# *Interactive comment on* "Debris-flow hazard assessment at regional scale by combining susceptibility mapping and radar rainfall" *by* M. Berenguer et al.

**M. Berenguer et al.**

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We thank Jean-Philippe Malet for his comments. Please, find below the detailed answers and the description of the modifications introduced to the text.

**2.1:** *The term hazard is used inappropriately throughout the text. According to the established literature on QRA for landslides, hazard is defined as the spatial and temporal occurrence of an event of a certain intensity. As the authors do not estimate the intensity of the events (either in terms of volumes or runout distances), the term hazard could not be used. I would suggest the authors to rephrase their sentences and the*

*title of the manuscript and use the terms "forecast of DF occurrence" instead of DF hazard assessment.*

AR: We have changed the title (now "Debris-flow forecasting at regional scale by combining susceptibility mapping and radar rainfall") as suggested by the reviewer. Throughout the text and in the figures the use of the term "hazard" has been replaced, and the expression "hazard level" has been replaced by "warning level". Also, we have modified the text in section 1 (Introduction) to clarify the objective of the presented work (page 4, lines 17-19): "The system has been designed to qualitatively assess DF hazard in all the subbasins of the monitored domain by issuing a three-class traffic-light code for warning levels 'low', 'moderate' and 'high'."

**2.2:** *The use of a fuzzy logic model for the susceptibility assessment based only on geo-morphometric variables is surprising. Important spatial predictors such as lithology (or geotypes) and soil depths (or proxies of soil depth) are not integrated in this assessment. However, this information seems available as it is used in the triggering model (model of Papa et al.) The authors should discuss this point and possibly propose a sensitivity analysis of the predictors of the susceptibility model.*

We agree with the reviewer on that neglecting predictors related to the soil or the lithology is an important simplification. A sentence reflecting this major simplification has been introduced in the text (page 20 line 10 - page 21 line 3):

"In this work, we have used two datasets available in the analysis domain:

- The geomorphological variables derived by Chevalier et al. (2013) to characterize DF susceptibility. This approach has the advantage of using information that is frequently available in many areas (from the analysis of a DEM), but neglects information relative to the soil depth or the lithology that are relevant predictors to characterize DF susceptibility.

- The results of the model of Papa et al. (2013) obtained by Bateman et al. (2011)

to characterize the magnitude of the rainfall situation. This model is rather complex and requires soil information that could also be valuable to improve the characterization of DF susceptibility.

One of the advantages of the developed technique is that its modules can be replaced easily. In this sense, other methods for assessing DF susceptibility (He et al., 2003; Marchi and Dalla Fontana, 2005; Ayalew et al., 2004; Lee, 2007) could be implemented. The integration of an alternative technique would require the expert adjustment of the membership functions for the new variables. Similarly, other techniques could be implemented for assessing the magnitude of the rainfall event. In this sense, an interesting alternative could be the use of Intensity-Duration curves, available in several locations (e.g. Wieczorek and Guzzetti, 2000; Corominas et al., 2002; Guzzetti et al., 2008; Brunetti et al., 2010; Portilla et al., 2010). In particular, the definition of the membership functions would be facilitated by those methods that provide information about the magnitude of the event or the probability of DF occurrence beyond the yes/no output of threshold methods (Brunetti et al., 2010)."

As mentioned in several parts of the text (e.g., page 8, lines 3-4, page 9, lines 10-12), Unzeta (2012) studied the sensitivity of the components of the susceptibility analysis. In particular, she studied

- the skill of each of the 18 geomorphological variables used by Chevalier et al. (2014) to characterize DF susceptibility individually through the analysis of the overlapping area of the pdfs for reactive and non-reactive subbasins (see Fig. R1),

- the correlation among variables, and

- the differences of the pdfs ($h_{k,r}(x)$) between Zones A and B.

Unzeta (2012) also described in detail the criteria used to design the membership

functions.

In our opinion, further description of these analyses goes beyond the scope of the manuscript.

**2.3:** *Further, I wonder why a topographic-hydrological index like water accumulation or water convergence uphill of a certain point has not been introduced as an additional topographic spatial predictor in the assessment?*

It has to be noted that the presented system outputs the warning level at subbasin scale (see, for instance, Fig. 1). Accordingly, rainfall inputs used to characterize the magnitiude of the event are aggregated at subbasin scale (i.e. the water accumulation uphill the outlet of each subbasin). The text has been modified for better clarity (page 12, lines 14-17): "We have chosen to use 30-minute accumulations aggregated over the area of each subbasin. This seems to be a good compromise to capture the rapid evolution of local convective phenomena affecting small areas at a reasonable computational cost. However, it seems that the reviewer proposes to use variables that are more meaningful when applied at pixel scale over a grid. The full analysis of 18 geo-morphological variables to characterize DF susceptibility (Unzeta, 2012), showed that other variables (such as the size of the subbasin A, the shape factor $A/l^2$, the Lemniscate ratio $l^2\pi/(4A)$ or the basin elongation $2\sqrt{A}/(l\sqrt{(\pi)})$)) were less skilfull at characterizing DF susceptibility in the analysis domain (as can be seen in Fig. R1).

**2.4:** *The effects of the membership degrees and weights for the predictive variables on the susceptibility and rainfall triggering calculations should also be discussed, and a sensitivity analysis provided.*

As mentioned in answer to comment 2.2, the details of the sensitivity analysis were described in the work of Unzeta (2012), where, besides of the sensitivity of the results to the shape of the membership functions, different rules were tested to combine subbasin susceptibility and the magnitude of the rainfall situation. A sentence has been introduced to explicitly mention this (page 13 line 15 - page 14 line 2): "After testing sev-

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eral alternatives (for full details, see Unzeta 2012), we have used the algebraic product and the algebraic sum, respectively (e.g., Bardossy and Duckstein, 1995)." Also, it is worth noting that the weights assigned to the features used in the susceptibility analysis have been obtained through an objective criterion that quantifies the predicting skill of the analysed features (as argued in section 3.1.2).

Full description of the sensitivity analysis of the results with the membership functions would compromise the focus of the manuscript and would make its extension go beyond reasonable limits.

**2.5:** *Figures: - A geomorphological map (including information on the relief) of the study region should be introduced in the manuscript for a better understanding of the work of the possible weather circulation patterns.*

We have modified Fig. 1 to adapt it to the requests of the reviewer. The location of the analysis domain is shown over the relief map. Further geomorphological information is provided in Fig. 6, where the hillshade map of the analysis domain is presented.

**2.6:** *Figure 1: to complement with some geographical locations for purpose of clarity*

Done.

**2.7:** *Figure 2: the rainfall accumulation map should be enlarged*

The figure has been slightly rearranged to increase the size of the accumulation map.

**2.8:** *Figure 6: a hillshade or an orthophotograph should be added in the background of the sub-basins*

We have added a hillshade map of the analysis domain to complement the figure.

**2.9:** *- Figures 9 and 11: the size of the maps should be increased –Change the term "hazard level".*

Figs. 9 and 11 have been rearranged for better clarity. The elements in the figures are

now larger.

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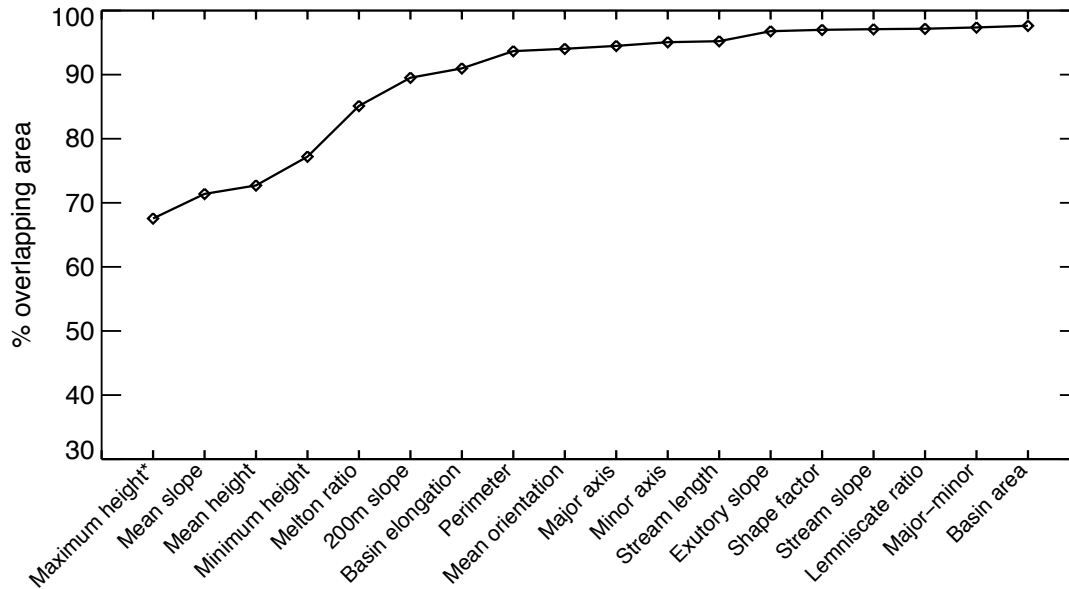
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**Fig. 1.** Overlapping area between the pdfs of reactive and non-reactive basins for the geomorphological variables analyzed by Chevalier et al. (2013).