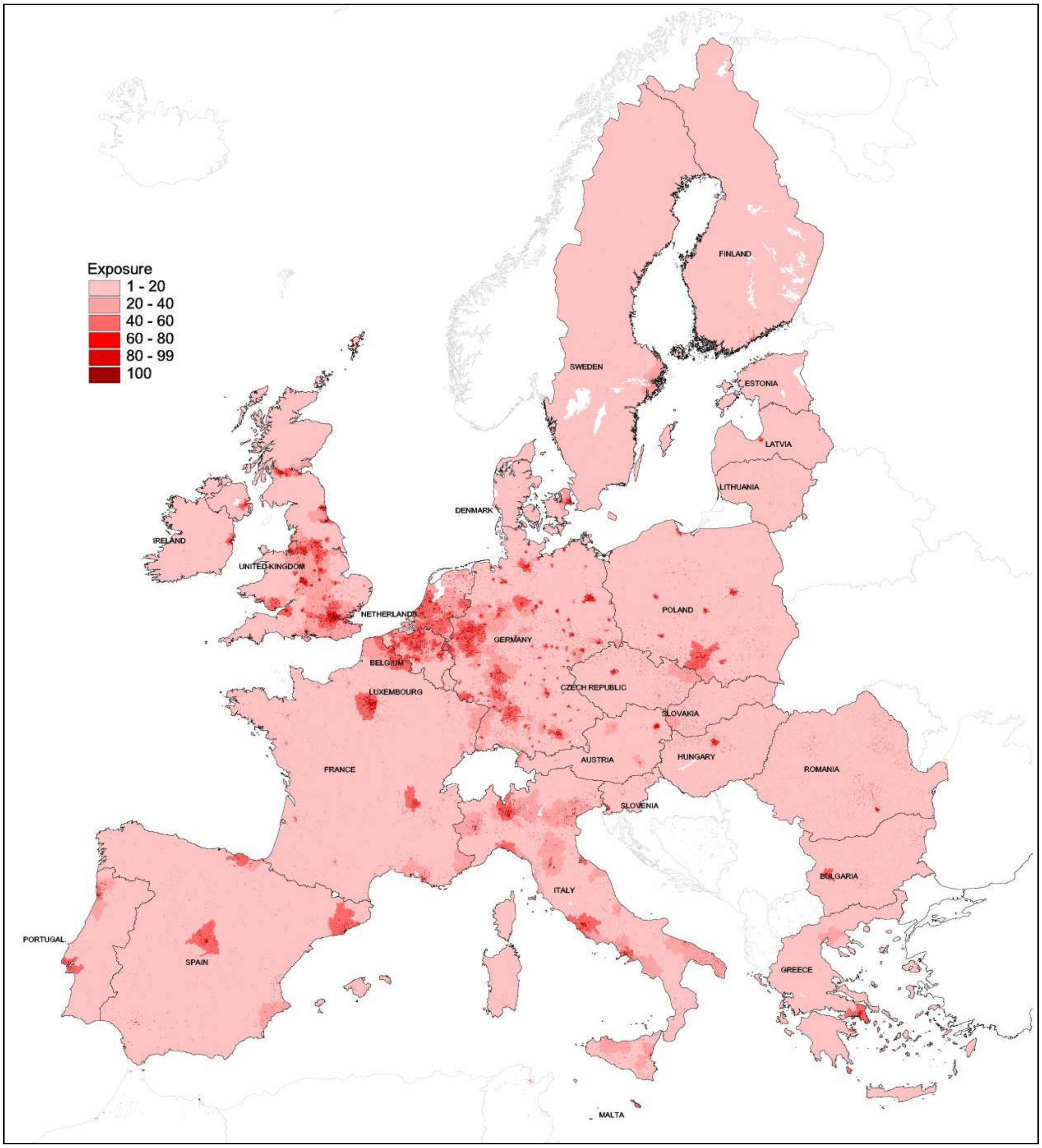


Figure 3: Exposure map

GDP per capita is so far the only proxy for vulnerability available for the whole EU + Bulgaria and Romania. A more detailed approach is foreseen to be used in the later on in the project. By using GDP per capita the assumption is that 'poorest' regions are worst prepared and are more 'vulnerable' to the effects of natural hazards. Moreover, natural hazards may even produce an increase in the gap between 'poor' and 'rich' regions.

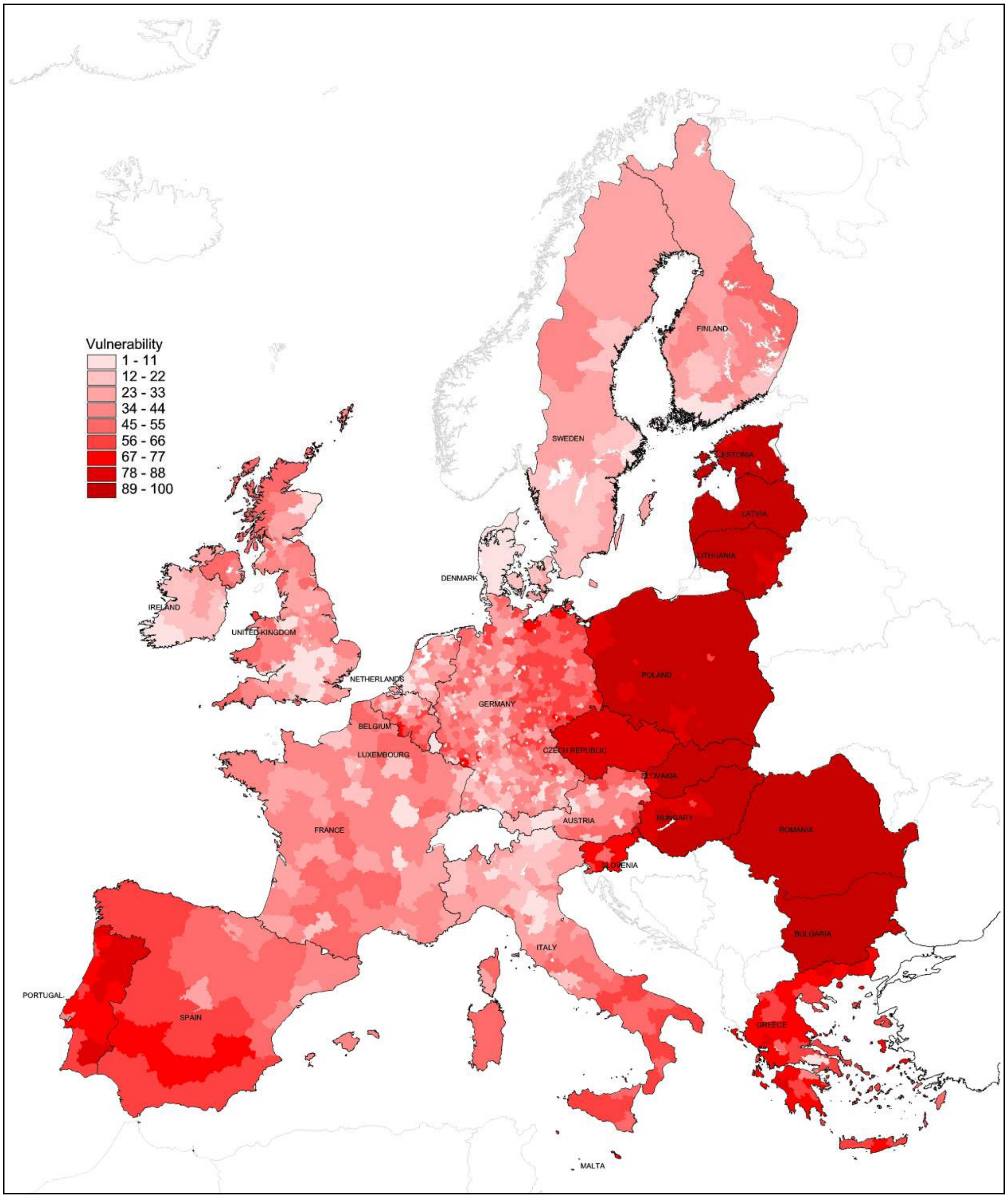


Figure 4: Vulnerability maps

In order to avoid 'artificial' weighting assignments among the input factors, a non-compensatory approach is used for the production of the standardised index map for flood risk (Barredo *et al*., 2005). Initially all input factors have been standardised in a range of 1 to 100. Being 1 the lower risk contribution and 100 the maximum. For GDP per capita and population density a linear standardisation with saturation is used. A saturation of 5% is used in both layers in order to avoid the effect of extreme values (low and high). The hazard factor has been standardised with a linear function considering its more homogenous histogram.

The integration of the standardised factors is done by simple multiplication of the corresponding input layers. In addition a risk-no risk mask layer has been included as well in order to define risk areas in only those pixels in which hazard > 0 is reported.

An experiment carried out by using a compensatory method (the weighted linear sum, WLS) showed results not so much in line with 'reality' (high overestimation of risk). The non-compensatory method gives more realistic results, in line with the original hazard values and historical records of past floods.

The products so far obtained are:

1) A flood risk model layer: Standardised index map for flood risk (spatial resolution 1 km). This layer show on each pixel (pixel size: 250 m with a spatial resolution of 1 Km) an index for flood risk. The layer can be classified on several risk levels, from very low to very high, as a function of the risk values (see Figure 5).

2) Flood risk layer by NUTS3: Risk assessment for NUTS3 areas. This layer shows the average value of risk for each NUTS3 area. As in the previous case it can be classified on several risk levels, from very low to very high, as a function of the average risk values (see Figure 6).

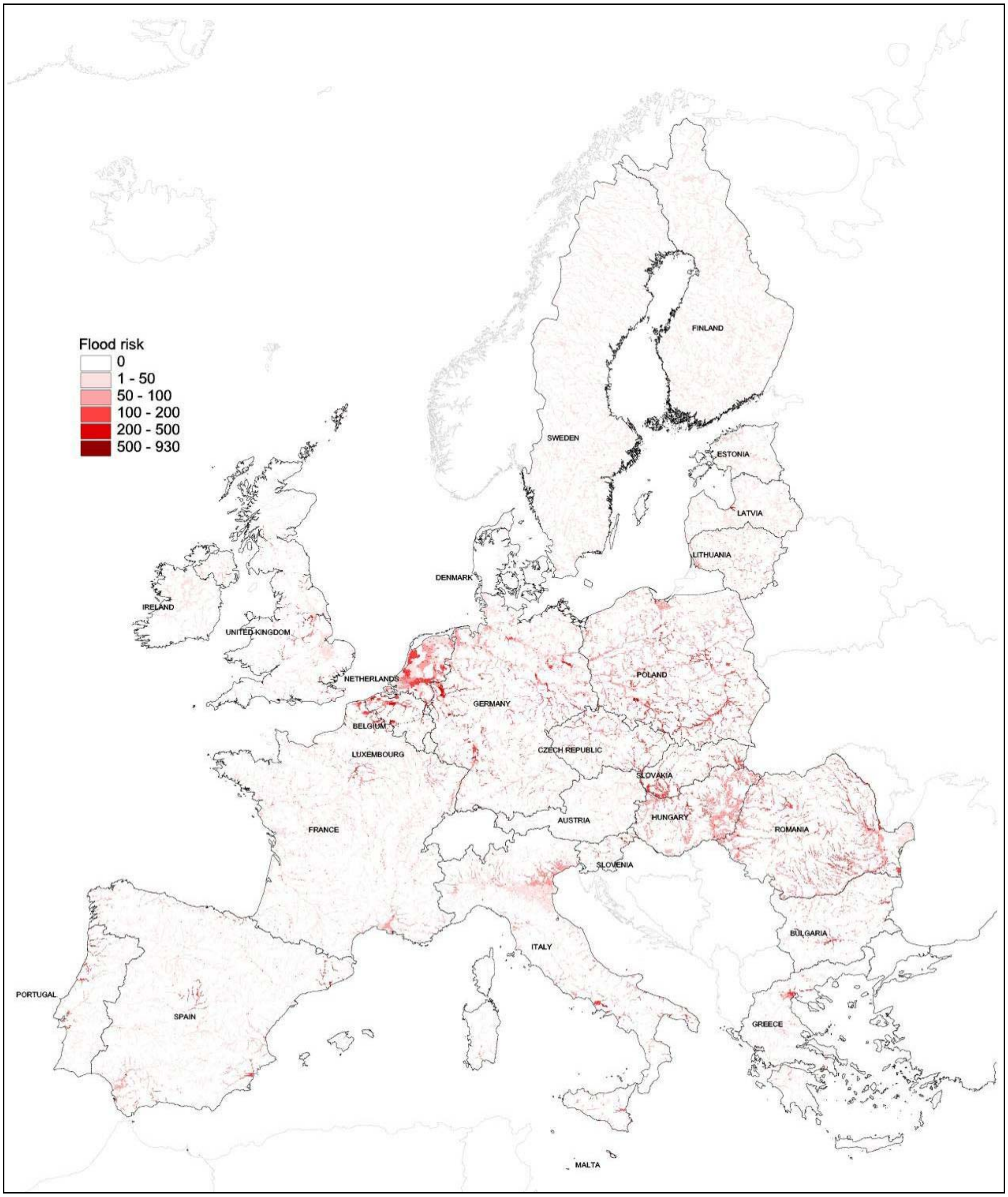


Figure 5: Risk map for flood

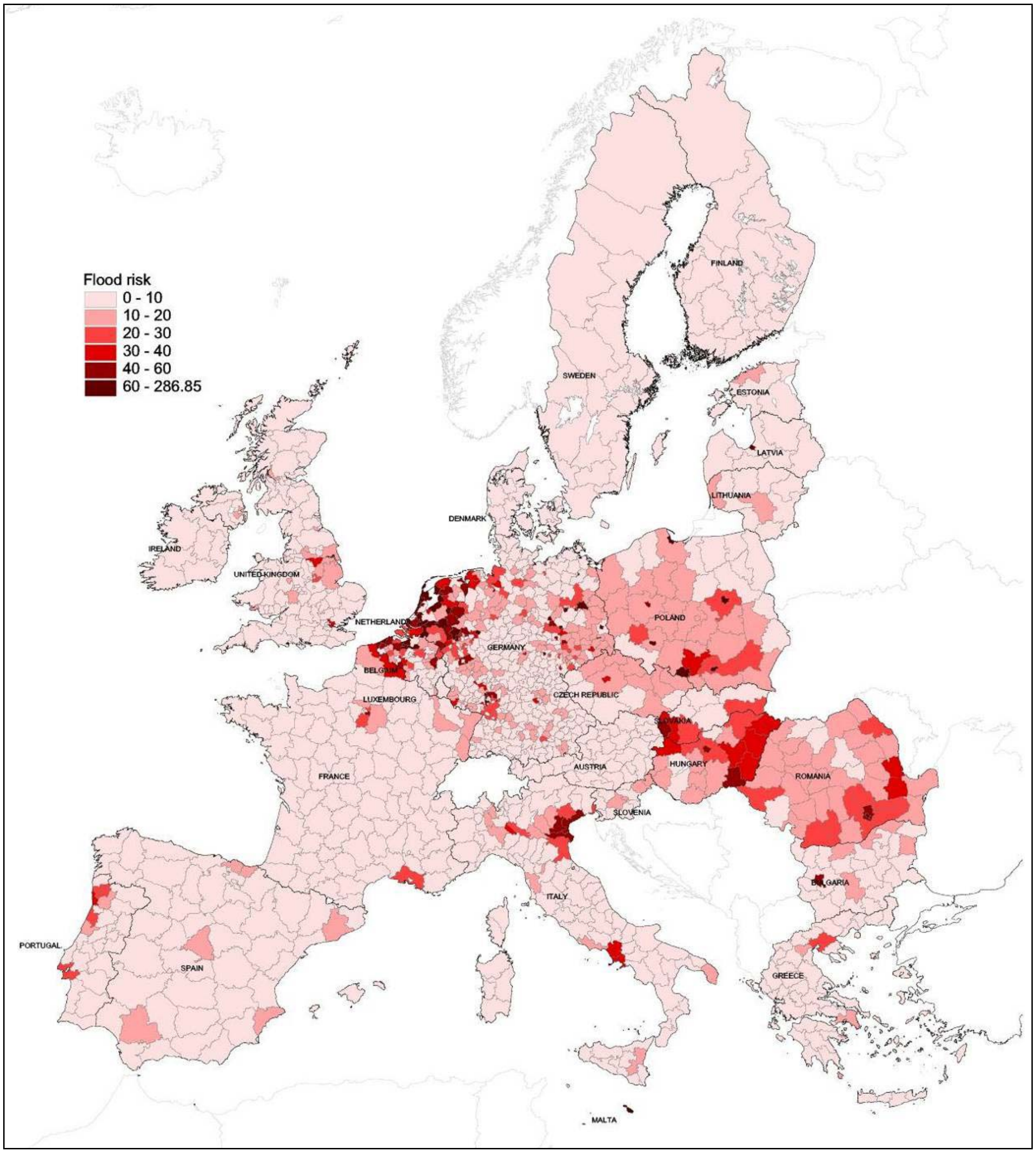


Figure 6: Risk maps – NUTS3 aggregation

3.1.1 Exposure to flood hazard: an example of multilevel historical analysis

In this section we illustrate an application of the European flood hazard map, with the aim of evaluating the exposure to flood risk in the whole European area and in the Elbe catchment.

The analysis is based on the use of the European database Corine Land Cover for 1990 and 2000 and the hydrological hazard map described in the previous section.

The results of the study demonstrate the efficiency of the combined use of the two databases in order to evaluate the exposure to floods and assess the environmental risk.

3.1.2 Analysis at European Scale

Over the past century, Europe has become an increasingly urban society. The changes in land use associated with urban development affect flooding in many ways. Urbanization generally increases the size and frequency of floods and may expose communities to increasing flood hazards (C. P. Konrad, 2003).

In recent years, dramatic river flooding has occurred in several regions of Europe causing numerous causalities and the damage reached unprecedented proportions. Such examples of massive floods are the Meuse in 1993, the Rhine and Meuse in 1995 and 1996, the Morava and Oder in 1997, the Tisza between 1998 and 2001, the Po, Yorkshire and Midlands in 2000, the Danube, Elbe, Gard and Styre in 2002 (De Roo *et al*., 2003). The situation is still more worrying seeing that mostly the built-up areas continue to grow mainly in floods prone areas. This trend contributes to an unsustainable development pattern, and furthermore the exposure to natural hazards is increasing in large regions of Europe.

For this analysis the resolution of the flood hazard map was reduced to 250-metres pixel-size in order to make it comparable with the Corine Land Use. The database will be enlarged in the future: in the follow-up versions of the flood hazard map it is planned to use higher resolution DEMs (250 and 90 metres grid-size) (Barredo *et al*., 2005).

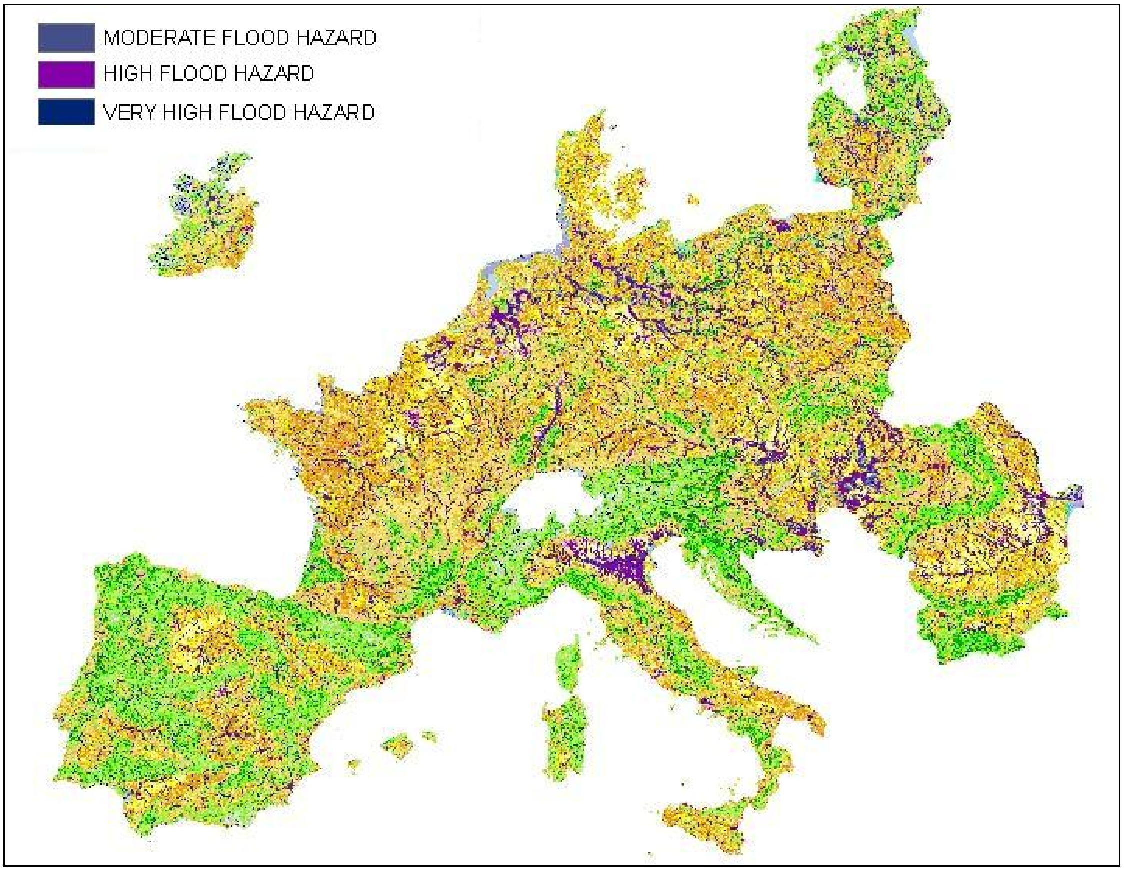


Figure 7: Overlay of Corine Land Cover 2000 and the European flood hazard map

With respect to Figure 7 it should be noted that in the CLC 1990 database some European countries were not included, so for this study these countries are not analysed.

The original hazard map legend contains seven classes:

1. Lakes;
2. Very low flood hazard;
3. Low flood hazard;
4. Moderate flood hazard;
5. High flood hazard;
6. Very high flood hazard

The analysis considers only the three most significant levels of risk: very high hazard, high hazard and moderate hazard. The historical land cover maps of Corine for 1990 and 2000 and the hydrological hazard map previously described were overlaid obtaining as a result the land use development in flood hazard prone areas.

The final total hazard area considered in the analysis is equal to more than 350,000 square kilometres, of which about nearly 30,000 are artificial surfaces.

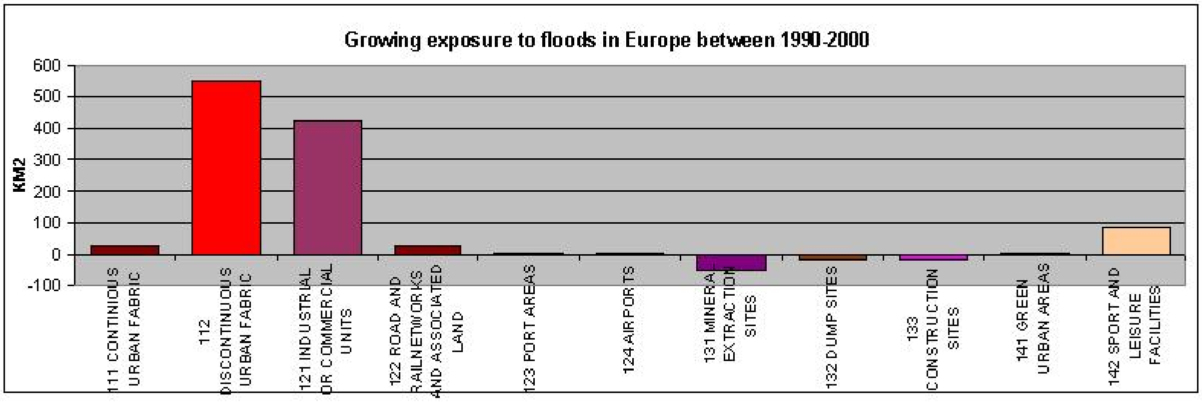


Figure 8: Artificial areas in Europe between 1990 and 2000

The chart in Figure 8 shows the increase of artificial surfaces development in Europe in flood prone areas. The first class we analysed is the residential, which includes continuous and discontinuous urban fabric.

Between 1990 and 2000 the "continuous urban fabric" land use in Europe rose by 27 km^2 and the "discontinuous urban fabric" by 552 km^2, equivalent to an increase of 3%. Also "sport and leisure facilities" class increased of 84 km^2. This confirms the initial statement on the increasing exposure to floods due to new artificial development.

The same trend is found for the "industrial and commercial units" class: this class rose by 11%, with a correspondence in square metres equal to 424 km^2 of industrial areas placed in flood hazard areas. Therefore, main developments occurred in areas potentially affected by flood are in this two classes and higher damage can be expected in those areas.

Otherwise, extraction, dump and construction sites were decreasing between 1990 and 2000. It's interesting to pay attention to the decrease of mineral extraction sites equal to 50 km^2 in 2000 (corresponding to -5% compared to 1990). These sites were replaced by urban, industrial or commercial areas, exactly where it would have been expedient to contain the growth of new urban areas because of the flood hazard.

3.1.2.1 Analysis in the Elbe River Catchment

The Elbe, 1,091km in length, forms one of the largest river systems in Europe. The Elbe River Basin (148,268 km^2) covers large parts of two central European countries, Czech Republic and Germany.

According to the territorial distribution of the river basin about two third of the catchment area belongs to Germany and one third to the Czech Republic. Austria and Poland have nearly the same small shares in the catchment. The basin covers different geographical regions from middle mountain ranges in the west and south to large flatlands and lowlands in the central, northern and eastern part of the basin.

The devastating flooding in August 2002 and the winter flooding 2002/2003 suddenly brought the Elbe region into the focus of public attention. These floods brought destruction and damage to large parts of the Elbe catchment[1].

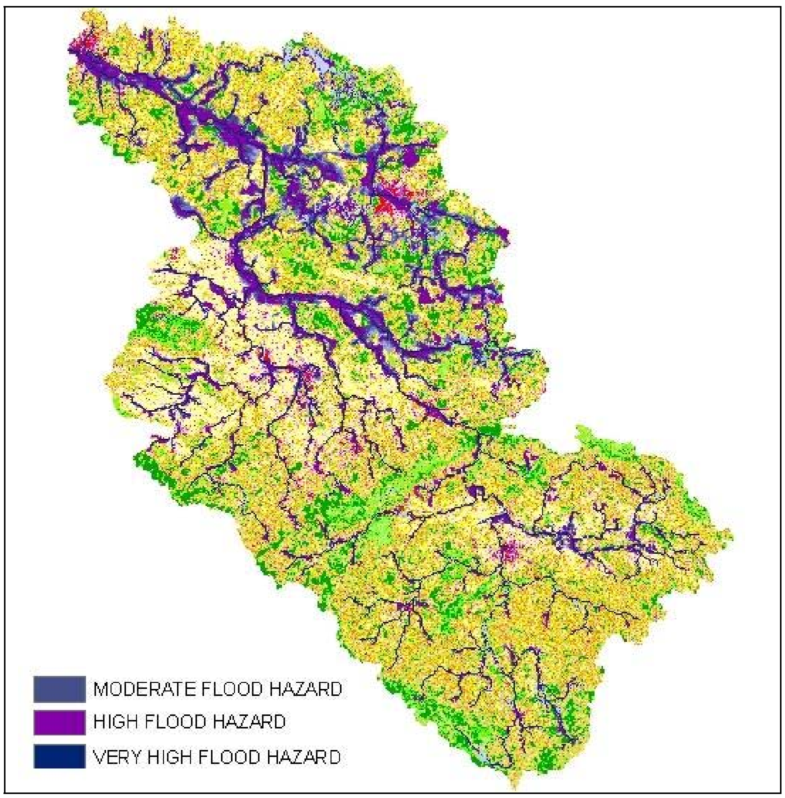


Figure 9: Overlay of Corine Land Cover 2000 and European hazard map in the Elbe catchment

The hazard area in Elbe catchment valued in the analysis is equal to more than 20,000 km^2, of which almost 2,600 are artificial.

[1] http://www.glowa.org/eng/elbe/elbe_overview.htm

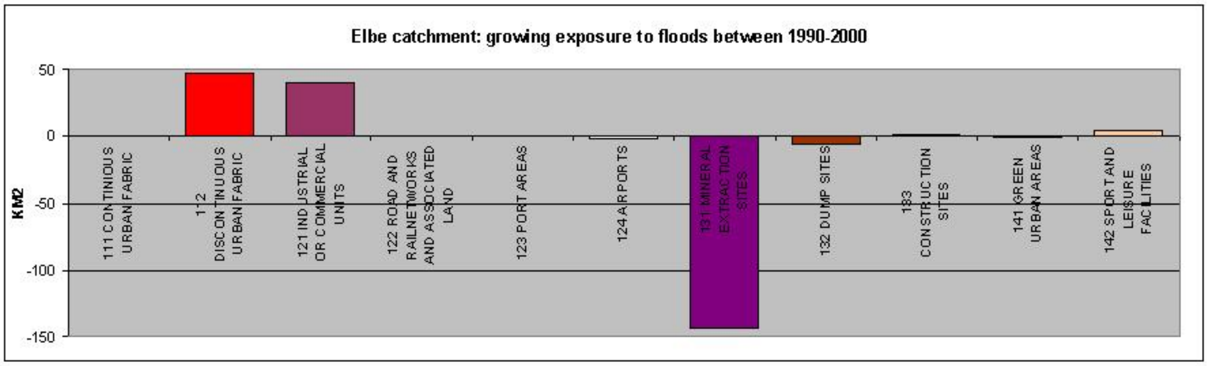


Figure 10: Artificial areas in Elbe catchment between 1990 and 2000.

As already observed for the European area, the main developments occurred in areas potentially affected by floods were in “discontinuous urban fabric” and “industrial and commercial units”. Between 1990 and 2000 the “discontinuous urban fabric” rose by 48 km^2, corresponding to an increase of 3%.

The same trend is seen for the “industrial and commercial units” class: in 2000 the class grew of more than 13% confronted with 1990, with a correspondence in square metres equal to 41 km^2 of industrial areas sited in flood hazard areas. This systematic trend of industrial and commercial development in flood hazard areas will lead to high damage expectations for businesses.

The loss of mineral extraction sites in the Elbe catchment is equal to 143 km^2 in 2000 (corresponding to almost -50% compared to 1990). This class is replaced with new residential, industrial and commercial structures in flood prone areas.

Exposure and, subsequently, risk rose in these zones: reduction of urban areas in hazard zone should be focus here.

3.2 DROUGHTS

Drought and water scarcity can be viewed from many aspects. Besides a lack of precipitation (meteorological drought) and a reduction in river discharge and water levels in lakes and reservoirs (hydrological drought), deficits in soil moisture give an integrative indication of a water stress situation at the land surface (soil moisture drought), as they combine the input and output of water by precipitation and runoff as well as the response of vegetation to a limited availability of water.

The European Potential Drought Hazard Map describes the likelihood of soil moisture deficits for 25 Member States of the European Union plus the two accession countries Romania and Bulgaria on the administrative NUTS-3 level.

Data were generated by model runs of the distributed hydrological model LISFLOOD that was driven by meteorological products of the ERA40 dataset of the European Centre for Medium-Range Weather Forecast (ECMWF).

ERA40 is a re-analysis of meteorological forecast data with most up-to-date assimilation techniques, resulting in a consistent global dataset of meteorological variables for the period 1958 – 2001. Daily ERA40 full-resolution surface analysis and surface forecast data have been extracted for Europe on roughly 90 km x 120 km, and subsequently re-projected and re-sampled and to a 5 km spatial resolution.

As the LISFLOOD model can also produce spatial information on the moisture content of the soil, its most current version was adapted and run with 44 years of ERA40 data in a daily time step.

The resulting daily maps of the volumetric soil moisture content have been converted to pF-values describing the soil water suction tension, i.e. the power a plant has to use in order to withdraw water from the soil. The higher the pF-value, the more difficult it becomes to take up water from the soil. With the soil moisture content expressed in pF-values the hydric state of different soil types can be compared throughout Europe.

The potential drought hazard map shows the number of days per year in which a threshold pF-value has been exceeded, averaged over 44 years of analysis, a longer period than a meteorological standard normal period of 30 years. It shows that south-eastern Spain, southern Portugal, southern Italy including Sardinia and Sicily, and southern Greece have been most strongly affected by soil moisture deficits in the past decades. Eastern Romania and Bulgaria as well as Hungary have also been susceptible to repeated soil moisture deficits. To a lesser extent, southern France and parts in south-east Great Britain experienced deficits, too.

The next step for the computation of risk maps for drought is the definition of main exposure for economic sectors and ecological assets. To the extent allowed by data availability also impact on quality of life and changes in lifestyles will be accounted for. Vulnerability maps will correspondingly be generated.

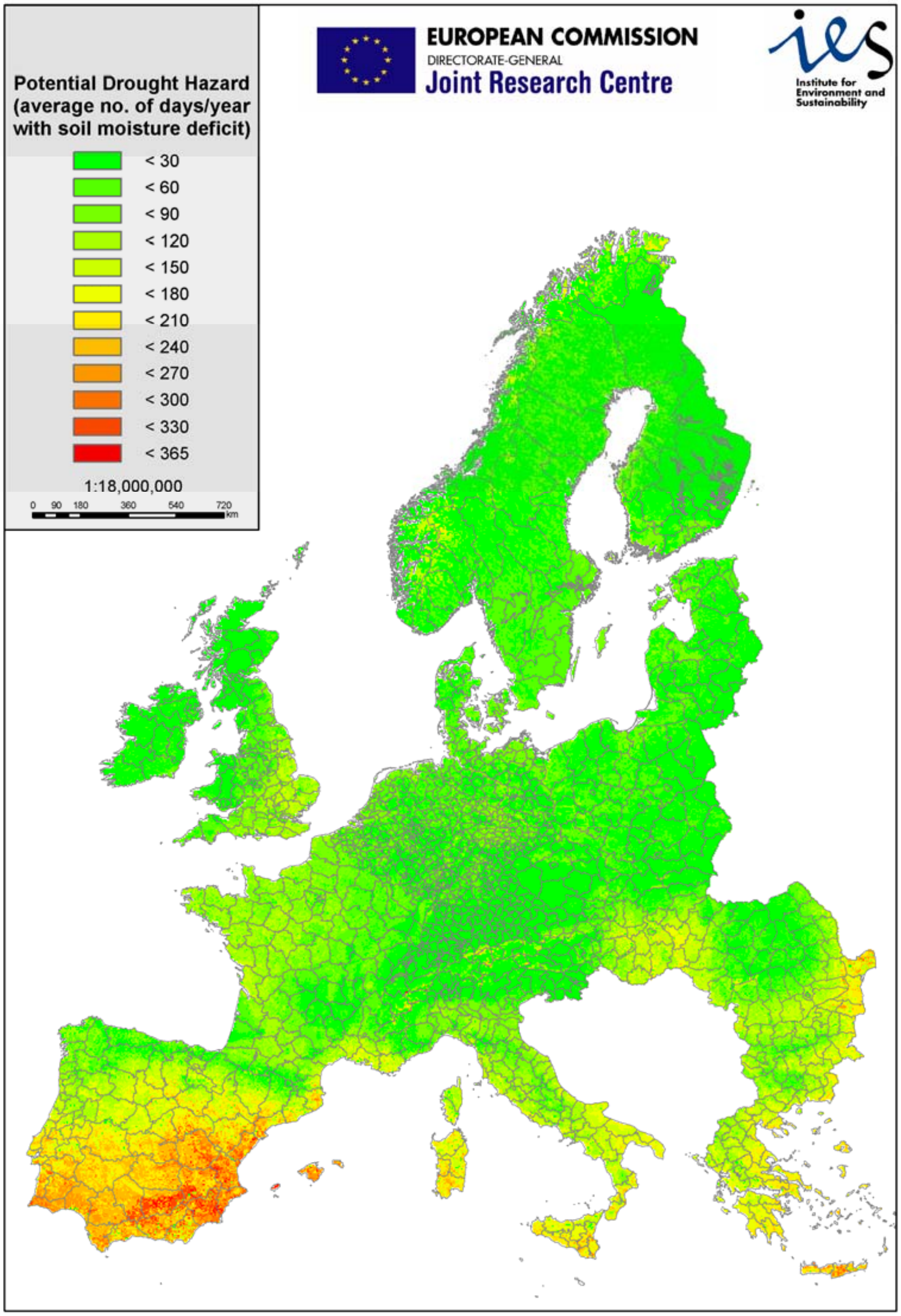


Figure 11: European Potential Drought Hazard Map

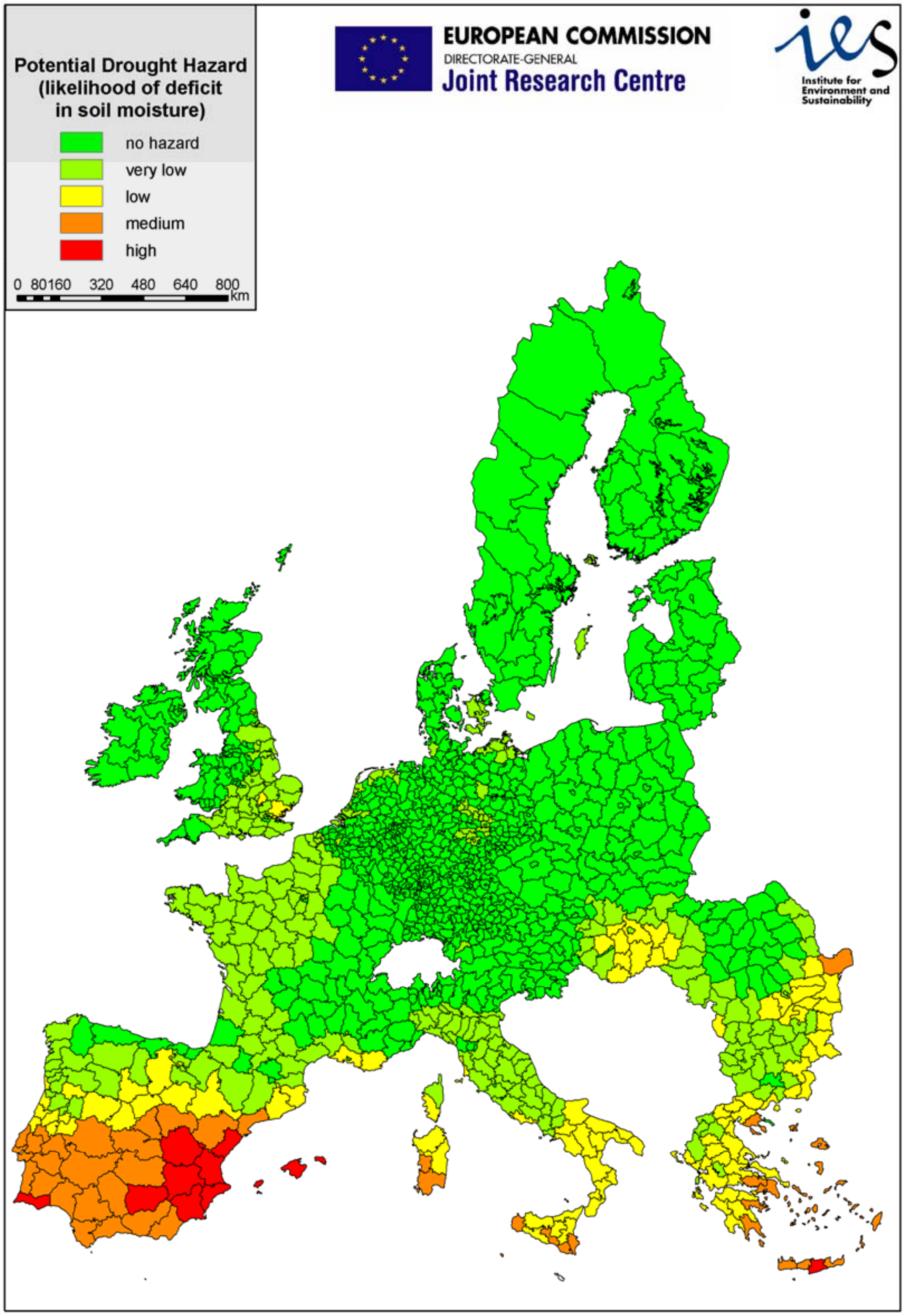


Figure 12: European Potential Drought Hazard Map – NUTS3 aggregation

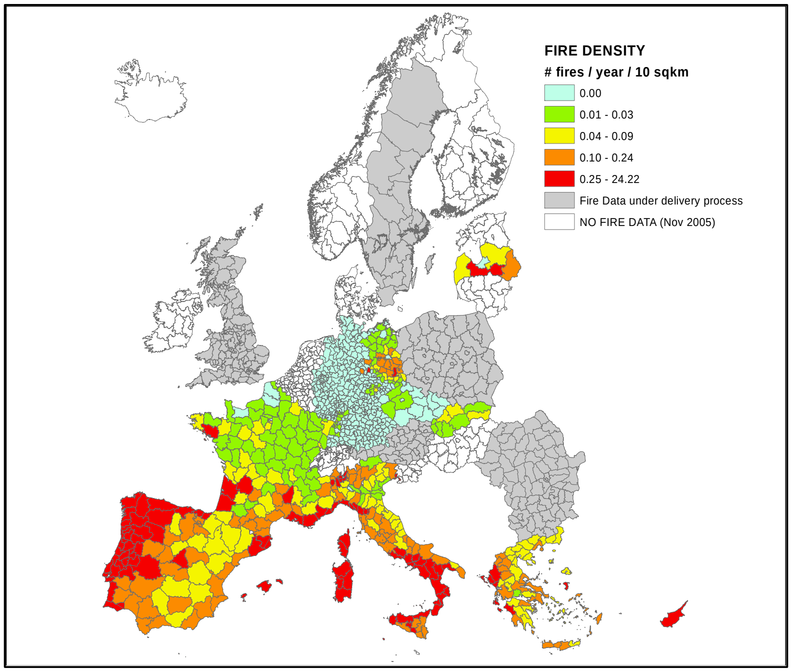
3.3 FOREST FIRES

In the forest fire domain there is not a generally agreed terminology on fire risk. According to the most widely accepted references fire risk is simply the potential for fire ignition, the chance of fire starting as determined by the presence and activity of causative agents (FAO, 1986; McPherson, Wade & Phillips, 1990). Nevertheless different approaches to forest fire risk assessment that take into account both probability and expected outcome of the undesired event have been recently proposed (Bachmann & Allgöwer, 1999; Chuvieco, Allgöwer & Salas, 2003). As mentioned previously, in the proposed approach a conceptual framework similar for the different natural hazards is addressed, therefore also for the fire risk component we will keep the proposed definitions framework (Kron, 2002).

The hazard component has been addressed so far in the study and it has been based upon historical fire records stored in the EU forest fire database of EFFIS, which is built with the data provided by Member States and managed by JRC. Additional GIS data layers processed are the administrative boundaries of GISCO and the CORINE 2000 database. The basic features of the map are constrained by available data at EU level, and predominantly by the spatial resolution of fire location data, which are not given as geographical coordinates but as administrative regions affected. Therefore the maps are based upon NUTS-3 level polygons, which are taken as geographical units described by specific fire hazard indicators.

The historical period considered for the analysis has been set to 10 years, which was taken as a reasonable compromise between catching a significant inter annual variability of weather conditions (for which a long period would be desirable), and getting a realistic picture of the current conditions (for which a period not too extended should be considered for homogeneity reasons). This is especially important for the socio-economical driving forces, continuously changing in time and so important for forest fires in Europe.

Two main indicators have been proposed so far, the fire density, i.e. fire frequency normalized upon time and space, and burned forest fraction, i.e. the forest burned area normalized upon time and forest land area. The two derived maps provide an estimate of the spatial distribution of fire hazard in EU and they currently cover 10 EU countries among the most prone to forest fires (Figure 13). These maps are still under development and new countries are going to be added in the near future, being the delivery of fire data to the EU fire database at JRC still an on going process.



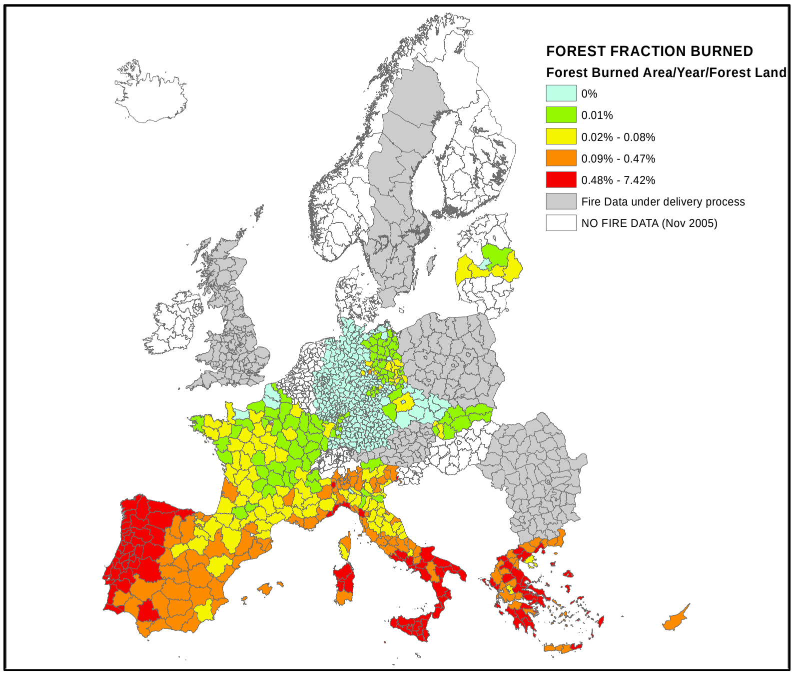


Figure 13: Maps of fire hazard indicators: fire density (top) and burned forest fraction (bottom) summarized at NUTS-3 level

3.4 HEAT WAVES

In the heat-wave case, the hazard is defined by particular meteorological conditions, based primarily on temperature. When appreciating of the effect of heat waves on living organisms temperature is combined with other meteorological parameters, as a minimum with relative humidity. Examples of specific indicators are:

- Temperature indicators:
  - maximum day time temperature;
  - minimum temperature at night;
  - days of average temperature above threshold;
  - accumulated temperature over a set period.

- Temperature and humidity indicators:
  - Heat Index (or Apparent Temperature);
  - HUMIDEX.

Using just temperature indicators the occurrence of a heat wave is generally defined by a threshold value, e.g. an average diurnal temperature exceeding 25 deg C. For combined indicators a more gradual approach is taken by defining ranges with increasing detrimental effects on the wellbeing, based on the ability of a body to reduce internal temperature through evaporation from perspiration. A HUMIDEX indicator exceeding 35 signifies strong discomfort and heavy physical activity should be reduced. The number of days when the HUMIDEX exceeded 35 for the summer of 2003 is given in Figure 14.

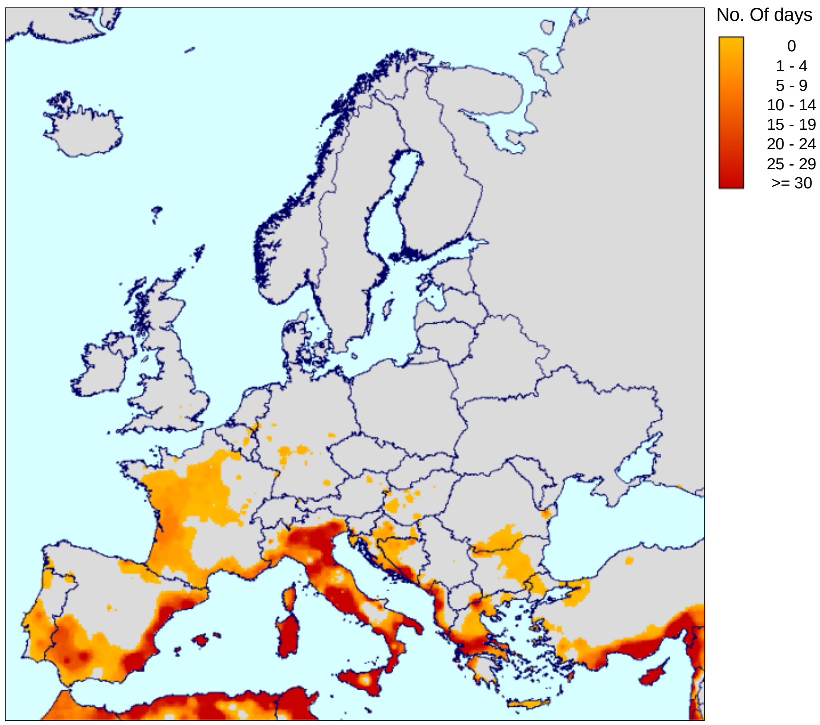


Figure 14: Heat wave extent 2003 computed as No. of days of HUMIDEX exceeding 35 during June, July and August

Exposure is the measure to which persons, infrastructures or other entities are subjected to the hazard at the location concerned. Typical indicators of exposure are the number of persons living or installations present in the area affected by the hazard.

Vulnerability is the lack (or loss) of resistance to the extreme event with the effect of causing harm. For persons vulnerability depends to a large degree on age. In particular persons 65 years or above are susceptible to suffer detrimental effects from excess heat. Infrastructures negatively affected by heat waves are for example power plants, which may have to reduce energy production as a consequence of a lack of water with sufficiently low temperature to cool the plants. Associated with a limited energy output is a direct economic loss of manufacturing industries.

Heat waves cannot be prevented from occurring. However, their effect can be mitigated by implementing suitable management strategies for urban planning and adapting facilities and infrastructures to direct effects from excessive temperatures and potential lack of energy.

A map on the risk of heat waves for European citizens is given in Figure 15. It depicts the exposure of the vulnerable age group of persons over 65 years to a heat wave indicated by a HUMIDEX exceeding 35 for the summer of 2003.

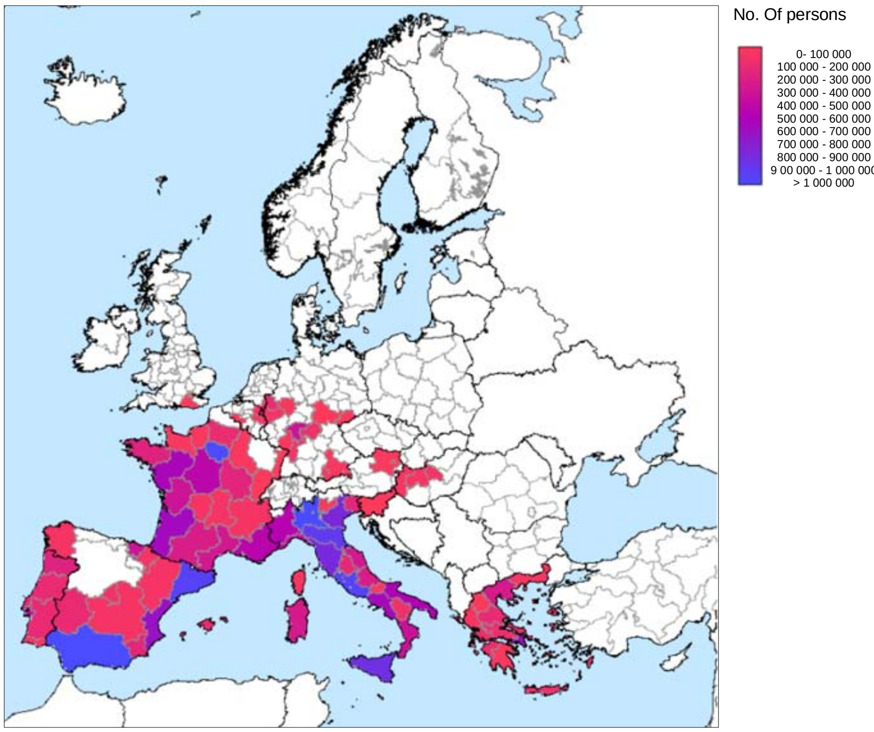


Figure 15: Heat wave risk map: No. of people over 65 years exposed to HUMIDEX exceeding 35 during June, July and August 2003

3.5 TOWARDS AN INTEGRATED MAP OF NATURAL RISKS

We define "multi- (or integrated) risk" as the combined risks from several natural hazards. This definition requires that the risks from multiple hazards be integrated into a unique representation. This does not necessarily mean that the risks should be "added," but rather that some analysis should be conducted to determine how the risks from the various hazards interact.

Different strategies can be followed to develop multi-risk/hazard mapping and assessment for large areas; however several questions still need to be answered to better understand the aim of multi-risk mapping (Barredo *et al*., 2005b). Firstly, purpose and expected recipient of the multi-risk assessments have to be defined. Usually the results of risk and multi-risk works are produced for policy and decision making, and to raise awareness in citizens and politicians. Thus the results of complex scientific work are often expected to reach a wide and diverse range of stakeholders. Therefore, the delivery of the results becomes a communication fact. While the evaluation of risk is based on scientific methods its communication depends also by the perception of risk of the receiver of the information (German Advisory Council on Global Change, 2000). Therefore the readability of complex scientific results for a wide range of players becomes a difficult task. In the case of multi-risk assessments for large areas the issue is even more challenging because of the different natural hazards with very different potential consequences for people and assets which have to be included in a unique framework.

There are two main approaches for multi-hazard/risk mapping (Barredo *et al*., 2005b).

The first one is more focused in communication. Thus more attention is given to the cartographic (visual) quality of the resulting maps. Examples of this communication-oriented approach are:

- Munich Re: World Map of Natural Hazards (Berz *et al*., 2001), and
- RMS (RMS, 2005): map of Catastrophic Risk in the United States, and the Latin American Natural Hazards Map.

The second approach is based in quantitative analysis-based mapping. Examples of this approach are:

- ESPON 1.3.1 (Schmidt-Thomé, Kallio, Jarva, Tarvainen, Greiving, Fleischhauer, Peltonen, Kumpulainen, Olfert, Bärring, Persson, Relvão & Batista, 2005), and
- Center for Hazards and Risk Research at Columbia University (Dilley *et al*., 2005).

Among the first precedents on multi risk/hazard assessment for large regions is the work produced by Munich Re in 1978 in its first World Map of Natural Disasters (Berz *et al*., 2001).

The aim of the work is to alleviate the need for documentation that concisely presents the type and magnitude of natural hazards as an aid to decision making. The third version of the map from 1998 was produced with the aid of GIS using techniques of digital cartography. The map includes six types of natural hazards for the whole globe. There are several advantages for this approach, among them one is that the map is both accessible and readily usable for stakeholders (Berz *et al*., 2001). The resulting map presents several types of natural hazards together with background information.

A similar approach to that presented above is used by Risk Management Solutions. Examples of multi-hazard/risk are the Catastrophic Risk Map of the United Sates and the Latin American Natural Hazards Map (RMS, 2005). Both maps cover large areas representing several natural hazards. The first map can be understood as the combined relative risk of the four most costly insured hazards. The second, the map for Latin America displays the risk associated with the main drivers of natural disasters: earthquakes and hurricanes. In this case risk is represented "as the average annual loss (AAL) to a representative unit of commercial exposure". Following this same communication-based approach, RMS produced a European Flood Risk map for urban areas across Europe. This map shows a relative index for flood risk for five flood types.

A rather different approach for multi hazard/risk mapping is followed in the works of ESPON 1.3.1 Project (Schmidt-Thomé *et al*., 2005) and the Center for Hazards and Risk Research at Columbia University (Dilley *et al*., 2005). The ESPON approach is based on the assessment of a number of natural and technological hazards for Europe. The results of this work can be summarised in the production of a multi-risk map at NUTS-3 level. The integration of the different hazards has been implemented by considering a unique vulnerability layer and an overall hazard layer. Thus, a multi-risk layer is the consequence of the integration of these two layers. This approach gives light in the geographical distribution of overall risk on the basis of a large number of assessments and analyses.

The work of Dilley *et al*. (2005) is a multi-risk assessment based on several natural hazards for the whole globe. Risk is calculated by assessing hazard, vulnerability and exposure. However, as in the previous study, the analysis is limited by issues of scale, availability and quality of historical data on the incidence of hazards. A number of risk maps are produced for specific hazards in addition to multi-risk maps for mortality and economic risk.

The overview presented here is not intended to be exhaustive, but it is a first step in the definition of a body of knowledge in the field of multi-risk assessment and mapping. A main result of this review is the constraint represented by the information available regarding hazard incidence for large areas. The accuracy/resolution (temporal, spatial) of such datasets limits the usefulness of the methods that can be employed for risk and multi-risk assessment for large areas.

The framework proposed in this report attempts to overcome weaknesses related to the definition and quantification of the hazards by employing validated models and data homogeneously generated across Europe. On the other side, the specificity of exposure and vulnerability allows to customise the final risk map according to a number of thematic applications (e.g. ecological assessment, property/assets loss, impact on population, etc.). The future efforts will be therefore dedicated to further improve the data processing chain and the overall presentation of the product.

4 CONCLUSIONS

This technical note has presented the status of progress of the activities related to the evaluation of the risks from weather driven extreme events. The overall framework aims to contribute to the evaluation of the European territory to depict its weaknesses and strengths. The need for information on natural risks as an aid to political and economic decision making is widely recognised (Berz *et al*., 2001). This defines a number of boundary conditions for the work to be performed.

Firstly, the geographical coverage must guarantee that the information is not only homogenous and comparable but also reliable (i.e. technical correct) all over the Continent. This is often a limitation for studies and projects dealing with the European dimension since historical data sets (which are most commonly used for study on weather and climate related events) might be incomplete or might not represent the complexity of a given situation. The work herein presented is based on the use of advanced modelling tools (e.g. LISFLOOD) for the simulation of extreme events and on data collected by the legally responsible institutions (e.g. the Member States for the forest fire database and National / European meteorological centres for meteo data) therefore reliability and coverage are guaranteed.

Secondly, the methodological approach must be able to relate the computed value (e.g. a specific risk indicator for a given area) to the observable causes (e.g. the intensity of the hazard and/or the value of the exposed assets) to understand issues and propose solution. The proposed analytical approach allows performing sectoral and thematic analysis, by selecting the typology of impacts to be observed in the various information layers produced during the processing.

Thirdly, and maybe most importantly, the methodology must allow performing long term strategic and perspective studies, to evaluate policy impacts and system (natural and anthropogenic) responses. Thanks to the sound modelling framework developed at the LMU, the definition of scenarios becomes an integrated component of the analysis.

Notwithstanding the progresses, still several steps need to be completed and improvements to be done. In short, the next phase of work will include:

- an increased resolution for the four hazard layers;
- the definition of key exposure and vulnerability elements for specific thematic sectors, such as the non-agriculture related impacts of drought;
- the analysis, based on macro-regions, of the European territory to quantify specific characteristics of each areas and identify ‘hot-spots’;
- the development of an interface with output of climate change models, by developing appropriate down-scaling methods.

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