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# Dynamic modelling for linear erosion initiation and development under climate and land-use changes in northern Laos

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## Abstract

Linear erosion (LE) induced either by piping or overland flow is one of the most active factors in the evolution of soils. During single storm events LE may remove enormous amounts of soil material from the uplands to the bottomlands and has thus become a broad challenge for food supply, food security, and human health. Recent and rapid changes in land-use and climate patterns in the sloping lands of tropical areas may dramatically increase LE. Our main objective was to investigate to what extent one could use direct flow velocity estimations from dynamic models for predicting LE initiation and development at the event level. The second objective was to estimate the impact of expected land-use and climate changes on LE. The study was conducted in the 0.62 km$^2$ watershed of northern Laos presented in Chaplot et al. (2005). Field observations of the formation and the development of LE features throughout 2001 were compared to flow velocity estimations from an existing surface water routing algorithm developed at Utrecht University ([De Roo, A.P.J., Wesseling, C.G. and Ritsema, C.J. 1996. LISEM: a single event physically based hydrologic and soil erosion model for drainage basins. I: theory, input and output. hydrological processes 10 (8): 1107–1117.]). In 2001, two main rainfall events were responsible for the formation or development of 14 linear features with a total length of 972 m and an erosion rate of 3.5 Mg ha$^{-1}$. The water routing algorithm was calibrated using the water and the sediment hydrographs observed at the watershed outlet during the first rainfall event. Assuming realistic estimations of flow velocity in hillslopes, a threshold of 0.062 m s$^{-1}$ for linear erosion estimated over 10-m cells was defined. This threshold, validated using the remaining rainfall event, accurately predicted the length (mean error of estimate

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of less than 15%) and location of LE features. Using this simulation tool, an increase of the percentage of land under cultivation from 9% to 100% resulted in 600% increase in linear erosion. The tested scenarios of climate changes had less impact on linear erosion.


*Keywords:* Linear erosion; Flow velocity; Dynamic modelling; Global change; Asia

## 1. Introduction

Linear erosion leads to irreversible damage of cropping systems by removing fertile horizons of soils and reducing the water holding capacity. Linear erosion is also responsible for off-site consequences such as debris flow or the fill of valley bottoms and reservoirs. Because these on- and off-site effects may dramatically jeopardize the future of natural ecosystems and the economic development of societies, the evaluation of linear erosion has thus become an essential issue. Recent concerns about changes of climate and land-use patterns caused by demographic, economic, political and/or cultural evolution, emphasise the need for better evaluation and spatial prediction of linear erosion. Furthermore, it is crucial to be able to predict the impact of expected changes of climate and land-use on linear erosion.

Many attempts at modelling the spatial occurrence of rills or gullies have been carried out. The cited literature shows that there has already been extensive research on the role of topographical attributes in gully incision (Poesen et al., 1997). The concept of topographic control on the erosive power of overland and concentrated flow (Horton, 1945) led to the determination of the position of linear features as the area between an upper boundary, where the flow velocity exceeds the shear stress, and a lower boundary that will halt gullying and where sedimentation processes mainly occur. Some topographical parameters, such as local slope gradient (S) and drainage-basin area (A) have thus been used to predict gully occurrence. The topographic thresholds for gully or rill initiation may vary from site to site depending on processes involved in gullying. When overland and concentrated flow is the main mechanism in linear feature formation, the threshold varies between $S \times A > 18$ (Moore et al., 1988) and $S \times A^{0.4} > 0.72$ (Desmet and Govers, 1997). Saturated overland flow induced a $\ln(A/S) > 6.8$ threshold (Moore et al., 1994). The topographic threshold for gullying's lower limit occurred when the slope gradient decreased below a certain level, for example below 4% in the Belgian loess belt (Nachtergaele et al., 2001).

However, these topographic thresholds alone may induce high prediction errors in the estimation of the spatial distribution of gullies. Indeed, when Vandekerckhove et al. (1998) applied this topographic threshold concept to different landscapes of Spain and Portugal, their results revealed that S and A were weakly correlated to gullying. The prediction of gully erosion was considerably strengthened by including additional information on land-use, soil stoniness, and horizon hydraulic conductivity. In addition, single topographic thresholds were unable to predict the evolution of gully morphology and in particular the retreat of their head-cuts. These results demonstrated that environmental factors other than