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## Application of SIGMA model for landslide forecasting in Darjeeling Himalayas

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SIGMA (Sistema Integrato Gestione Monitoraggio Allerta – integrated system for management, monitoring and alerting) is a landslide forecasting model at regional scale which is operational in Emilia Romagna (Italy) for more than 20 years. It was conceived to be operated with a sparse rain gauge network with coarse (daily) temporal resolution and to account for both shallow landslides (typically triggered by short and intense rainstorms) and deep seated landslides (typically triggered by long and less intense rainfalls). SIGMA model is based on the statistical distribution of cumulative rainfall values (calculated over varying time windows), and rainfall thresholds are defined as the multiples of standard deviation of the same, to identify anomalous rainfalls with the potential of triggering landslides.

In this study, SIGMA model is applied for the first time in a geographical location outside of Italy, i.e. Kalimpong town in India. The SIGMA algorithm is customized using the historical rainfall and landslide data of Kalimpong from 2010 to 2015 and has been validated using the data from 2016 to 2017. The model was validated by building a confusion matrix and calculating statistical skill scores, which were compared with those of the state-of-the-art intensity-duration rainfall thresholds derived for the region.

Results of the comparison clearly show that SIGMA performs much better than the other models in forecasting landslides: all instances of the validation confusion matrix are improved, and all skill scores are higher than I-D thresholds, with an efficiency of 92% and a likelihood ratio of 11.28. We explain this outcome mainly with technical characteristics of the site: when only daily rainfall measurements from a sparse gauge network are available, SIGMA outperforms other approaches based on peak measurements, like intensity – duration thresholds, which cannot be captured adequately by daily measurements. SIGMA model thus showed a good potential to be used as a part of the local Landslide Early Warning System (LEWS).