A landslide warning concept for Switzerland based on daily rainfall thresholds

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INTRODUCTION

Rainfall is a key triggering variable for many natural hazards in Alpine environments, most notably floods, landslides and debris flows. Although most of the damage in Switzerland is due to floods (Hilker et al., 2009), landslides potentially affect larger areas and their locations are more difficult to predict. Statistical predictive models relate landslide occurrence to explanatory pre-disposing variables such as hillslope angle and shape, soil type, land cover, etc. Regional or event landslide inventories are then used to estimate the parameters of the models. The intensity of triggering rainfall may be included as a discriminatory factor or as a minimum rainfall threshold in landslide rainfall intensity-duration threshold curves.
A key problem is the lack of long-term rainfall and landslide data, which precludes a proper validation of the models and quantification of prediction errors.
In this paper we address the predictability that can be ascribed to daily rainfall as a triggering process for landslides. We have two specific goals: a) to present a method to objectively define rainfall thresholds that are associated with landsliding by combining two long-term datasets of landslides and precipitation in Switzerland; and b) to analyze the rainfall thresholds in conjunction with the susceptibility of the landscape to landsliding (geology, erodibility, etc.). On this basis we explore the potential of a simple landslide warning concept which on the basis of a daily rainfall forecast can indicate regions with landslide potential, including associated prediction errors.

METHODS

WSL has been systematically collecting information on flood and mass movement damage since 1972 (Hilker et al., 2009). We extracted over 2000 landslides with known location and date from this dataset. We matched the landslide location sites to the 2x2 km gridded MeteoSwiss dataset RhiresD.
At each site we extracted rainfall events (consecutive days with rainfall exceeding 1 mm) and computed for each of these the following properties: total depth, duration, mean intensity, maximum daily intensity.
Rainfall events were divided into two groups: those that triggered landslides and those that did not.
The prediction of trigerring events was based on the event properties exceeding a threshold. We tested different thresholds and for each we computed performance measures such as sensitivity, specificity, AUC, true skill statistic, comparing event predictions and landslide observations. The optimum threshold for each event property was then selected as the one maximizing the percentage of both true positive and true negative predictions.
The same approach was repeated for landslides divided into meaningful landslide susceptibility classes by lithology, surface erodibility, vegetation cover, mean annual precipitation, etc. Resampling methods were used to quantify the threshold estimation error.

RESULTS

1. All event properties except event duration have some predictive power, with specificity and sensitivity between 0.7 and 0.85. The corresponding country-wide estimated threshold values were 43 mm for event total, 25 mm/d for the maximum daily intensity and 14.6 mm/d for the mean intensity. Probability maps of triggering rainfall which can be used for landslide susceptibility assessment were generated with these thresholds, for instance in Fig 1 for the maximum daily intensity threshold of 25 mm/d. The predictive performance is generally higher in the summer months when heavy convective rain is the dominant storm type. The definition of rainfall thresholds is naturally limited by the daily resolution used and the fact that physical process understanding of actual landslide

triggering is not explicitly included in this approach.
2. Two landslide susceptibility variables were found to significantly impact rainfall thresholds: land surface erodibility and mean annual precipitation. The inclusion of erodibility based on a geotechnical classification by Kuehni and Pfiffner (2001) showed that rainfall triggering thresholds are generally lower on more erodible soils, while areas with high mean annual precipitation showed higher rainfall triggering thresholds (e.g. Tessin in southern Switzerland). The latter result is likely related to the landscape-scale balance between climate, erosion and soil formation, and indicates that regions with high mean annual rainfall have the surface stripped of soils on susceptible slopes and a higher rainfall threshold is needed to generate landslides there.

CONCLUSION

A methodology for an objective selection of rainfall events which are associated with landslides across Switzerland based on a long-term landslide inventory and a new gridded daily precipitation dataset was presented. The approach allows the estimation of rainfall thresholds, the quantification of prediction error, and the mapping of precipitation triggering potential as a basis for landslide risk analysis (e.g. Nicolet et al., 2013). An elementary landslide warning concept can be based on this analysis in conjunction with accurate rainfall forecasts.

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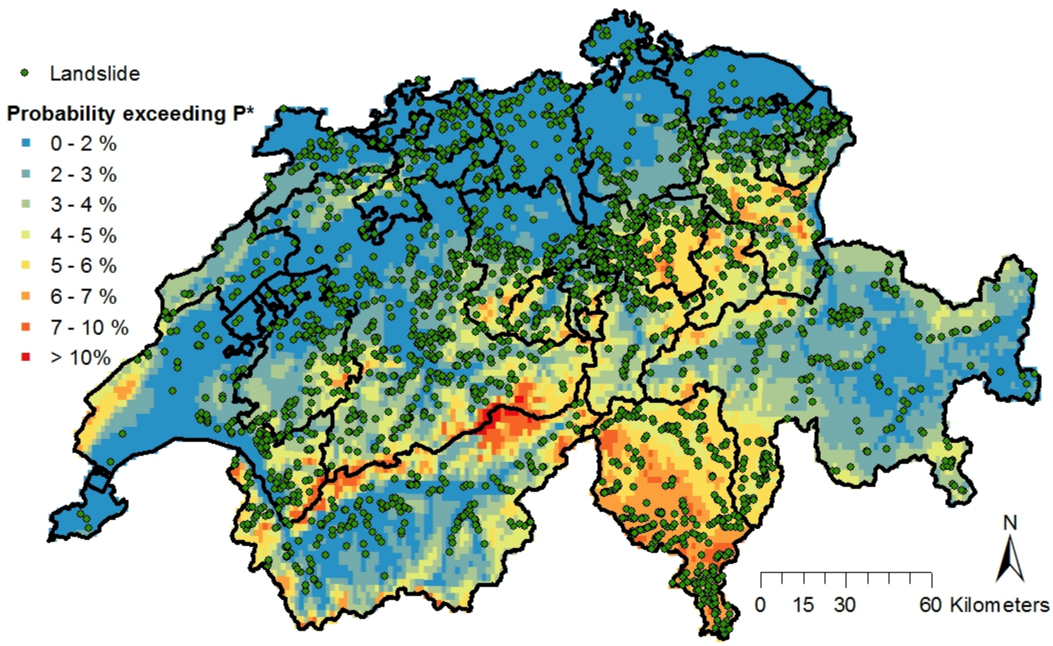

Figure 1. The probability of exceeding a daily rainfall threshold of P* = 25 mm/day estimated for the period 1972-2012 from the gridded precipitation dataset RhiresD (MeteoSwiss) as the percentage of days when P* was exceeded for each cell. Green dots show the landslide locations in the period 1972-2014 from the WSL Landslide Dataset (Hilker et al., 2009)

KEYWORDS

shallow landslides; rainfall extremes; statistical prediction; warning system

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