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# Improving transferability strategies for debris flow susceptibility assessment: Application to the Saponara and Itala catchments (Messina, Italy)

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ABSTRACT

Debris flows can be described as rapid gravity-induced mass movements controlled by topography that are usually triggered as a consequence of storm rainfalls. One of the problems when dealing with debris flow recognition is that the eroded surface is usually very shallow and it can be masked by vegetation or fast weathering as early as one-two years after a landslide has occurred. For this reason, even areas that are highly susceptible to debris flow might suffer of a lack of reliable landslide inventories. However, these inventories are necessary for susceptibility assessment. Model transferability, which is based on calibrating a susceptibility model in a training area in order to predict the distribution of debris flows in a target area, might provide an efficient solution to dealing with this limit. However, when applying a transferability procedure, a key point is the optimal selection of the predictors to be included for calibrating the model in the source area. In this paper, the issue of optimal factor selection is analysed by comparing the predictive performances obtained following three different factor selection criteria. The study includes: i) a test of the similarity between the source and the target areas; ii) the calibration of the susceptibility model in the (training) source area, using different criteria for the selection of the predictors; iii) the validation of the models, both at the source (self-validation, through random partition) and at the target (transferring, through spatial partition) areas. The debris flow susceptibility is evaluated here using binary logistic regression through a R-scripted based procedure.

Two separate study areas were selected in the Messina province (southern Italy) in its Ionian (Itala catchment) and Tyrrhenian sides (Saponara catchment), each hit by a severe debris flow event (in 2009 and 2011, respectively).

The investigation attested that the best fitting model in the calibration areas resulted poorly performing in predicting the landslides of the test target area. At the same time, the susceptibility models calibrated with an optimal set of covariates in the source area allowed us to produce a robust and accurate prediction image for the debris flows activated in the Saponara catchment in 2011, exploiting only the data known after the Itala-2009 event.



## 1. Introduction

The term, “debris flow”, refers to an extremely rapid surging flow of saturated debris in a steep channel, usually triggered by rare and extreme meteorological events (Hungr et al., 2013), typically taking the form of multiple occurring phenomena. In the Mediterranean region, these extreme meteorological events are strongly localized, hitting sectors of few tens square kilometres. Hence, highly susceptible areas might have never been stressed enough by intense rainfall to respond with a large landslide scenario. Moreover, debris flows activate in the hillslopes as very shallow flow/slide landslides and their morphological signature can be masked in a just few years by either rapid vegetation growth, weathering or by anthropic activity. Thus, even in areas that have been hit by severe storms, complete and reliable debris flow inventories can be hardly obtained, so that an effective calibration of landslide susceptibility models is hampered (Cama et al., 2015; Guzzetti et al., 2012; Lombardo et al., 2014, 2015, 2016a, 2016b). To deal with this lack of landslide inventories, several authors have successfully tested spatial transferability procedures.

Transferability refers to the procedure of calibrating a susceptibility model in a source (training) area, and validating it in a target (test)

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area, without major loss in predictive performance (Costanzo et al., 2012a; Lombardo et al., 2014, 2015; Petschko et al., 2014; von Ruette et al., 2011). A key point in all of these studies is the similarity of the geomorphological conditions and of the triggering event between the source and train areas.

Von Ruette et al. (2011) applied logistic regression to assess landslide susceptibility for both geomorphologically 'similar' study areas with different rainfall patterns and for 'dissimilar' study areas with landslides triggered by the same rainfall event. However, in their study, the transferability procedure is implemented without defining and adopting criteria for evaluating the similarity between the input variables in the calibration and validation areas. Petschko et al. (2014) addressed the problem of heterogeneity in lithological characteristics when assessing susceptibility by means of Generalized Additive Models both in spatial and non-spatial partitions, introducing modelling domains based on lithological units. This approach usually improves overall predictive performance because it considers the diversity of geotechnical conditions throughout the study area (Blahut et al., 2010; Petschko et al., 2012), but it requires homogeneity in the lithological domains between source and target areas.

Transferability procedures were also applied to two adjacent and very similar catchments (Giampilieri and Briga Messina- Italy), which were hit by the same storm event, demonstrating that the susceptibility obtained by transferring a Logistic Regression model can result in excellent predictive performance (Lombardo et al., 2014) also in comparison with the Stochastic Gradient Treeboost (Lombardo et al., 2015). However, in the aforementioned case, the selection of the model predictors was not based on similarity.

In this investigation, a test was carried out to ascertain the best factor selection criterion for optimal model building and transferring, considering the case of distant source and target areas hit by two different storm events. Unlike the aforementioned studies, an a priori analysis of similarity between source and target areas was performed and the performances of models built according to different factor selection criteria compared (see also Costanzo et al., 2012b). Besides, to detect the possible role played by the difference in the severity of the two triggering events, source and target areas were swapped and the transferring performances compared. For all of the prepared model, the debris flow susceptibility was evaluated by means of Binary Logistic Regression (BLR) and validated through Receiver Operating Characteristics (ROC) plots and confusion matrices.

The study areas are the Itala and Saponara catchments, which are located on the Ionian and Tyrrhenian sides of Messina province (Italy), respectively. The two areas were hit by two different extreme meteorological events. In particular, on the 1st of October 2009, the Itala catchment was struck by an extreme rainfall event far greater than any recorded in the previous 30-year period (Cama et al., 2015). On that occasion, 37 people died and hundreds of millions of euros of damage to buildings and infrastructure was estimated. Two years afterwards, on the 22nd of November 2011, a rainfall event, characterized by similar intensity and cumulative rain, hit the Saponara area triggering multiple debris flows and the death of three people.

Although the two catchments are located in the same climatic and geomorphological context (the Mediterranean climate, on the Peloritani Belt), they are characterized by heterogeneities, whose influences on the predictive performance of transferred models will be explored here.

The Saponara-2011 event constitutes a typical case for highlighting the relevance of transferability strategies in debris flow susceptibility model building, as in this catchment, few debris flow morphological signature could be observed after the 1st of October 2009, in spite of the hundreds that were triggered on the 22nd of November 2011. The possibility of using the Itala-2009 event to calibrate a model for the Saponara catchment would have been a way to deal with this hazard assessment and management impasse.

## 2. Study area

The Saponara and Itala catchments are located on the two opposite sides of the Messina province, the former facing the Tyrrhenian Sea, to the North, the latter overlooking the Ionian Sea, to the East (Fig. 1). Table 1 summarizes the main morphological characteristics of the two catchments, which share an analogous physiography, being both symmetrical and characterized by high ridges and steep slopes, connecting to deeply incised stream valley bottoms (Table 1).

This setting is the result of concurrent tectonics and high regional uplift rates. In fact, the whole north-westernmost edge of Sicily geologically reflects the concomitant Tyrrhenian Sea opening and the Ionian plate subduction under the Calabrian-Peloritan arc (Aldega et al., 2011; De Guidi and Scudero, 2013). This complex system can be summarised in a stack of different Alpine tectonic units, sometimes including a crystalline basement under remnants of Meso-Cenozoic covers (Massari and Prosser, 2013). In particular, the rocks outcropping in the two catchments encompass paragneiss and micashists of the Aspromonte Unit (Varisican metamorphites) and marbles and phyllites of the hercynian Alí Unit (Upper Triassic-Cretaceous), while differences in the Saponara catchment are due to the presence of lower Serravallian to lower Messinian deposits: i) marl and sandstone; ii) grain stone; iii) limestone and claystone.

The aforementioned regional setting gave rise to several steep and small catchments with a highly torrential hydrologic regime on both the north-eastern and south-western slopes of the Peloritani Mountain Belt, such as the two test catchments that are considered in this investigation. The streams are generally short, no longer than 10 km and measuring an average length of 4–5 km. The high slope of the streams (average of 10–15%) and the small extension of the catchments determine short concentration times, always <1 h. For this reason, although these torrents are usually dry, under rainfall events, the flow and the sediment transport rapidly increases frequently determining flooding in the coastal plain sector. Consequently, the infrastructure (especially roads) located near the riverbanks is exposed to a high to medium-high level of flood or debris-flood (Hungr et al., 2013) risk. More intense rainfall events, which are much less frequent and typically more localized, can cause the activation of slope phenomena such as multiple debris flows. For example, Cama et al. (2015) observed that the daily rainfall intensity of the 2009 event was unique in 30 years at least. This extreme event produced the saturation of the soil and the activation of the multiple debris flows, which caused huge damages to infrastructures, private buildings and fatalities.

In terms of climatic settings, the two catchments share the same Köppen class (Köppen, 1923), the Mediterranean (Csa)-type. In fact, the typical trend presents a wet season from September to March followed by a dry season from April to August. Consequently, the two catchments are similarly exposed to precipitation with estimated mean discharges, in the 1950–2000 period, of 769 and 746 mm/year for Saponara and Itala respectively (http://www.worldclim.org/; Hijmans et al., 2005).

Despite the fact that the annual amount of rainfall is analogous for the two catchments, the Peloritani belt acts as a regional meteorological barrier for single-cell storms causing extreme events. When a given cumulonimbus moves from the sea inland, it is confined either on the Tyrrenian or on the Ioninan side, resulting in very different (from dry to severely rainy) meteorological scenarios just a few kilometres apart. Storm events in the September–October transition period have been recorded in both areas (Cama et al., 2015) whose high intensity is the result of the warm Mediterranean water and the slow inland movement connected to the westerlies fall down.