

# Landslide susceptibility mapping at 1:1M scale over France: exploratory results with a heuristic model

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**ABSTRACT:** In the framework of the European Soil Thematic Strategy, a project to map landslide susceptibility at the scale of Europe (i.e. 1:1 Million) was suggested in 2007 by the European Soil Bureau Network (ESBN). The methodology consists to identify the potential areas subject to landslide types by expert knowledge using available thematic and environmental data. The choice of the 1:1 M scale allows the use of harmonized data sets for all Member States as input to the susceptibility model. Since a coherent landslide inventory map or geographical database does not exist at the European level, a pan-European landslide susceptibility map can only be prepared without inventory data, e.g. through heuristic modelling using European level landslide conditioning- and (optionally) triggering- data. In a first step, the performance of the susceptibility model is tested with some landslide inventory maps (density of landslides per administrative unit) available for France, Italy, Great Britain, Czech Republic and some Spanish regions. This work presents the susceptibility map created for France which quality is evaluated over six departments known for their numerous slope instabilities. This project is part of the European Expert Group on ‘*Guidelines for Mapping Areas at Risk of Landslides in Europe*’ coordinated by the JRC since October 2007.

## 1 INTRODUCTION

In the framework of the European Soil Thematic Strategy, and the associated preparation of a directive on the protection and sustainable use of soil, landslides were recognized as a soil threat requiring specific strategies for risk assessment and management. For instance, a Pan-European hazard map based on quantitative criteria is available for water erosion (Kirkby et al., 2003) or is being developed for soil compaction and soil organic matter decline. For landslide, the only Pan-European hazard map available is the one produced in 2005 within the ESPON Hazards Project based on national expert opinion of the European Geological Surveys. This map was constructed by asking some experts to mark the NUTS 3 level areas of their respective country or region that have the possibility of landslide hazards in general terms (Fig. 1). The process was based on available data and willingness of the national expert to participate, and thus the proposed map is very uncertain in some regions or/and misses some relevant information in other regions. Analysis of this map also pinpointed that the NUTS 3 level is too coarse to highlight landslide prone areas.

Consequently, the Soil Information Working Group (SIWG) of the European Soil Bureau Network (ESBN) proposed some criteria for harmonized risk area delineation which adopts a nested geographical approach based on ‘Tiers’ (Eckelmann et al., 2006) and exploit thematic data of different type, quality, and resolution using a variety of methodological and technological approaches (Hervàs et al., 2008; Fig. 2):

- The ‘Tier 1’ assessment is aimed at the general (i.e., synoptic) identification of areas potentially subject to landslides, providing a low-resolution (1:1 M scale) evaluation of landslide threats using existing thematic and environmental data.
- The ‘Tier 2’ assessment is intended to perform more detailed analyses in the areas identified by Tier 1, and should provide results at a higher spatial resolution using existing and new data currently not available in all European countries.

The objective of this work is to present preliminary results obtained for the creation of the landslide susceptibility map for France, which quality is evaluated over six departments known for their numerous slope instabilities. The aim is to pinpoint the limitations, data needs, practical selection of criteria (classes, parameter values) and adjustments to the

general methodology to carry out the global assessment at the European scale. The same preliminary analysis is currently performed in Germany, Italy, Hungary and Great Britain, as part of the European Expert Group on ‘Guidelines for Mapping Areas at Risk of Landslides in Europe’ coordinated by the JRC.

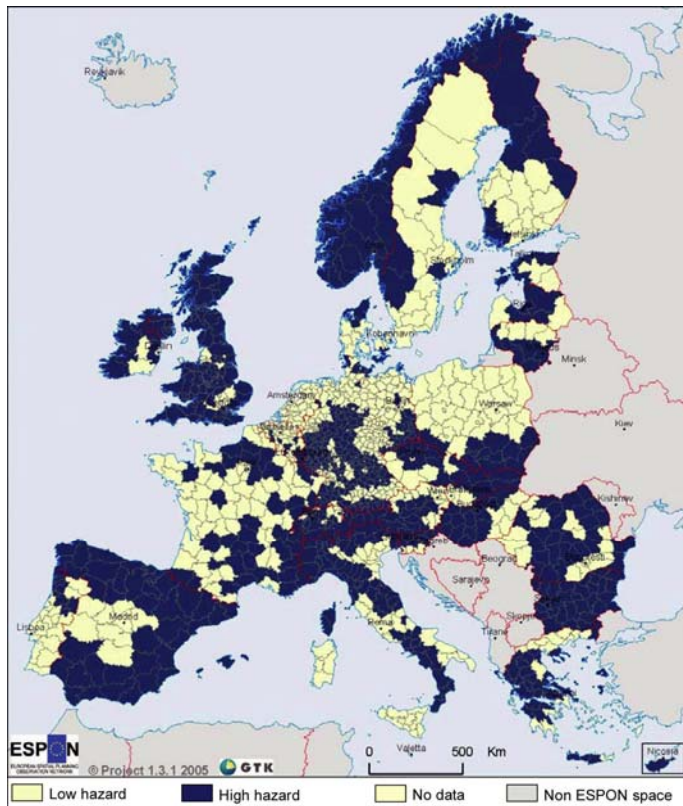


Figure 1. Areas with landslide hazards, based on national expert opinion of the European Geological Surveys. In order to keep the comparability of simply displaying the landslide hazard, probability and risk factors are excluded from the map.

## 2 METHODOLOGY FOR ‘TIER1’ ANALYSIS

The main requirement for a ‘Tier 1’ assessment of areas prone to generic landslide types is the free availability of relevant conditioning and triggering factor data. This could allow all Member State to use common data sets as input to the methodology to produce a harmonized landslide susceptibility map across Europe. Making a landslide hazard map for the whole Europe has been considered not feasible because of the frequent lack of historical records about the temporal occurrence of landslides in most countries.

Consequently, the methodology proposed by the JRC Landslide European Expert Group (Hervás et al., 2007) is to adopt a qualitative evaluation technique using a reduced set of data, including common information on the instability conditioning factors (e.g. soil/bedrock, slope angle and land cover). Adoption of an index-based evaluation method can allow the production of a continent-wide landslide susceptibility map for Europe, provided it is calibrated with representative landslide data (Fig. 2).

<b>• Tier 1 approach:</b> <b>Generic landslide susceptibility map using a heuristic weighting-rating model</b>	
Mapping unit: grid approach (pixel size of 90m)	Mapping scale: 1:1M
<b>Input data</b> - Slope angle (SRTM data, 90 x 90m) - Landcover (Corine Land cover) - Lithology and soil parent material (from 1:1M EuSoil database) Possible input data - Climate data, eg. rainfall totals (from 12x12km daily values of PRUDENCE) - European earthquake catalogue	
<b>• Tier 2 approach:</b> <b>Landslide susceptibility map (by types) using a multivariate statistical model</b>	
Mapping unit: municipality / catchment	Mapping scale: 1:250,000
<b>Input data (conditioning factors)</b> - Tier 1 data - Second order topographical attributes (from SRTM data, 90x90m or better if available) - Bedrock / Engineering soil database (including hydraulic & geotechnical properties) - European major discontinuity map, eg. faults - Soil moisture map - Daily climate data, eg. rainfalls totals (from 12x12km values of PRUDENCE) - Peak Ground Acceleration map, eg. PGA (from ESPON GSHA Project) <b>Input data (predicted variable): landslide occurrence (landslide inventory needed)</b>	
<b>• Possible Tier 3 approach:</b> <b>Landslide susceptibility/hazard map using a process-based model</b>	
Mapping unit: catchment	Mapping scale: 1:10,000
→ Focus only on the high-susceptible areas identified by Tier 2	

Figure 2. Proposed methodology and input data for the Pan-European landslide susceptibility assessment (Hervás et al., 2007).

## 3 APPLICATION TO FRANCE: METHOD

A tentative application of the methodology for France is presented in order to test the method and identify some possible limitations. For the France landslide susceptibility model, a minimum set of conditioning factors has been selected:

- (1) a slope gradient map, which is derived from the NASA SRTM (Shuttle Radar Topographic Mission) DEM acquired from X and C-band Interferometric Synthetic Aperture Radar (Reuter et al., 2007). The DEM has a resolution of 3 arc seconds (approx. 90 m); the horizontal accuracy is lower than  $\pm 20$  m for more than 90% of the DEM cells, and the vertical accuracy is  $\pm 16$  m in absolute elevation and  $\pm 6$  m in relative elevation. A slope gradient map has been computed and 13 classes (interval of  $5^\circ$ ) are used for the analysis.
- (2) a soil parent map, derived from the geological database of the French Geological Survey (BRGM) at 1:1M scale. The original map has been classified in 24 lithological classes, representative of the main geological units observed in terms of lithology, structure and age.
- (3) a landcover map, derived from the Corine Land Cover (CLC) dataset available for Europe. The database is obtained by combination of Landsat MSS and Spot XS imageries. An update with Landsat ETM+ imageries from 2000 has been performed in 2004. Each objects with an area larger than 25ha are represented. Level 1 (10 classes) of the CLS database is used in this work at 1:1M scale.

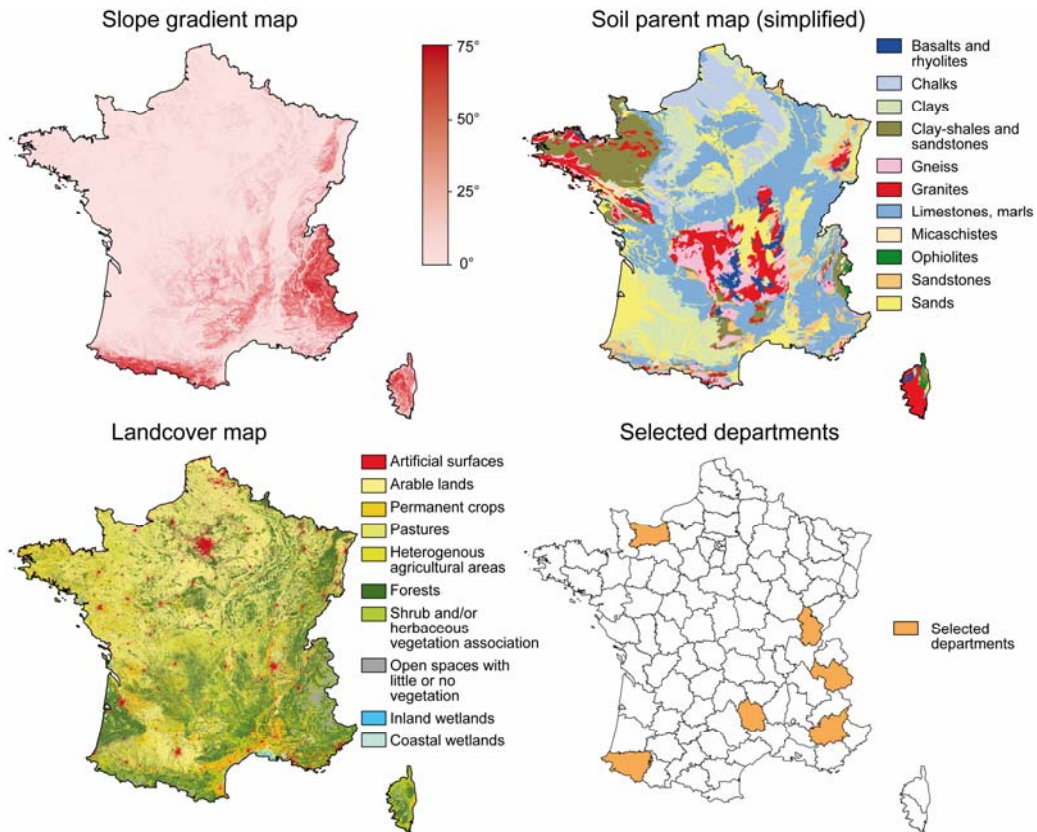


Figure 3. Thematic maps of the landslide conditioning factors used for the Tier 1 susceptibility analysis for France, and departments selected for testing the performance of the model.

First, the spatial and semantic consistency of all thematic data have been controlled, and second, the data have been rasterized to a grid-based mapping unit of 90 m corresponding to the resolution of the DTM. The thematic maps of the landslide conditioning factors at the France scale are presented on Figure 3.

The susceptibility analysis has been carried out with a spatial multi-criteria evaluation (SMCE) technique available in ILWIS®. The multi-criteria model is based on the decision support-system and an analytic hierarchy process (AHP). A tree-shaped structure is used in order to associate the thematic variables and weighting factors for each class of variables. The methodological framework of this work is detailed in Figure 4, and can be subdivided in six steps:

- (1) A distinction of the input data in two distinct areas, e.g. the plain and the mountain areas, in order to take into account differences in the topographical conditions favourable to slope. The criteria used to define the plain areas and the mountain areas are based on the European criteria proposed by Nordregio (2004).
- (2) A distinction between the different landslide types in order to take into account specific set of conditioning factors for each landslide type; the analysis has been carried out for four landslide types, eg. topples and rock-falls, collapses and subsidence, slides, and flows.
- (3) The calibration of weights for each class of variables according to the relationship between

the input data and the landslide types. The weights can be assigned by different approaches (directly by expert knowledge, or indirectly by pairwise comparison matrix and/or by ranking; Castellanos Abella & van Westen, 2008). For this research, we selected a direct weighting procedure. First, a value between 0 and 100 is assigned for each class of variable, and second the values are standardized by the maximum.

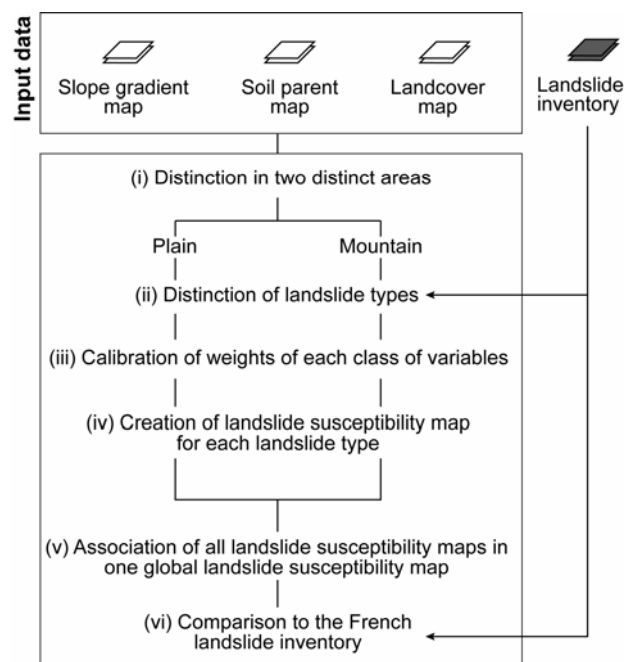


Figure 4. Methodological framework.

- (4) The creation of a landslide susceptibility map for each landslide type. For each simulation, the total weights are analyzed by expert judgement: the susceptibility classes are defined according to the thresholds observed on the cumulative curves presenting the total weights vs the cumulative area.
- (5) The creation of a unified landslide susceptibility map by combining the four susceptibility maps calculated at step (4). The susceptibility maps are merged, and for each cell, more importance is given to the higher susceptibility class identified previously and independently of the landslide type.
- (6) The comparison of the susceptibility map to the landslide inventory available for France (BDMvT). The BDMvT database (<http://www.bdmvt.net/>) has been created in 1994 and is developed by the French Geological Survey (BRGM) in collaboration with the 'Ministry of Ecology, Energy, Sustainable Development and Spatial Planning', the 'Ministry of Education and Research', the 'Laboratoire des Ponts et Chaussées' and the 'Service de Restauration des Terrains en Montagne'. It is an incomplete inventory of observed landslides. The landslide type, the location, the date, the activity, and sometimes the lithology affected are mentioned for each event. The BDMvT database is not exhaustive, and some uncertainties in terms of landslide type, date of occurrence and location are observed. The occurrences of landslide events have been mapped at the municipality level.

#### 4 APPLICATION TO FRANCE: RESULTS

In this preliminary work, the susceptibility analysis has been realized for six departments (NUTS 3 level), affected by several types of slope instabilities and characteristic of several topographical, lithological and landuse units of France. These departments are (Fig. 3): *Alpes-de Haute-Provence* (04), *Calvados* (14), *Jura* (39), *Lozère* (48), *Pyrénées-Atlantique* (64) and *Savoie* (73).

First, the weights for each class of variable have been defined with the help of descriptive statistics of landslide occurrences per conditioning variables. One major problem in this procedure was related to the uncertainty in the location of some landslide occurrences in the BDMvT database, for which only the municipality name is known. Therefore, a trial and error procedure was used in order to calibrate the weights in accordance with our expert opinion. Figure 5 shows the different weights used for the analysis, both for the plain and mountain areas and for all landslide types. The high weights attributed to the low slope gradient classes (0-5°, 5-10°; 10-15°)

in the plain areas are used in order to consider specific processes such as subsidence observed in flat areas, or falls, slide and flows observed along soft or hard rocks sea cliffs, as for instance in *Calvados*.

Second, Figure 6 shows the susceptibility maps obtained for the four landslide types for the department 'Savoie'. The maps use a binary scale and indicate the possibility of landslide occurrence or not. The possibility of landslide occurrence is considered for a final weight value >0.5 for each calculation cell. This threshold is conservative.

Slope gradient classes	Plain				Mountain			
	T&R-F	C&S	S	F	T&R-F	C&S	S	F
1. 0-5°	50	80	50	60	20	10	10	20
2. 5-10°	20	20	60	20	20	20	30	20
3. 10-15°	20	10	20	10	30	10	60	40
4. 15-20°	10	10	0	0	40	10	60	60
5. 20-25°	0	0	0	0	60	0	60	60
6. 25-30°	0	0	0	0	60	0	60	60
7. 30-35°	0	0	0	0	60	0	30	60
8. 35-40°	0	0	0	0	80	0	20	20
9. 40-45°	0	0	0	0	80	0	10	20
10. 45-50°	0	0	0	0	60	0	0	10
11. 50-55°	0	0	0	0	60	0	0	10
12. 55-60°	0	0	0	0	20	0	0	0
13. > 65°	0	0	0	0	20	0	0	0
Soil parent classes	T&R-F	C&S	S	F	T&R-F	C&S	S	F
1. Clays with flints	0	80	20	10	0	0	0	0
2. Marbles	0	0	0	0	0	0	0	0
3. Reef limestones	10	0	0	5	10	0	10	0
4. Marls and clays	10	5	30	10	40	5	60	60
5. Chalks	10	20	10	20	0	0	0	0
6. Sandstones and derivated	0	0	0	0	0	0	0	20
7. Clays, sands and gravel	10	0	10	10	10	20	20	30
8. Clay-shales and limestones	20	10	10	20	70	10	50	60
9. Clay-shales and micascshistes	10	5	10	5	40	20	40	50
10. Clay-shales	10	5	0	5	40	20	40	50
11. Dolomies	0	0	0	0	10	0	0	0
12. Sandstones	0	0	0	20	50	0	10	20
13. Calcshistes	10	0	10	0	70	0	10	0
14. Limestones and marls	40	20	20	40	90	30	50	50
15. Basalts, ophiolites	0	0	0	20	70	20	0	30
16. Marls and limestones	0	0	0	0	0	0	0	0
17. Marls, sands, and sandstones	20	20	80	20	70	20	60	70
18. Quartzites	10	0	0	0	50	0	0	20
19. Fine sands	10	0	0	0	20	0	0	10
20. Gravels and sands	10	20	10	0	20	0	10	10
21. Gabbros and dolerites	0	0	10	0	10	0	0	0
22. Gneiss	0	0	0	20	40	0	20	20
23. Periodites	0	0	0	0	10	0	0	0
Landcover classes	T&R-F	C&S	S	F	T&R-F	C&S	S	F
1. Artificial surfaces	10	10	10	10	10	10	10	10
2. Arable lands	10	30	20	30	10	0	10	0
3. Permanent crops	0	0	0	0	0	0	10	0
4. Pastures	10	60	80	10	10	10	20	10
5. Heterogenous agricultural areas	10	10	10	10	10	10	20	10
6. Forests	10	10	10	10	10	30	80	50
7. Shrub and/or herbaceous vegetation association	0	0	0	0	0	80	50	40
8. Open spaces with little or no vegetation	0	0	0	0	0	10	10	10
9. Inland wetlands	0	0	0	0	0	0	0	0
10. Coastal wetlands	0	0	0	0	0	0	0	0

Figure 5. Expert calibrated weights used in the analysis (T&RF: topple and rockfall; C&S: collapse and subsidence; S: slide; F: flow).

A unified landslide susceptibility map is then created by merging the single landslide susceptibility maps; more importance is given to the cells affected by the possibility of landslide occurrence. The unified susceptibility map for the six departments is detailed on Figure 7, and is compared to the landslide inventory map of the BDMvT database. This inventory map consists in a binary map representing the municipality where landslide occurrences have or not been inventoried.

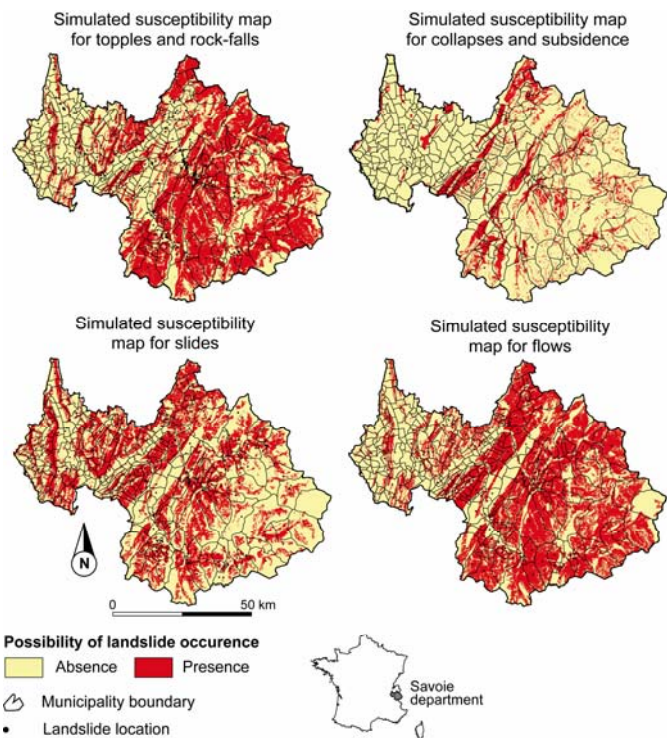


Figure 6. Landslide susceptibility map for the ‘Savoie’ department for the four landslide types.

Figure 7 indicates that 71% of the municipalities affected by landslides are well predicted by the simple heuristic model (global landslide susceptibility map). The predictive power of the model is very good for some departments, such as *Calvados*, *Lozère* and *Savoie*. For the departments *Alpes-de-Haute-Provence*, *Jura* and *Pyrénées-Atlantique*, the model is very conservative and highlights more possibilities of landslide occurrence than observed; this misfit may be explained by:

- (1) the incompleteness of the BDMvT database for some departments. This is particularly true for the department *Alpes-de-Haute-Provence* severely affected by all types of landslide due to the widespread outcrop of clay-shales (Maquaire et al., 2003), and where only 18 occurrences of landslide are inventoried in the landslide database.
- (2) the inappropriateness of some thematic classes for some departments because of the generalization of the classes of variables for the 1:1M scale analysis. This generalization does not allow to identify specific environmental conditions prone to landslide areas for some areas departments, such as for instance the department *Pyrénées Atlantique* where 13 municipalities (40%) are not predicted to be susceptible to landslides, as they have experienced slope instabilities in the past.

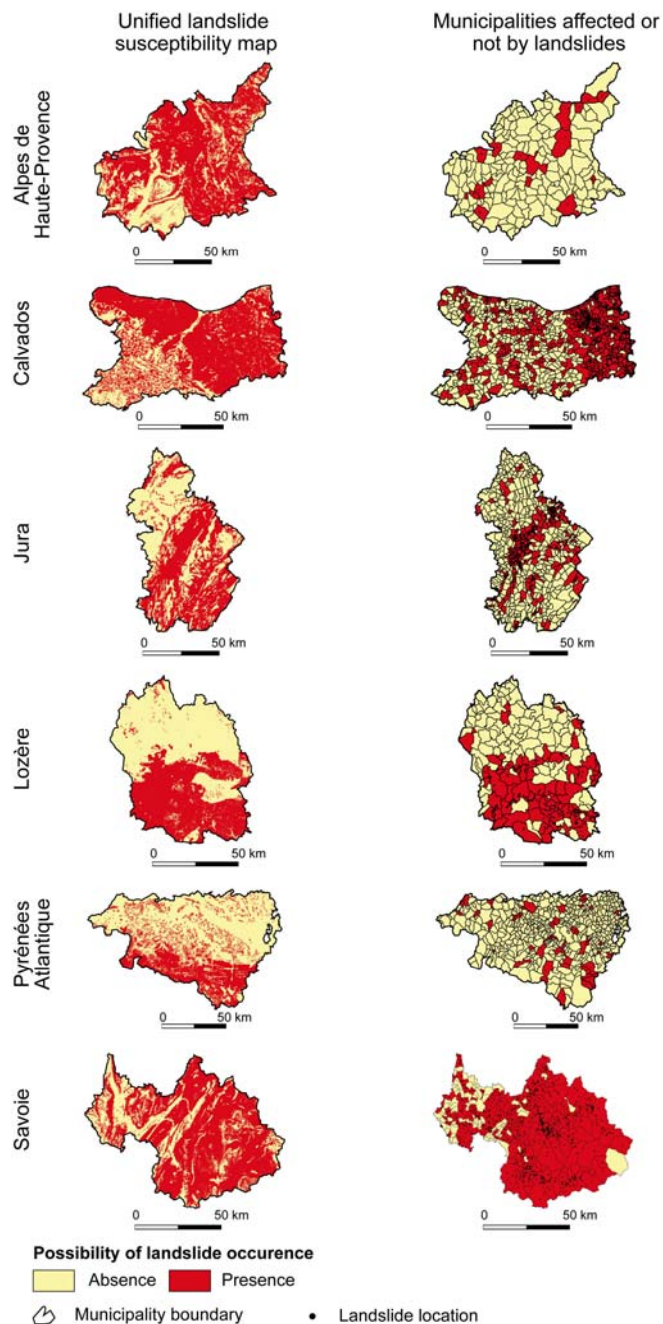


Figure 7. Unified landslide susceptibility maps and municipalities affected or not by landslides.

## 5 DISCUSSION AND CONCLUSION

This work is a first methodological attempt to model landslide susceptibility at 1:1M scale (Tier 1) for France, in the context of the future creation of a European-wide and harmonized landslide susceptibility map for generic landslide types. The method is based on the selection of a minimum set of landslide conditioning factors freely available at the European scale in order for all Member States to use common data sets. The objective of this map is mainly to highlight the areas prone to future landslide occurrence or reactivation. The methodology has consisted in dividing each thematic data into classes, to which a relative weight has been given. The weights have been calibrated according to an inventory of landslides occurrences available for France at the

municipality level. A heuristic qualitative spatial multi-criteria model is then applied on a grid mapping unit of 90m. As a first step, susceptibility maps in two classes (possibility of landslide occurrence / no possibility of landslide occurrence) are created for four landslide types over 6 French departments.

One of the main output of this research is that different weights for the conditioning factor classes should be used for differentiating the landslides types, and differentiating the landslides in plain and mountain areas. Attribution of the weight is a crucial point in this approach, and should be evaluated by expert organizations

## ACKNOWLEDGMENTS

This work is part of the European Expert Group on 'Guidelines for Mapping Areas at Risk of Landslides in Europe' coordinated by the JRC since October 2007. The authors thank the responsible of the BDMvT database at BRGM for the access to the data.

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