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EUR-OPA MAJOR HAZARDS AGREEMENT
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Kick-off meeting of the Project

"Pan-European and nation-wide landslide susceptibility assessment"

BGR, Berlin, Germany
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Spatial agreement of predicted patterns in landslide susceptibility maps

S. Sterlacchini[1], G. Bordogna[1] & C. Ballabio[2]

[1] National Research Council of Italy
Institute for the Dynamic of Environmental Processes
simone.sterlacchini@idpa.cnr.it

[2] Land Resources Management Unit H5
Institute for Environment & Sustainability (IES)
European Commission - DG JRC

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BGR (Federal Institute for Geosciences and Natural Resources)

JRC (European Commission, Joint Research Centre, Institute for Environment and Sustainability, Climate Risk Management Unit)

Contents

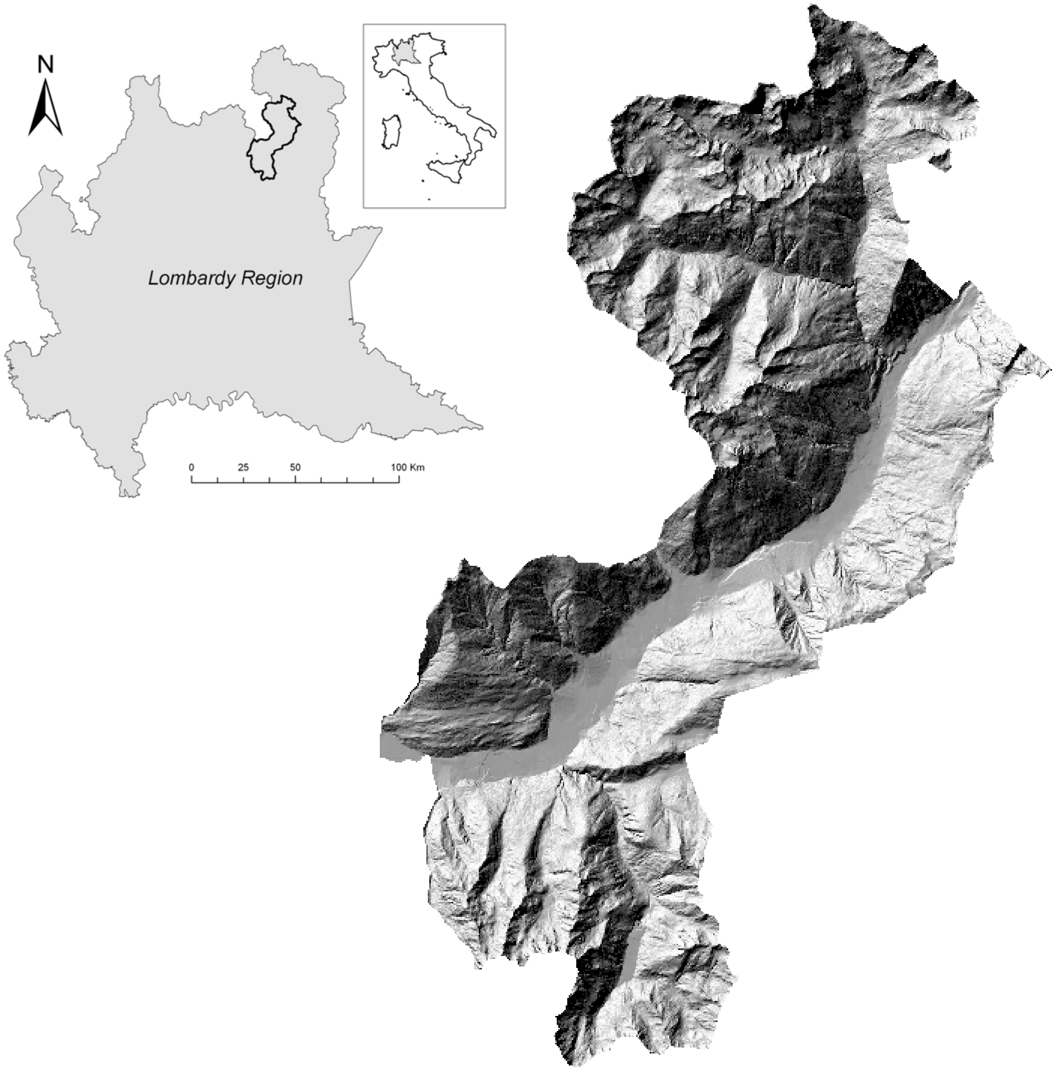
Introduction

The aim of the study is to assess the degree of spatial agreement of different predicted patterns in landslide susceptibility maps with almost similar success and prediction rate curves.

If two or more models have a similar performance, the choice of the best one is not a trivial operation and cannot be based on success and prediction rate curves only.

It may happen that two or more susceptibility maps with similar accuracy and predictive power do not have the same degree of agreement in terms of spatial predicted patterns.

Study Area



Municipality	Inhabitants
Aprica	1.631
Bianzone	1.236
Grosio	4.816
Grosotto	1.645
Lovero	643
Mazzo di Valtellina	1.066
Sernio	463
Teglio	4.714
Tirano	9.155
Tovo di S. Agata	580
Vervio	237
Villa di Tirano	2.959
Total	29.338

Study Area

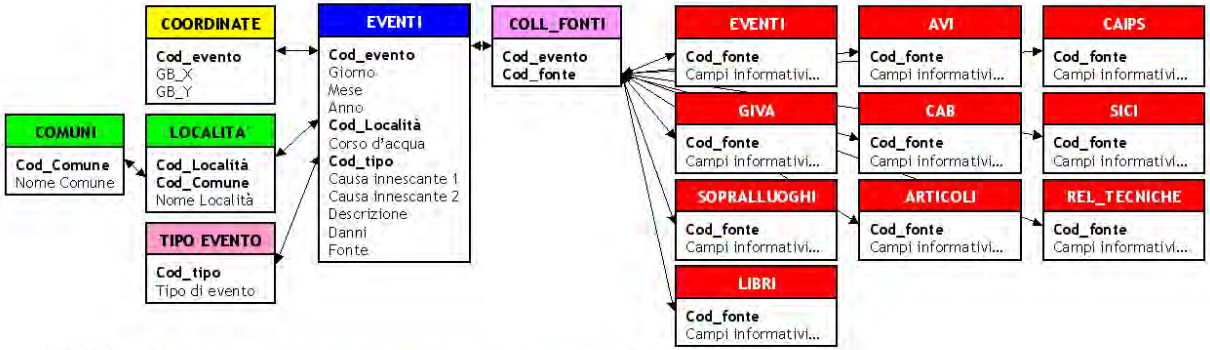
Valtellina has an unenviable history of intense and diffuse landslides. Landslides are among the most significant hazardous events in the area as well as one of the primary causes of casualties and economic losses. The most destructive landslide events, triggered by heavy rainfalls, were recorded during the months of:

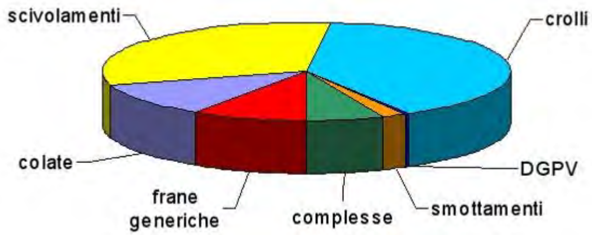
- May 1977, May 1983, May 1987,
- November 2000, November 2002, and July 2008

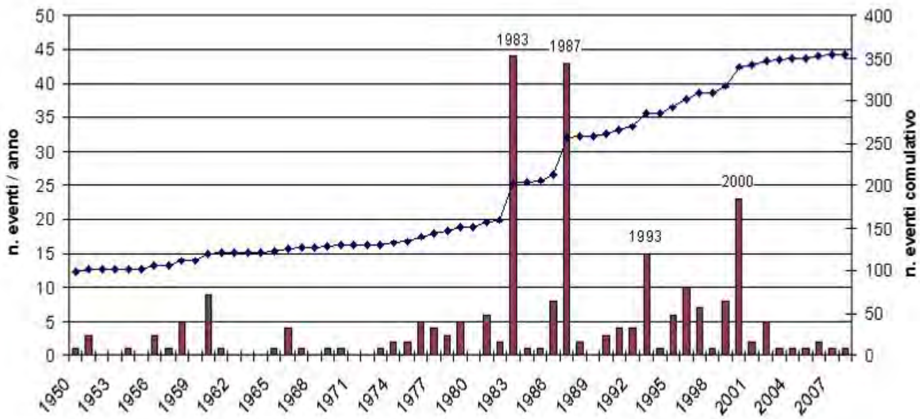
Field surveys allowed the mapping of shallow soil slips, slumps and debris flows affecting Quaternary covers.

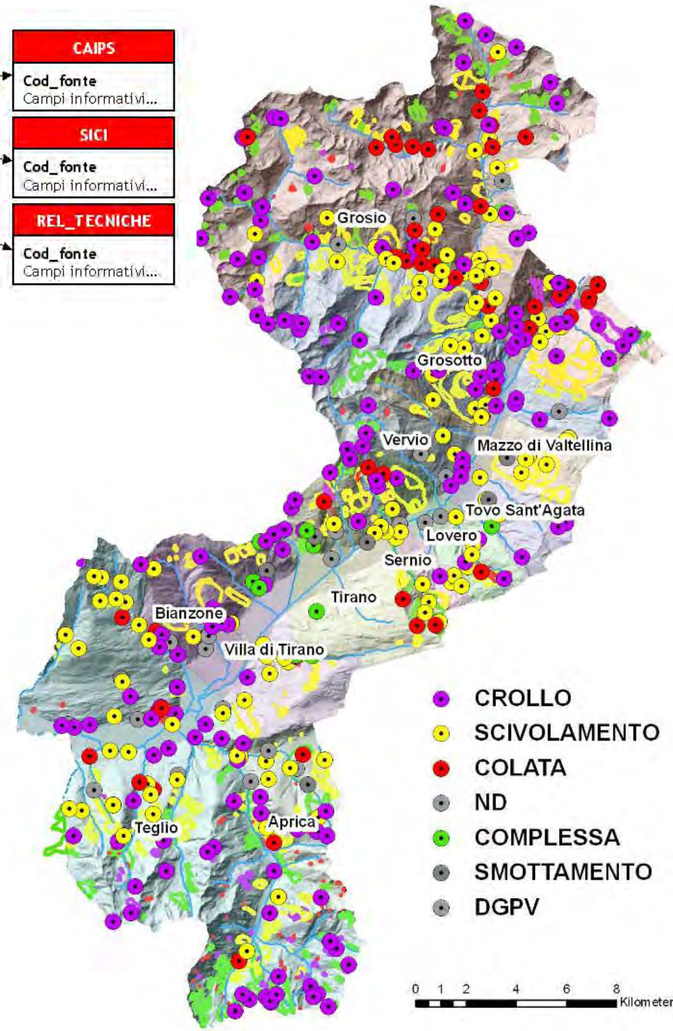
Study area

Database of Historical Events





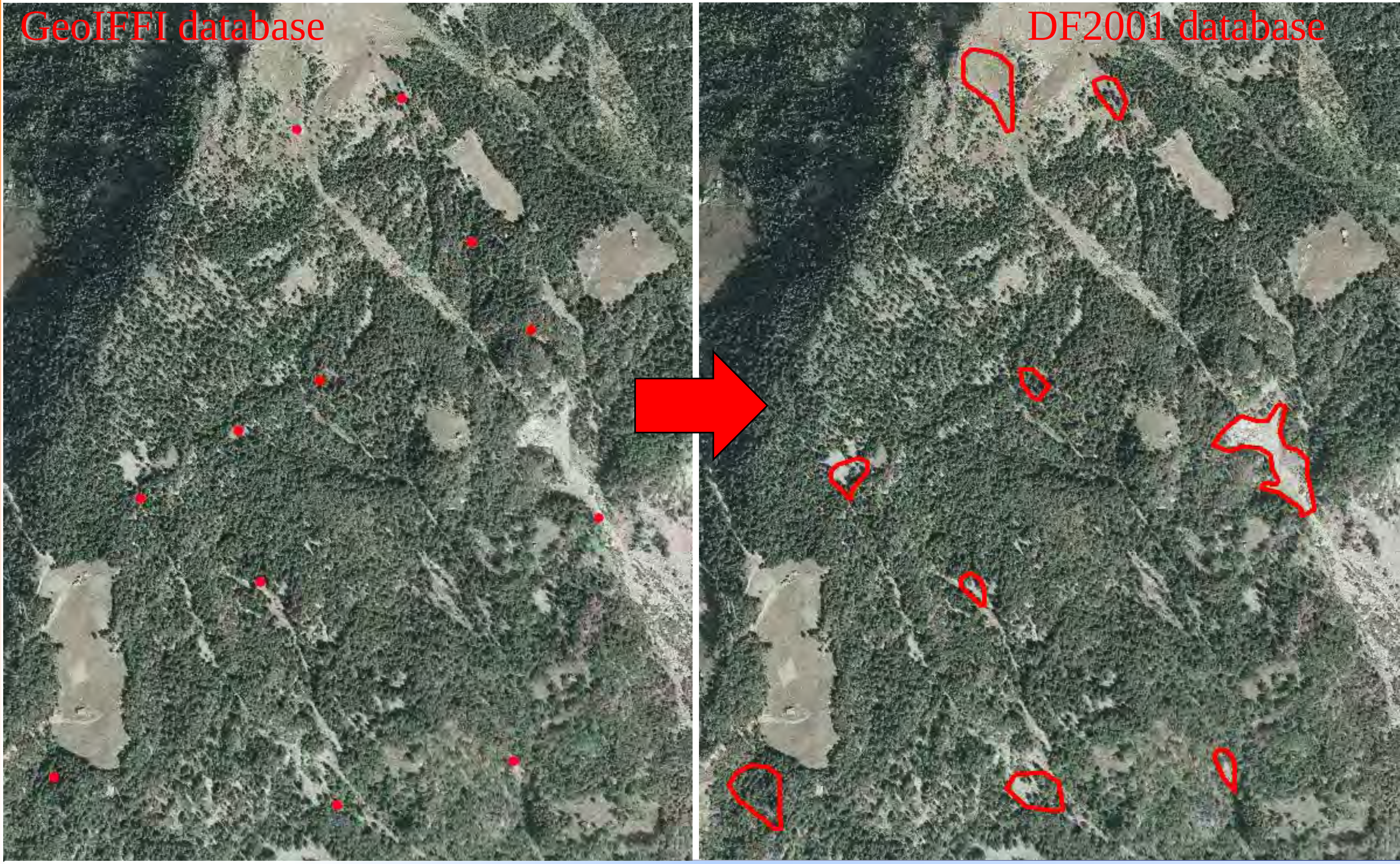




Spatial agreement of predicted patterns in landslide susceptibility maps

Study Area

Debris Flows



Spatial agreement of predicted patterns in landslide susceptibility maps

Experimental Strategy and Modeling Technique

We fixed:

- the number of classes within each explanatory variable,
- the landslide dataset and its partition,
- the modeling technique (WofE), and
- the classification technique applied to the predicted results.

We have only changed the number of explanatory variables in each experiment.

Experimental Strategy and Modeling Technique

(explanatory variables and number of classes within each explanatory variable)

Morphometric and geo-environmental factors used in each experiment. Expert knowledge and previous results from indirect statistically-based methods suggest <u>slope, land use, and geology as</u> the best landslide proneness “driving controlling factors”.

Response number	Slope	Aspect	Internal relief	Land use	Geology	Fault distance	Planar curvature	Profile curvature
1	X	X	X	X	X	X	X	X
2	X	X	X	X	X			
3	X	X		X	X	X		
4	X			X	X			
5	X				X			
6	X		X	X	X	X	X	X
7	X		X	X	X			
8	X			X	X	X	X	X
9	X			X	X		X	
10	X			X	X			X
11	X		X	X	X	X	X	
12	X		X	X	X			X
13	X			X				

Spatial agreement of predicted patterns in landslide susceptibility maps

Experimental Strategy and Modeling Technique

(landslide dataset)

The 573 debris flow scarps were partitioned into two mutually exclusive subsets (each containing 50% of the total number of landslide scarps) by random selection:

- the success subset (287 landslide scarps) was used to set-up and calibrate the models,
- the predictive subset (286 landslide scarps) was used to validate the models.

Experimental Strategy and Modeling Technique

The modeling technique used in this study (**Weights-of-Evidence**) has been implemented by USGS within a Geographical Information Systems by means of a tool called ARC-SDM.

WofE efficiently investigate the spatial relationships among past events and multiple predisposing factors, providing useful information to identify the most probable location of future landslide occurrences.

WofE is a well-documented and widely applied modeling technique in many scientific fields.

Spatial agreement of predicted patterns in landslide susceptibility maps

Experimental Strategy and Modeling Technique

Prior Probability (P_{prior})

$$P_{prior} = \frac{N_{pix}(Slide)}{N_{pix}(Total\_Area)}$$

Calculation Weights

$$W_{ij}^{+} = log_e \frac{P\{V_{ij} | F\}}{P\{V_{ij} | F^{\wedge}\}} \qquad W_{ij}^{-} = log_e \frac{P\{V_{ij}^{\wedge} | F\}}{P\{V_{ij}^{\wedge} | F^{\wedge}\}}$$

Posterior Probability (P_{post})

$$\log_e O\left\{F \mid W_{11}^{k} \cap W_{12}^{k} \cap W_{21}^{k} \ldots W_{nm}^{k}\right\} = \sum_{i=1}^{n} \sum_{j=1}^{m} W_{ij}^{k} + \log_e O_{priori}\{F\}$$

Spatial agreement of predicted patterns in landslide susceptibility maps

SRC and PRC

The success rate curve (SRC) was aimed at estimating how much the model fits the occurrence of landslides (success subset) in each experiment.

The success rate curve (SRC) method was applied by plotting on the x axis the cumulative percentage of susceptible areas (starting from the highest probability values to the lowest ones) and on the y axis the cumulative percentage of events included in the success subset: the steeper is the curve, the larger is the number of events falling into the most susceptible classes.
The degree of fit does not express how well the model predicts future landslides because the events in the success subset were used to construct the prediction map.

SRC and PRC

The prediction rate curve (SRC) was aimed at estimating how much the model predicts the occurrence of landslides (prediction subset) not used in each experiment.

The curves were calculated in a similar way as the SRCs but using an independent subset of occurrences (predictive subset).

The number of events that fell into each susceptibility class of the prediction map yielded prediction rates, which were used to predict the occurrence of future landslides. The PRC method was chosen to support the modeling results and assess the robustness of the models.

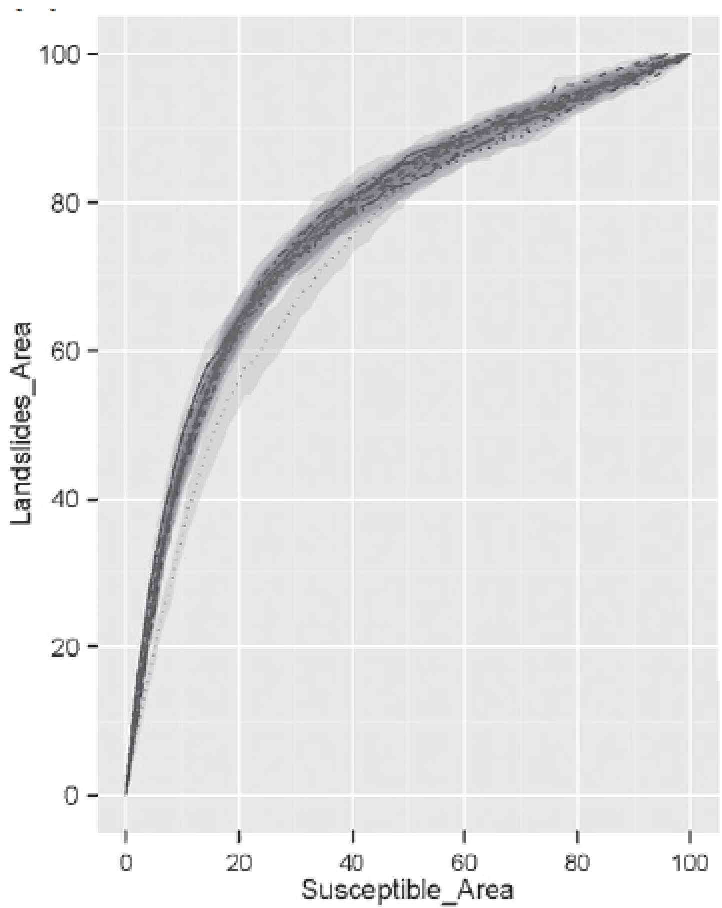
SRC and PRC

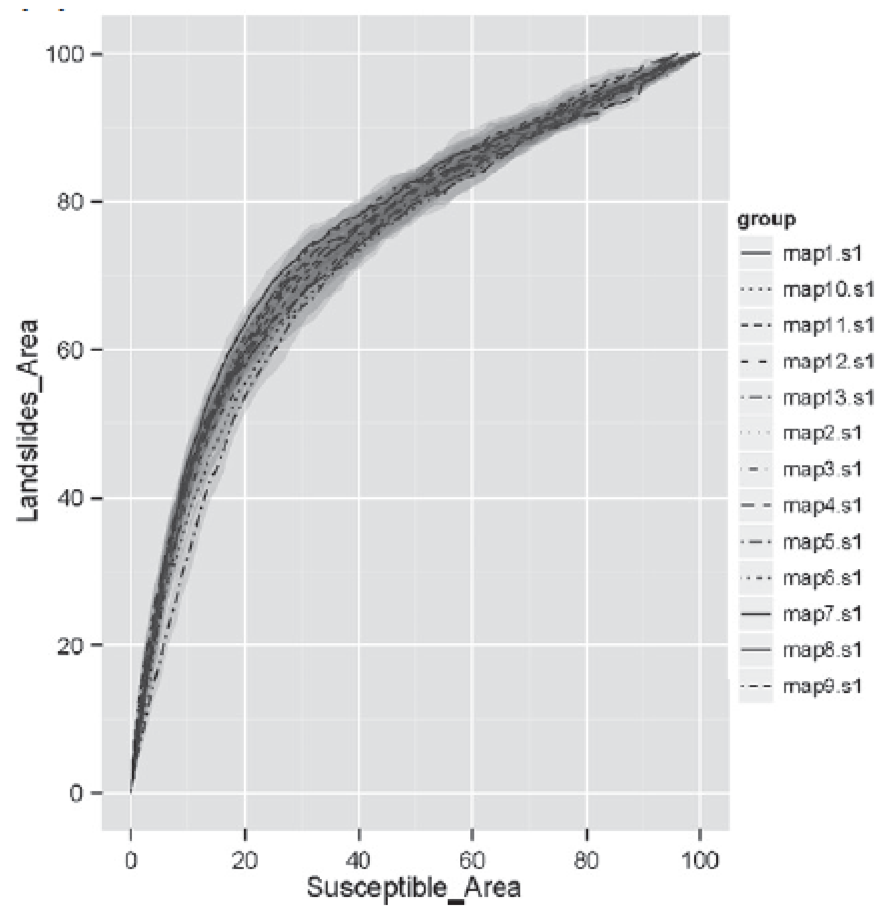
The values of the area under curves (AuC) were very similar for different models, ranging from 84.36% to 86.49% for the success rate curves and from 82.46% to 85.66% for the prediction rate curves (excluding experiment no. 5)

Response number	AUC for SRC (%)	AUC for PRC (%)
1	86.48	83.32
2	86.12	82.74
3	86.49	84.16
4	85.27	84.58
5	80.94	79.53
6	85.90	84.44
7	84.36	82.46
8	86.16	85.16
9	86.19	84.48
10	85.41	82.98
11	85.78	85.66
12	85.57	83.68
13	84.87	83.80

Spatial agreement of predicted patterns in landslide susceptibility maps

SRC and PRC





Out of 13 models, 12 of them seem to be similar in their performance. Especially in the initial part of the curves, it was impossible to tell one model from another because the curves were very close to each other and the CI bands were substantially overlapping.

Spatial agreement of predicted patterns in landslide susceptibility maps

Post Probability Maps

The idea is of a general agreement among maps.

It is very difficult to define the best curve and, as a consequence, to provide to the end-user with the best post probability map.

Degree of Spatial Agreement

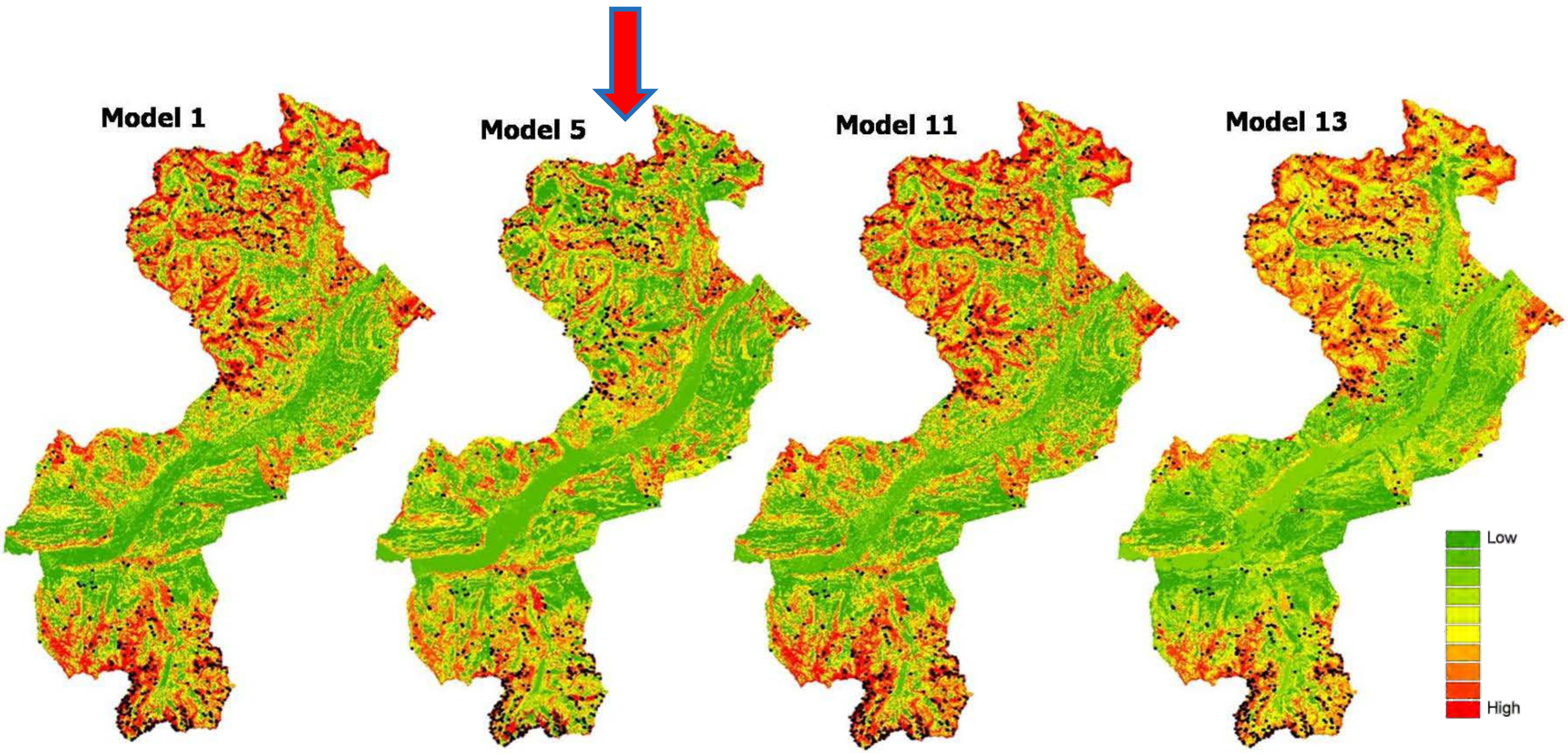
Different statistical techniques (kappa statistic, principal component analysis) have been applied:

- ✓ Kappa Statistics,
- ✓ PCA,
- ✓ GISAPP

GISAPP is an ongoing tool to perform an integration of information based on a soft fusion strategy of contributing factors derived from multi-source spatial data.

Degree of Spatial Agreement

Post-probability maps were classified into rank-based maps, by using an equal-area criterion, to compare the predicted results.



Spatial agreement of predicted patterns in landslide susceptibility maps

Degree of Spatial Agreement

After the reclassification, each map had the following characteristics:

- the 10 classes almost included the same number of pixels, and therefore each class covered the same area on the map (about 1/10 of the entire study area, about 45 km^2);
- the 10th ranking class represented the highest 10% of susceptible area.

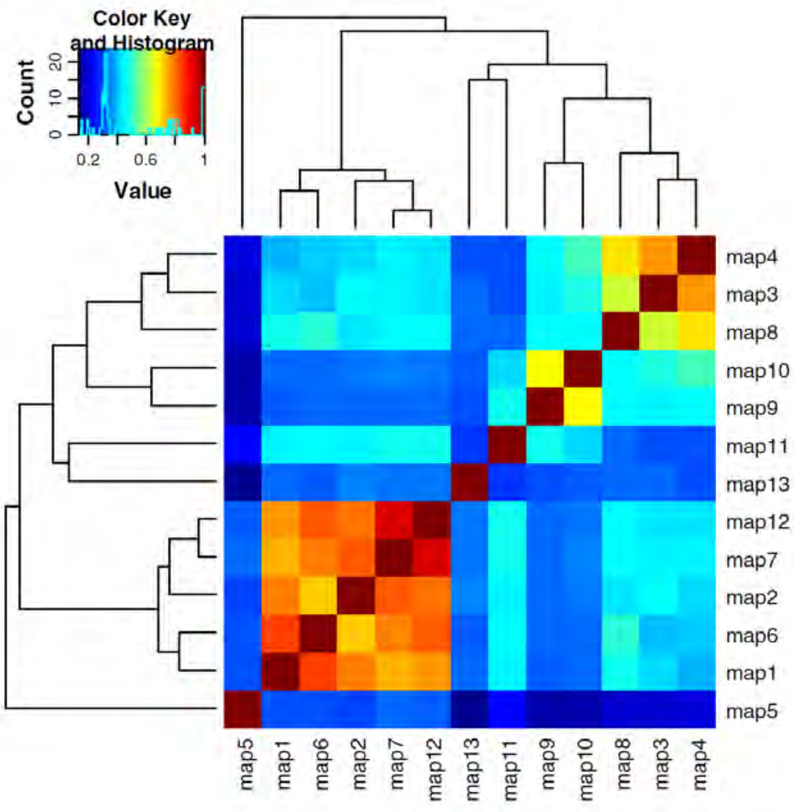
This map preparation was made relatively simple to compare the spatial distribution of the susceptibility classes and make the following steps more straightforward. A set with 10 classes is a pure compromise between the poor descriptive power of a few classes and the non-interpretability of tens of classes.

Cohen’s Kappa Statistic

Heat map matrix and dendrogram of the Cohen's kappa statistic has been derived to test agreement among maps. The kappa value expresses the rate of agreement between two classified maps (10 equal-area classes).

Each row represents how much each map is in agreement with the others. The identical dendrograms on the top and on the left of the heat map matrix also show the closeness of two maps in terms of agreement.

Cohen's Kappa Statistic

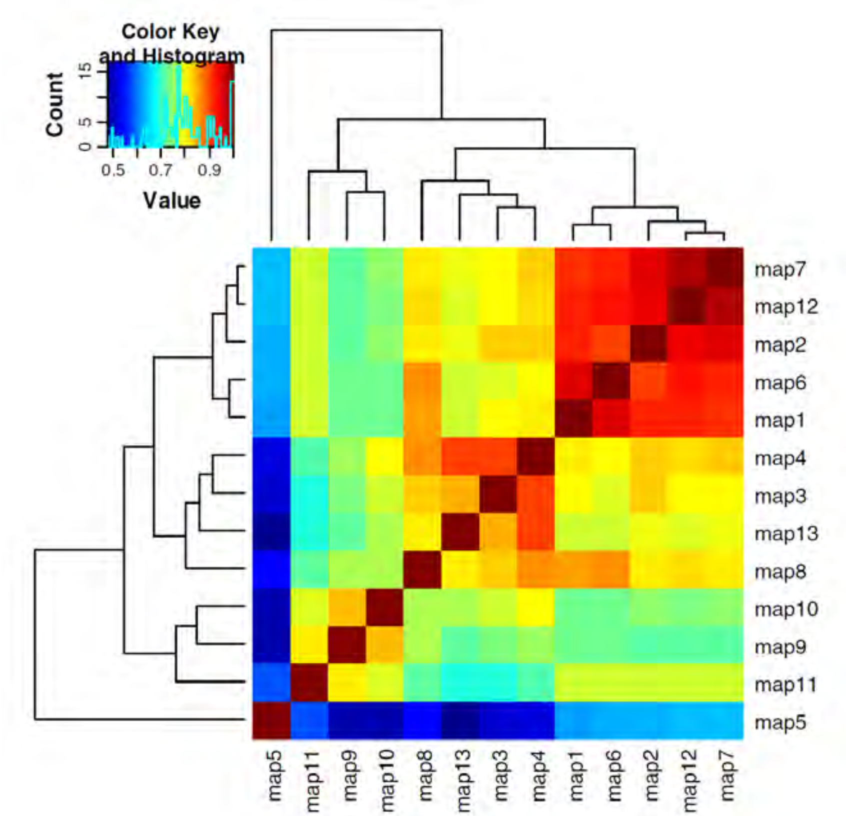


The agreement among the maps is also shown by the dendrograms on the top and left sides of the heat map matrix.

Two maps in agreement are shown as close "leaves" of a common branch in the dendrogram (as maps 7 and 12 or maps 1 and 6).

Kappa values are expressed from blue(0.0) to red (1.0) colors.
The higher the value, the better the agreement is.

Cohen’s Kappa Statistic



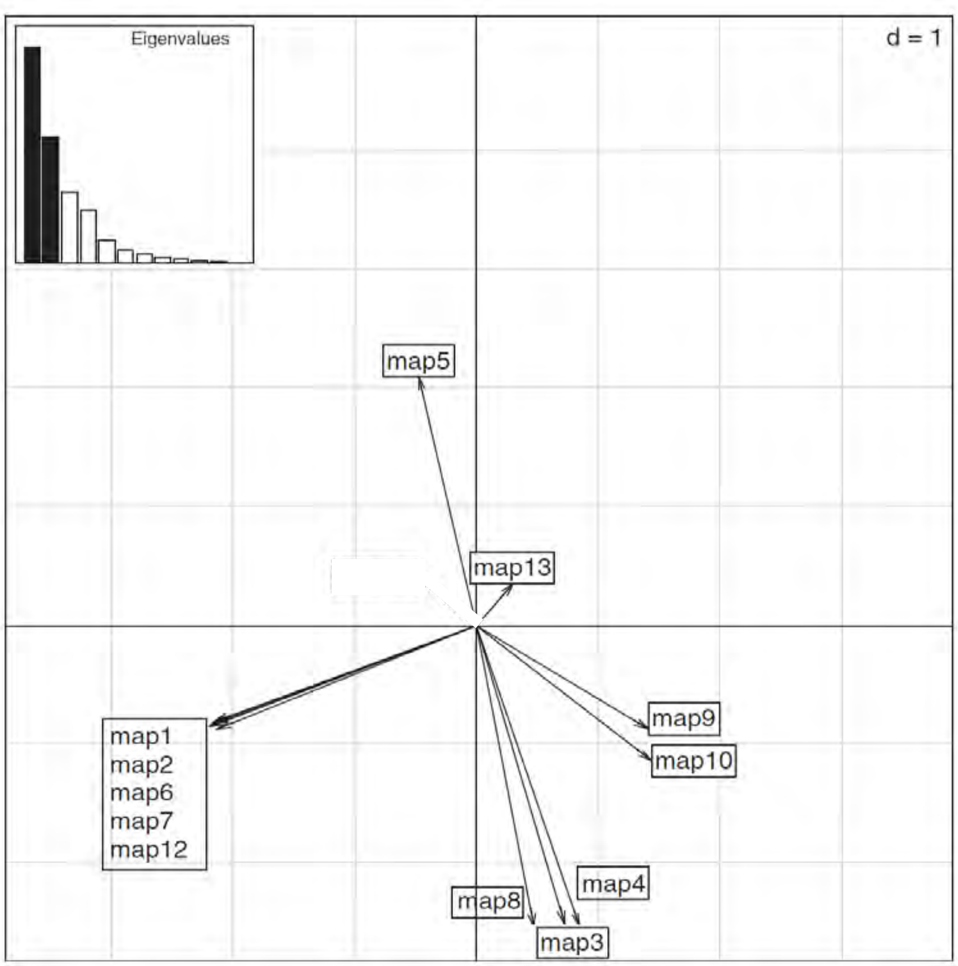
TIP:
The kappa statistic summarizes the agreement among different maps; however, no information is made available about the location where the prediction of two or more maps agreed and where they do not.

Heat map and dendrogram of the Cohen's kappa statistic of agreement among maps for the most susceptible classes only.

Spatial agreement of predicted patterns in landslide susceptibility maps

Principal Component Analysis

(considering all the susceptibility classes)

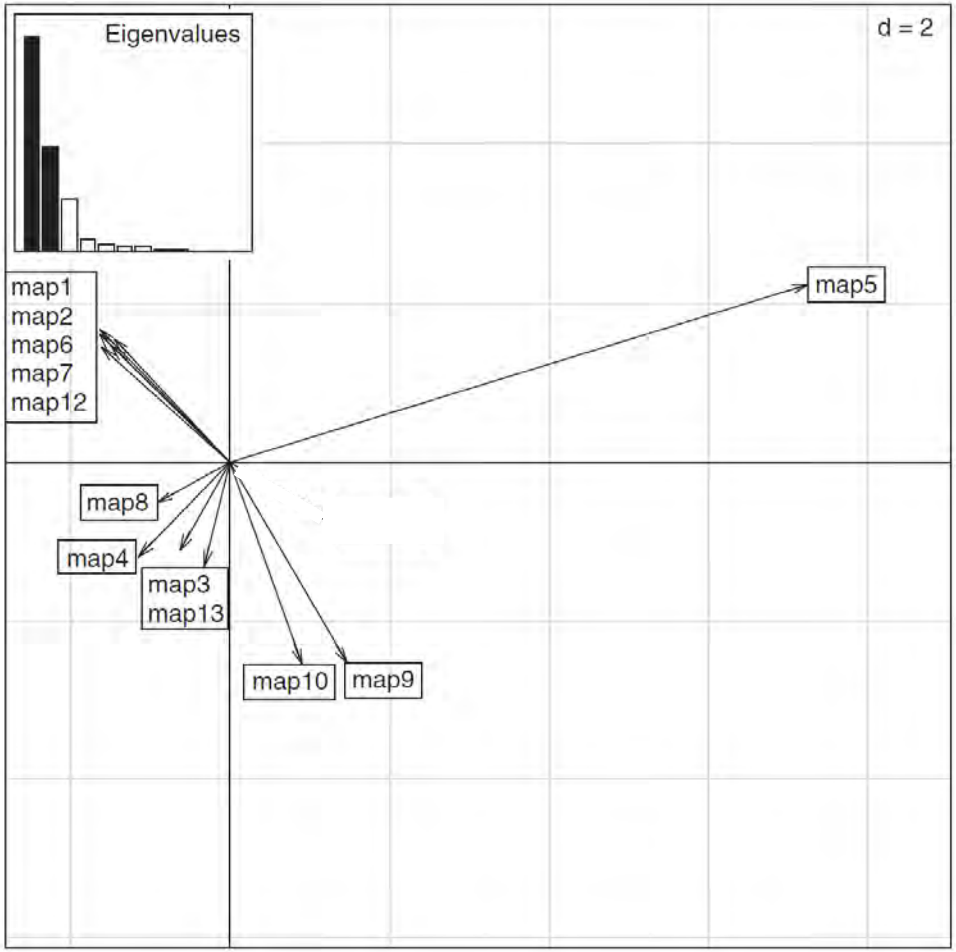


From PCA, it seems that the maps are clustered into three different clusters. The largest one is composed of map no. 1, 2, 6, 7, and 12.

Two maps stand alone: map 5 and 13 (only two explanatory variables have been used).

Principal Component Analysis

(considering the most susceptible classes)



From PCA, considering the most susceptible classes only, it seems that the maps are again clustered into three different clusters. The largest one is composed by the same maps as before: no. 1, 2, 6, 7, and 12.

Only one map stands alone: map 5.

Outcomes from Statistical Techniques

Cohen's Kappa Statistic and Principal Component Analysis outcomes do not properly confirm the outcomes from success and prediction rate curves calling for significant differences within the output spatial patterns of the predicted maps as well as within the highest susceptibility classes although these maps share similar success/prediction rates.

GISAPP

The next step concerns the possibility to map the consistency (agreement /disagreement) of the predictions of different models (with very similar success/prediction rates), making possible to spatially identify sectors of the study area in which the predictions could be in agreement or discordant. For this reason, a tool has been designed to quantify the spatial distribution of different modeling outcomes.

GISAPP

The GISAPP is an ongoing tool to perform an integration of information by a soft fusion strategy of contributing factors (maps) that could be derived from multi-source spatial information.

The soft fusion strategy is able of integrating data to compute an overall “indicator”, leading to reduce a large quantity of data to a more simple and interpretable form.

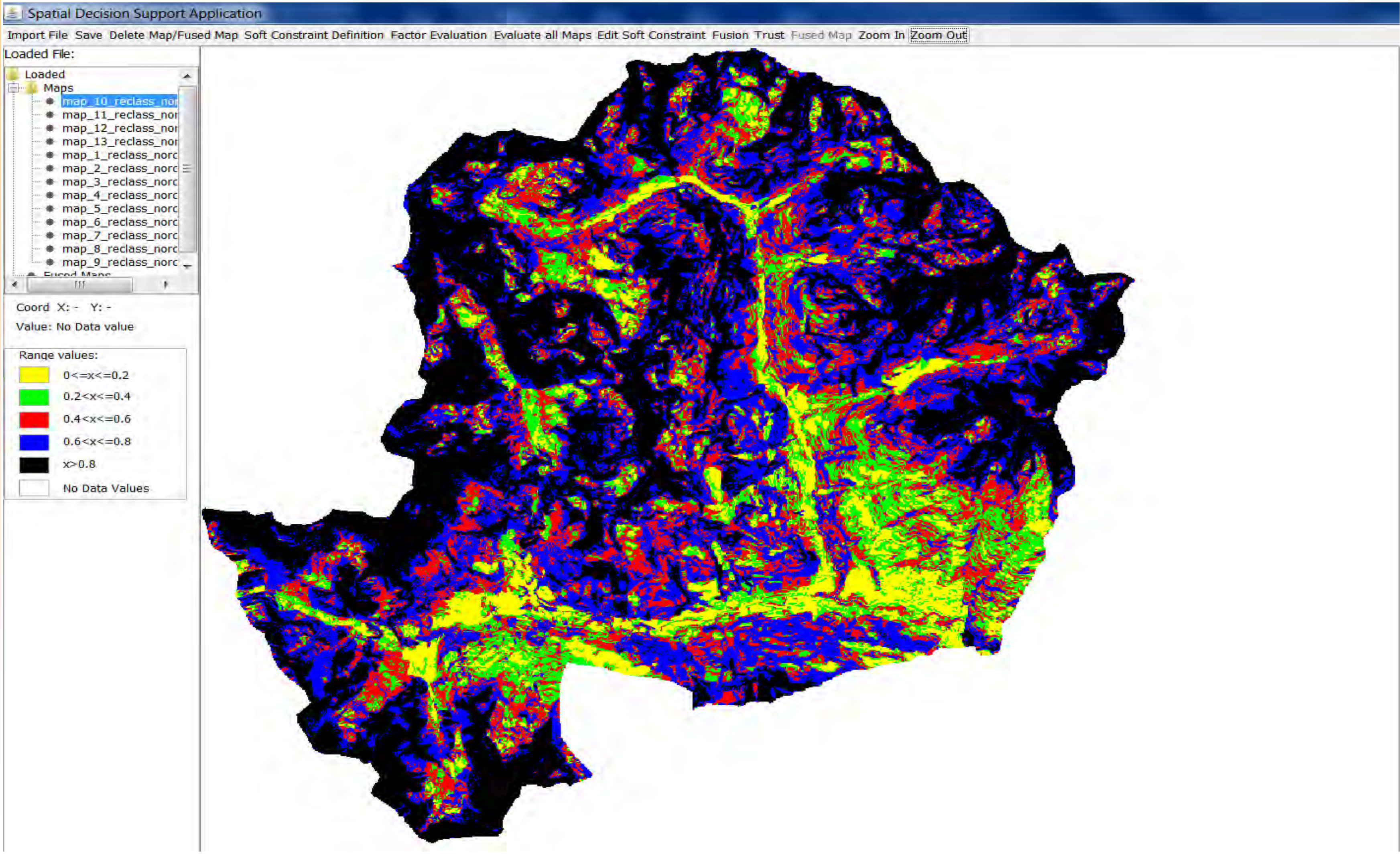
GISAPP

The soft fusion strategy can be defined by the user through a linguistic quantifier (expressing the semantics of the fusion) such as “most of”, “few”, “at least 30%”, etc. in order to aggregate a set of a set of numeric values that can be class identifiers, classification ranks, contributing factors (equally or not-equally weighted by their relative importance) into a synthetic overall value that represents the agreement among the fuzzy majority expressed by the quantifier of the arguments.

Soft fusion techniques can be flexibly defined by taking advantage of the rich variety of Fuzzy Aggregation Operators that can help to create realistic, human-centred representations of environmental phenomena.

GISAPP

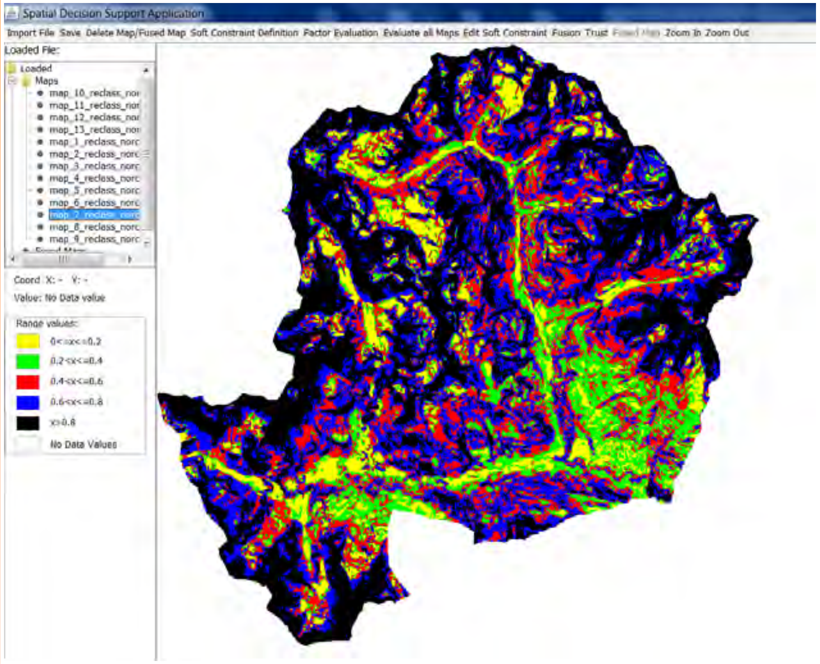
Add Maps – Northern sector



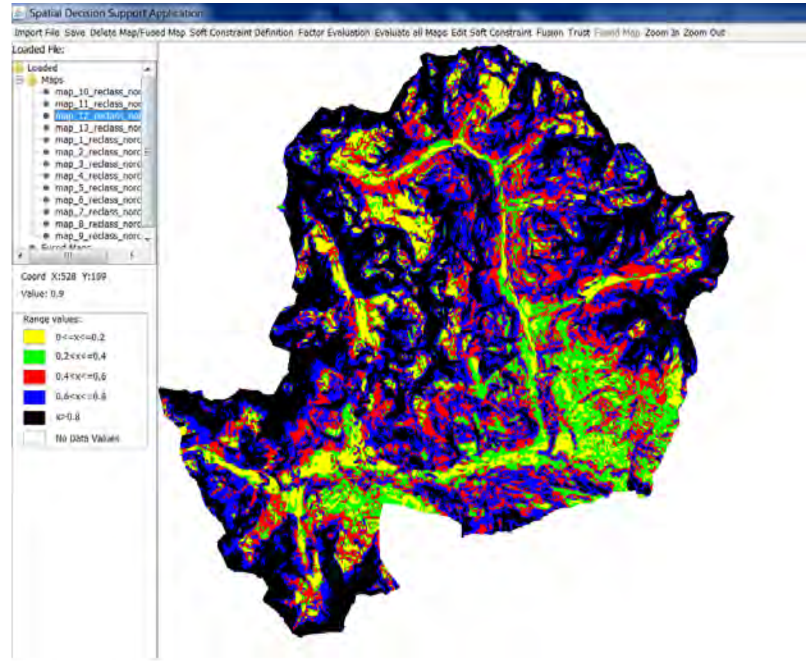
Spatial agreement of predicted patterns in landslide susceptibility maps

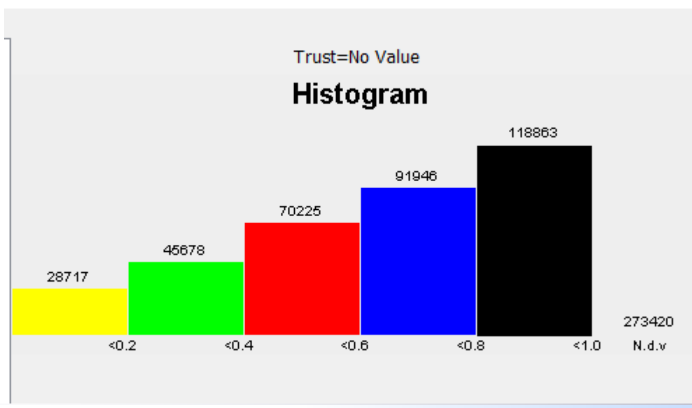
GISAPP

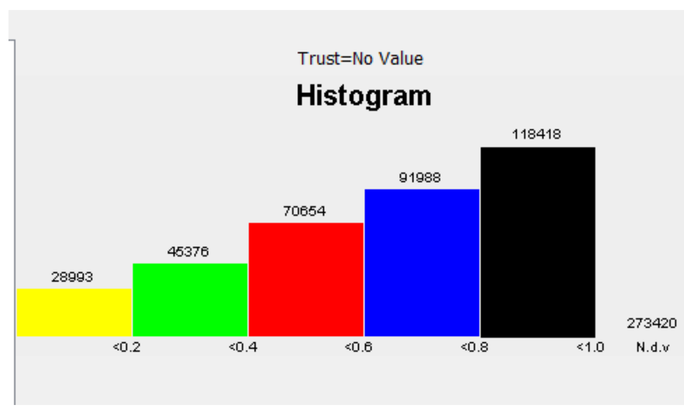
Map 7 – Northern sector



Map 12 – Northern sector



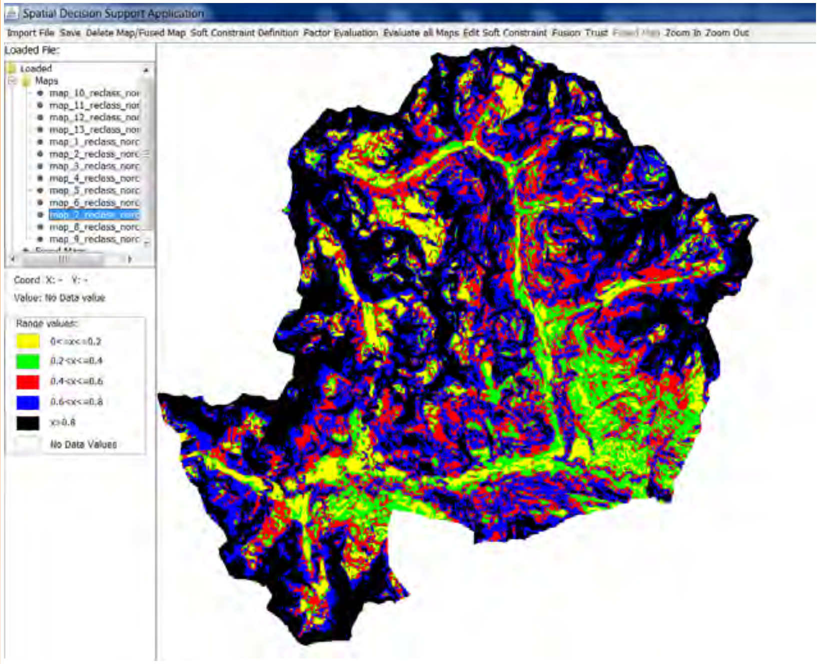




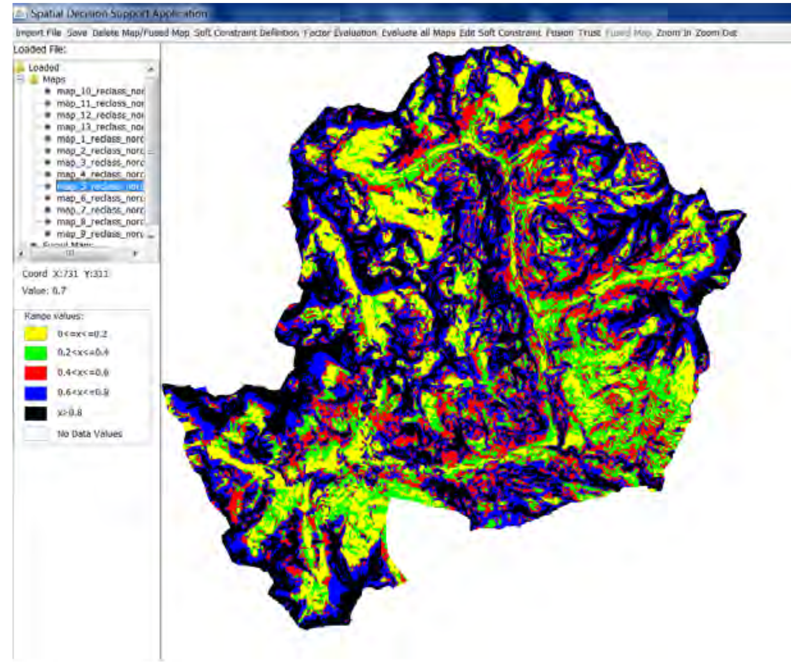
Spatial agreement of predicted patterns in landslide susceptibility maps

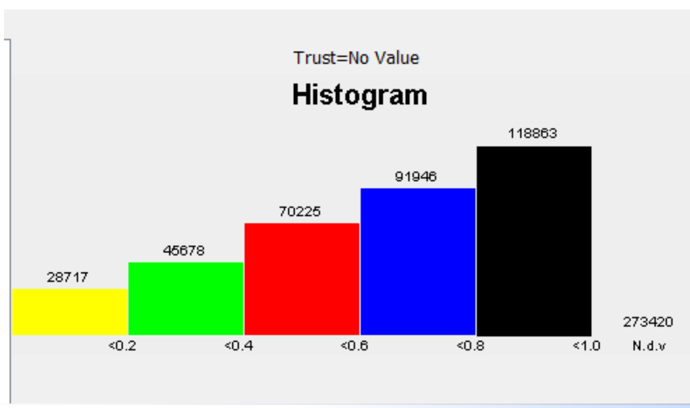
GISAPP

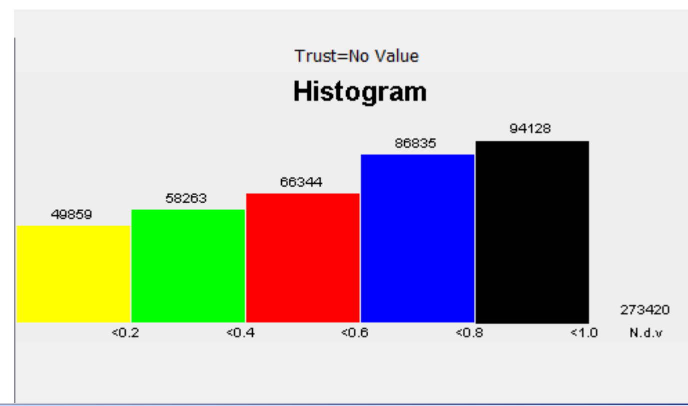
Map 7 – Northern sector



Map 5 – Northern sector







Spatial agreement of predicted patterns in landslide susceptibility maps

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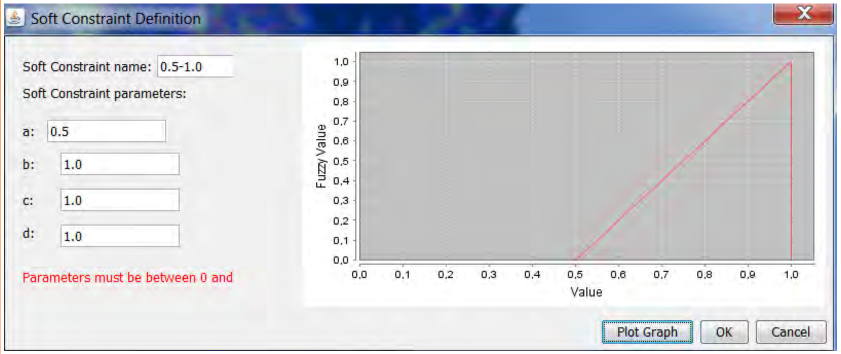
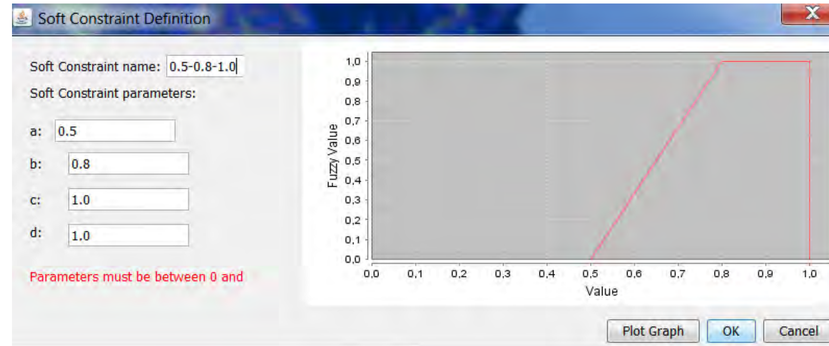
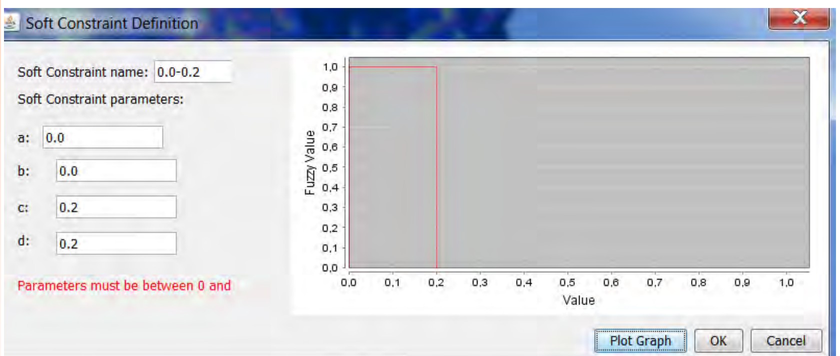
Soft constrain definition

0.5 – 1.0 Linear constrain

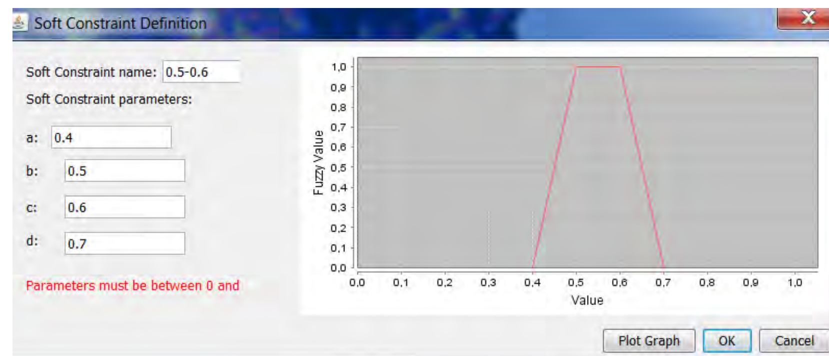


0.5-0.8-1.0-1.0 Trapezoidal constrain





0.0-0.0-0.2-0.2 Rectangular constrain



0.4-0.5-0.6-0.7 Trapezoidal constrain

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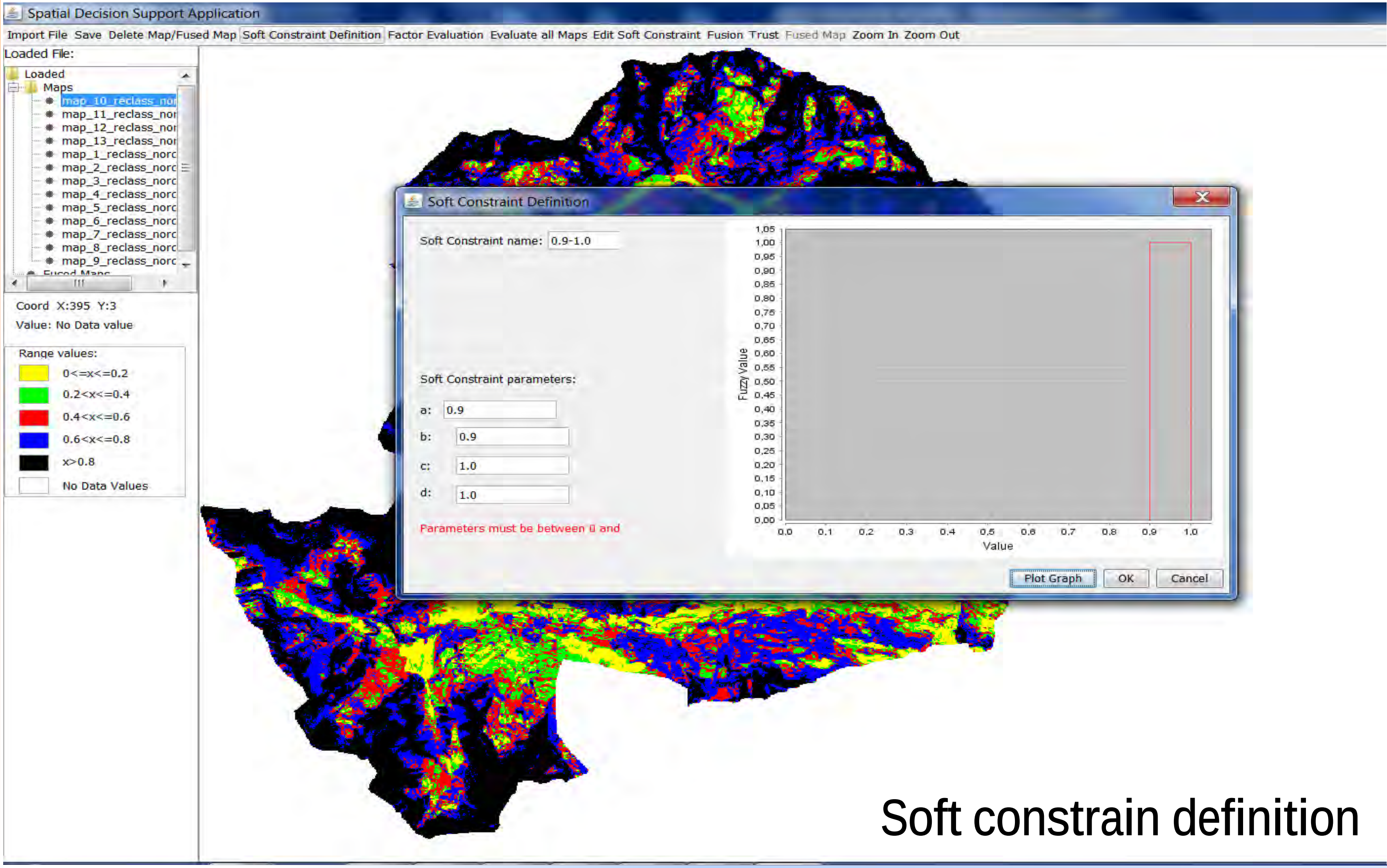
0.9-0.9-1.0-1.0 Rectangular variation – Northern sector



Soft constrain definition

Spatial agreement of predicted patterns in landslide susceptibility maps

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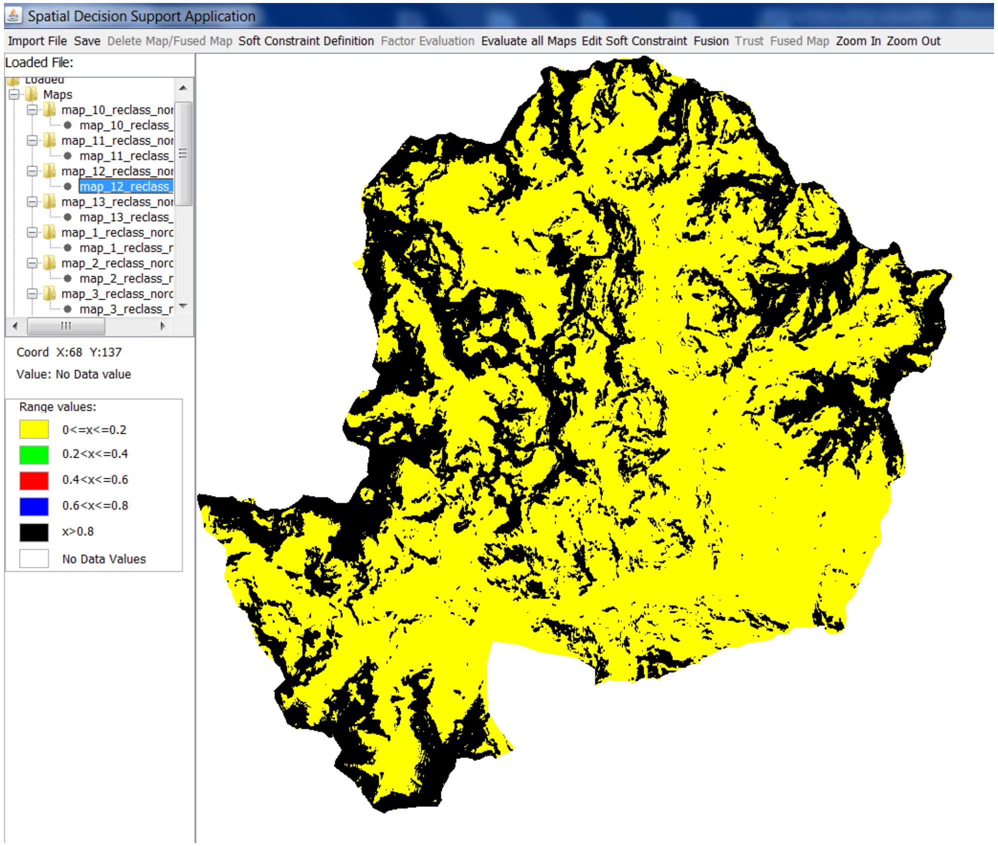
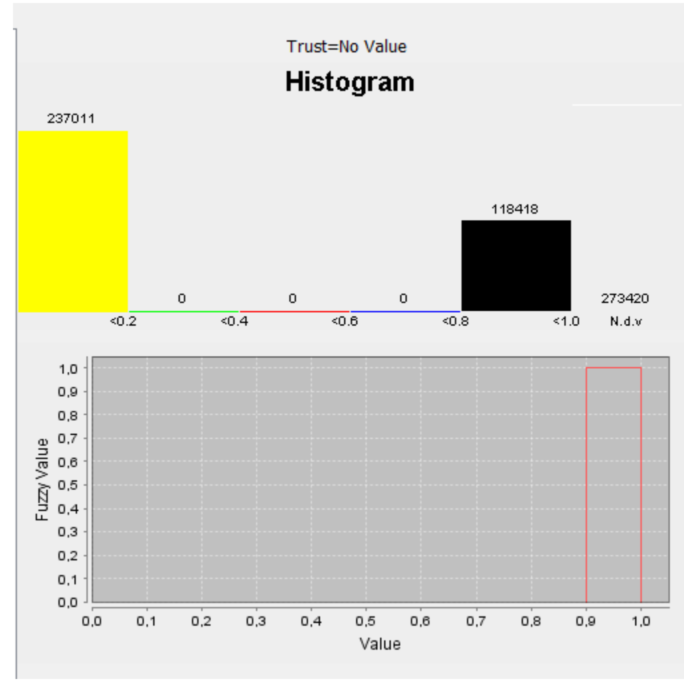
Map 12 – Northern sector





Spatial agreement of predicted patterns in landslide susceptibility maps

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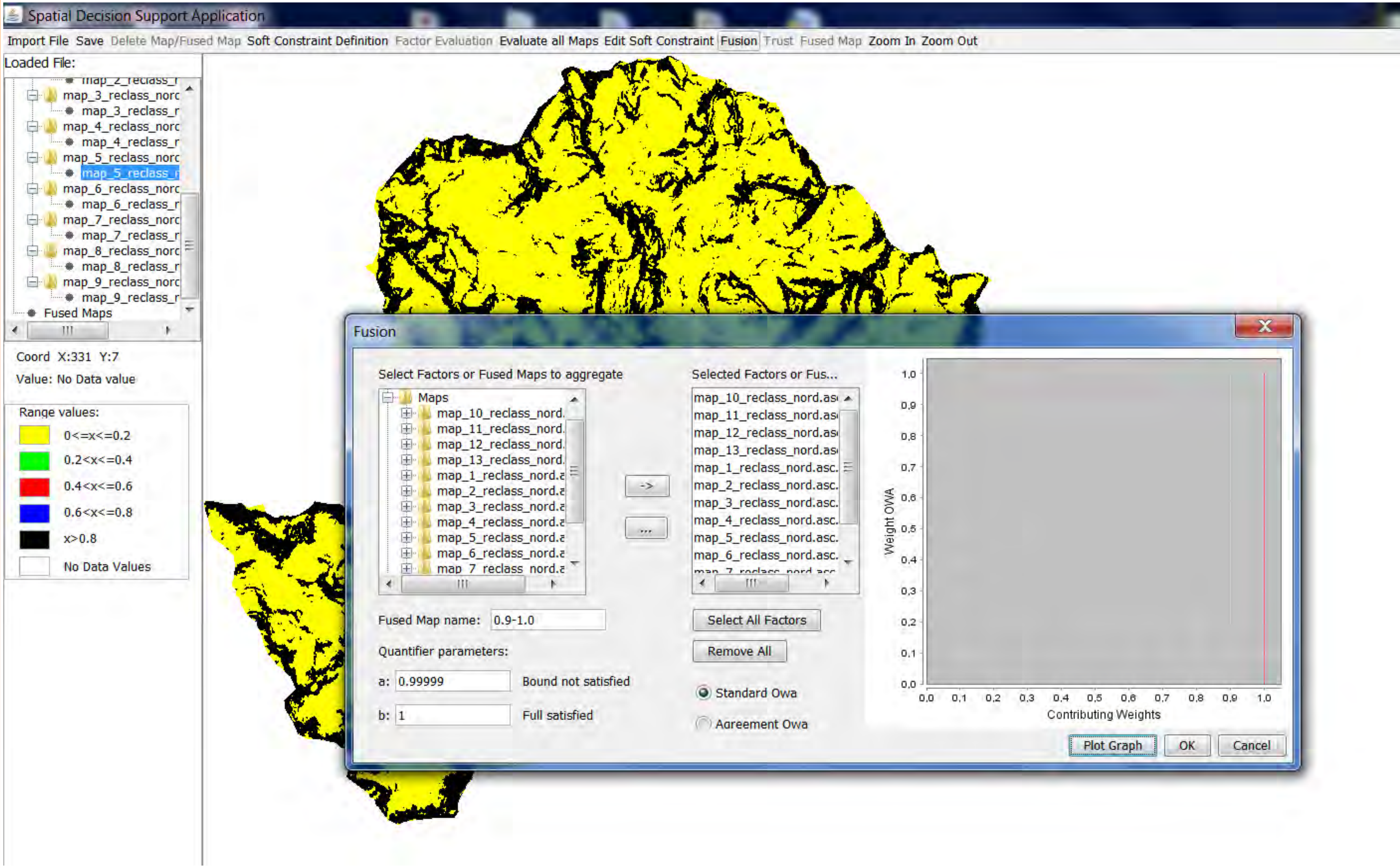
Fusion of all maps (bit maps) – Northern sector



Spatial agreement of predicted patterns in landslide susceptibility maps

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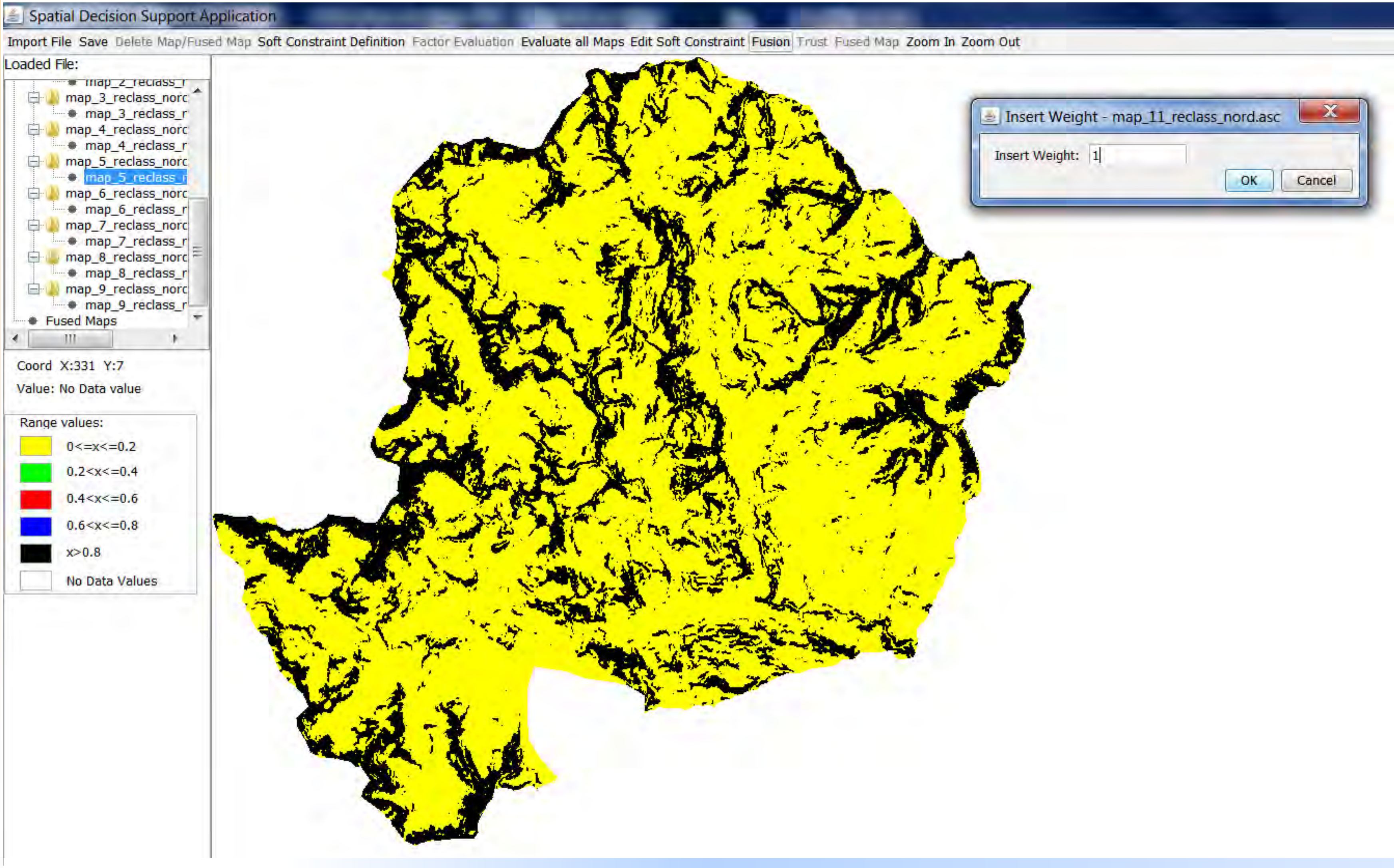
Weight assignment in data fusion – Northern sector



Spatial agreement of predicted patterns in landslide susceptibility maps

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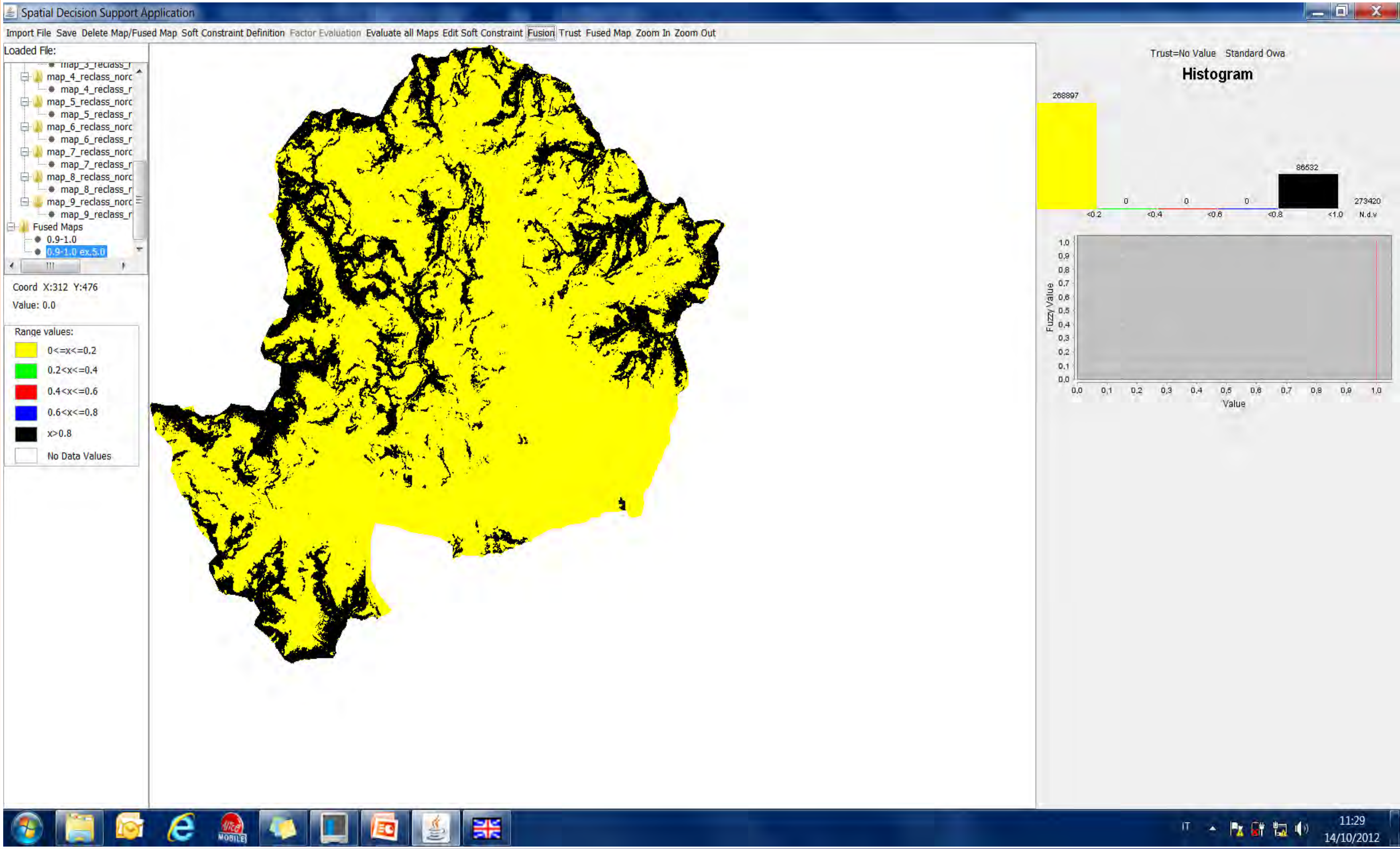
Fused maps – Northern sector



Spatial agreement of predicted patterns in landslide susceptibility maps

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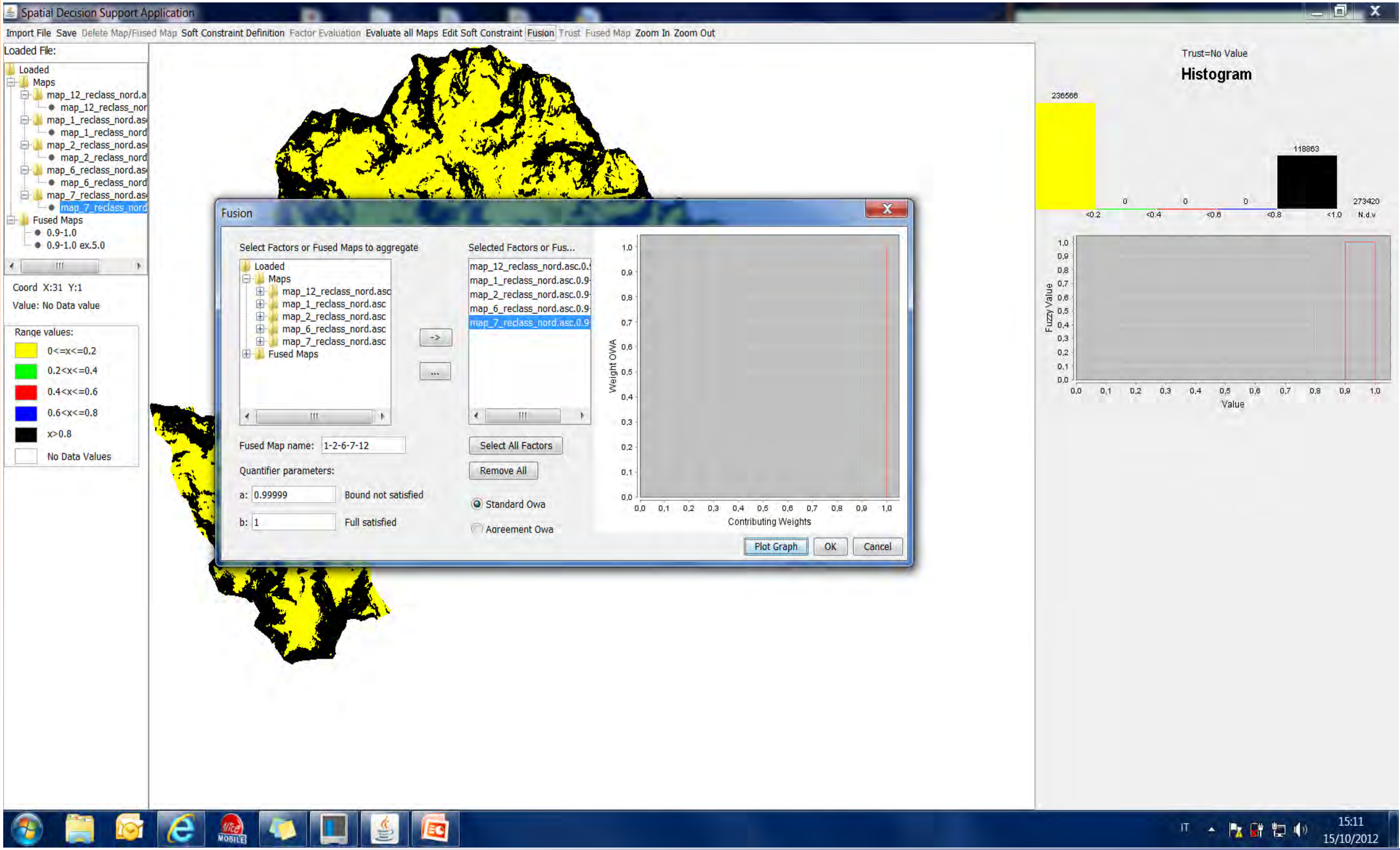
Fused map (1-2-6-7-12) – Northern sector



Spatial agreement of predicted patterns in landslide susceptibility maps

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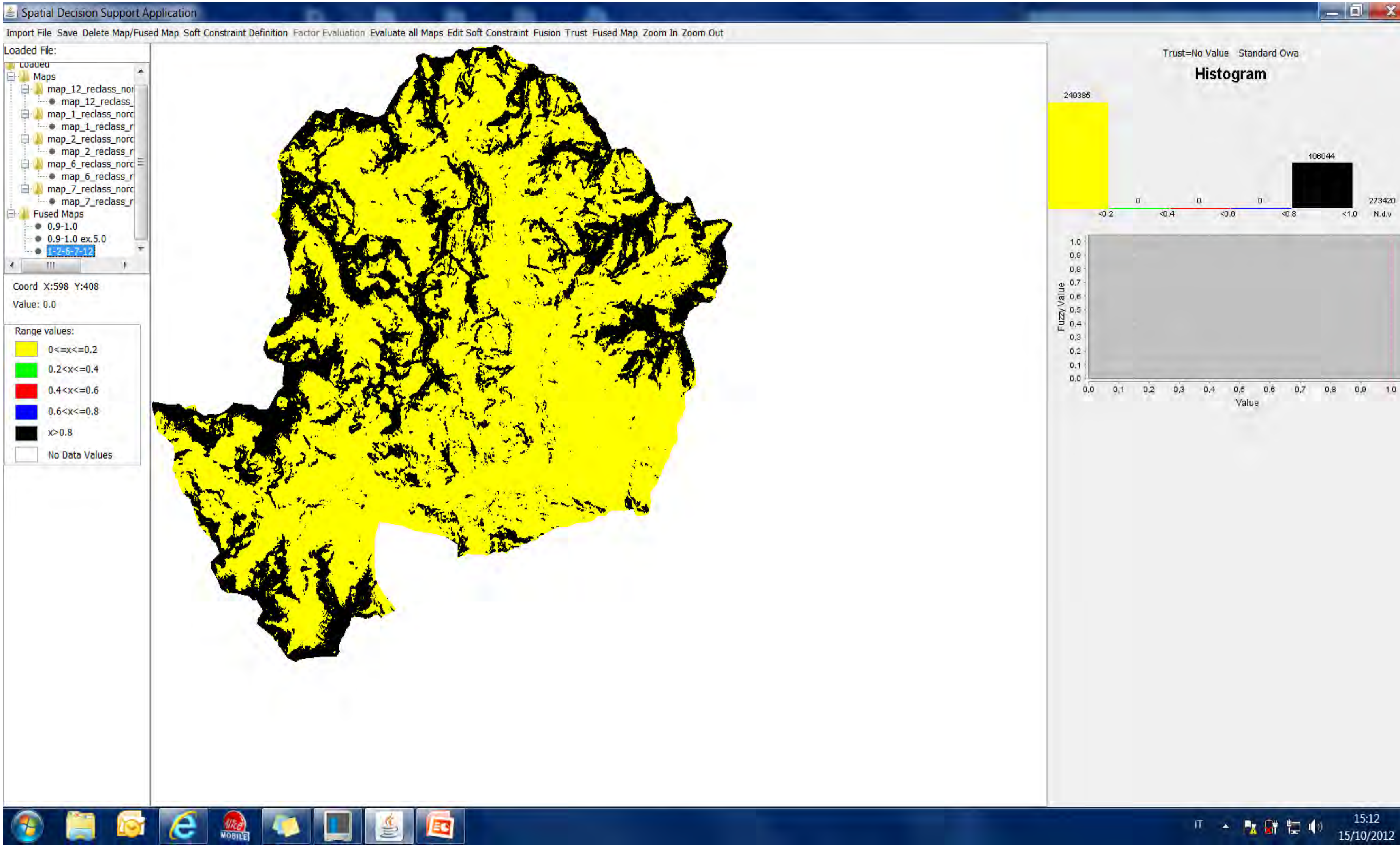
Fused map (1-2-6-7-12) – Northern sector



Spatial agreement of predicted patterns in landslide susceptibility maps

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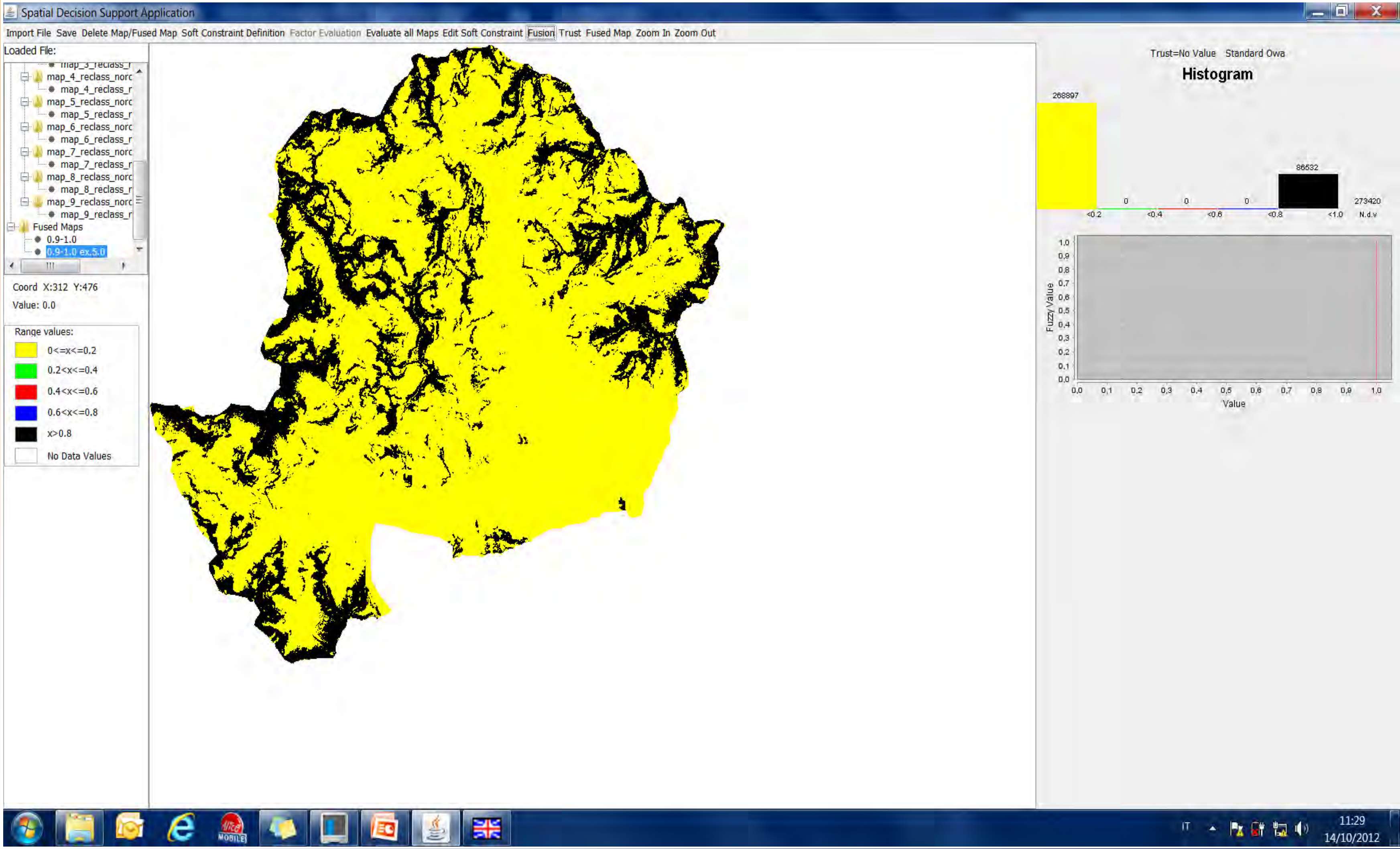
Fused map (all maps) – Northern sector



Spatial agreement of predicted patterns in landslide susceptibility maps

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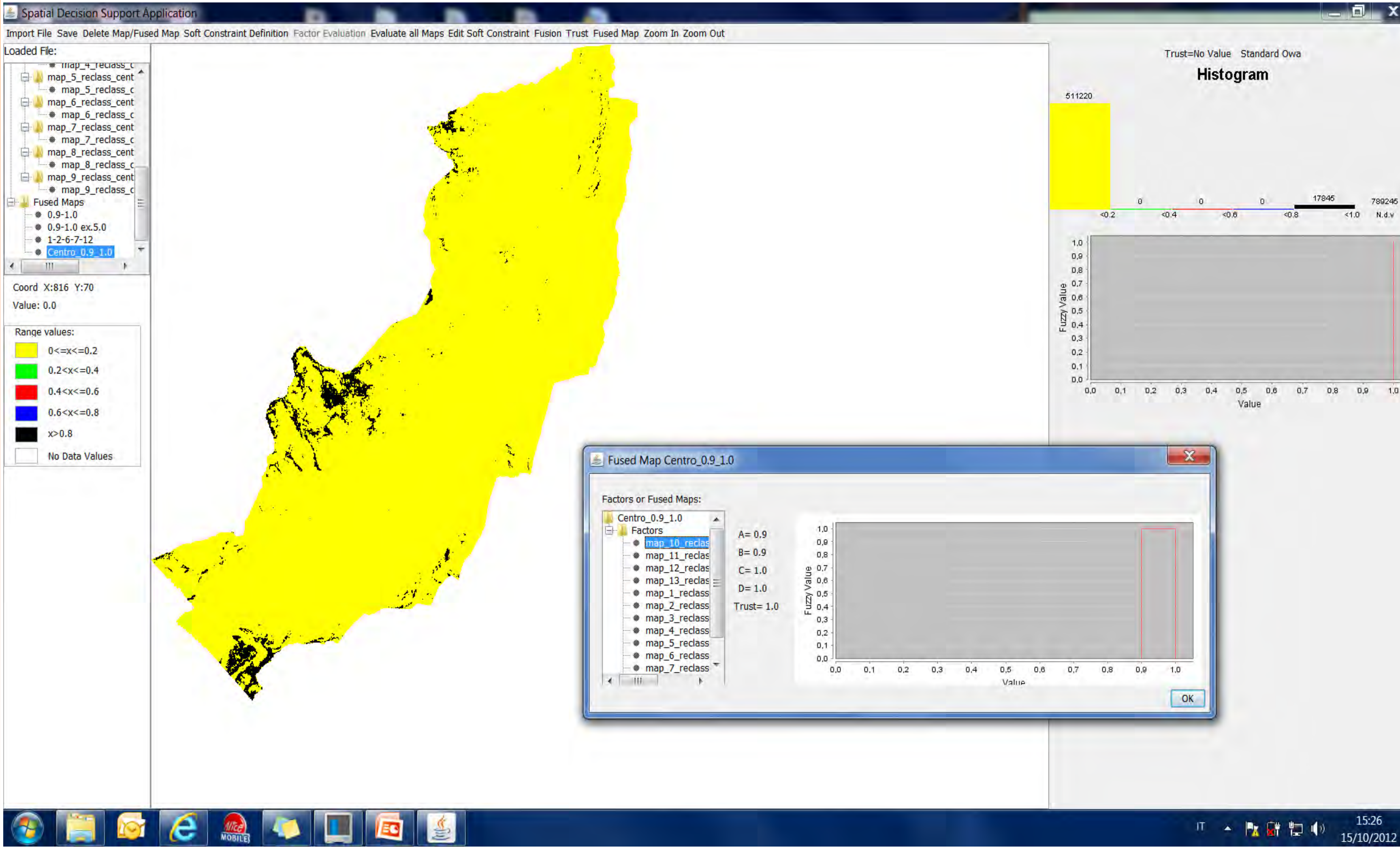
Fused map (all maps) – Central sector



Spatial agreement of predicted patterns in landslide susceptibility maps

Concluding Remarks

- Susceptibility maps with similar predictive power may not be considered equivalent in terms of spatial patterns of predicted results.

Most of the models implemented produced equally (or, at least, not statistically different) predictions in terms of success/prediction rate curves (excluding the experiment no. 5). However, the spatial distribution of the post-probability values of each map is not as similar.

- When we transpose predicted values from maps to graphs (for the evaluation of the success and predictive rates of each map), we lose the spatial location of those values.

Concluding Remarks

- The application of appropriate statistical techniques and tools called for an important inter-class and spatial variability of the predicted patterns within the study area.

- For this reason landslide susceptibility maps should be distributed together with map documents aimed at defining the level of accuracy of the predicted results to provide the end-users with informative selection criteria.