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A statistical approach to predict gully initiation susceptibility with common spatial data

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In many Mediterranean and arid landscapes, permanent gullies are common features and quite often they represent the dominant soil erosion process. The initiation and the development of a gully and gully systems are complex and somehow stochastic. From field evidences it is known that gully channel formation and upslope migration is usually very rapid just after the initiation of the gully. In order to prevent the undesired effects of gullies, there is thus a need to anticipate the places were new gullies might initiate. To model where gully erosion will occur by the extension of an existing gully or the formation of a new gully is difficult and requires detailed field investigations and high resolution accurate Digital Topographic Models (DTMs), which is usually not easy to obtain.

From detailed field measurements and high-resolution DTMs, several studies have demonstrated strong inverse relationships between contributing area and slope at channel heads over several catchments in different climatic and morphological environments. The knowledge of such area-slope thresholds (A-S) at gully heads allows prediction of the location of gully initiation.

This research proposes an approach that combines the A-S thresholds with a logistic regression analysis (LR). The LR is low data demanding and requires predictor variables that can be extracted from common spatial data (topographic and lithologic maps, aerial photographs).

We focus on a 51 km^2 sub-basin of the Isser River watershed, close to the town of Algiers (N Algeria), where gully erosion affects most slopes. The lithology (mainly marls) and the vegetation (mainly cultivated lands with sparse scrublands) are quite homogenous. We mapped 181 gully systems from the interpretation of 1:20 000 aerial photographs available only for one period. The gullies extend up to several kilometres in length and up to 10 meters in depth. They cover 16% of the study area. A DTM was derived from a 1:50 000 topographic map at 20 m resolution. Considering the size of the gullies, this resolution allows to distinguish between the gully triggering area and the gully extension area.

The first step was to locate the initiation areas of the existing gullies. They were determined by applying A-S thresholds found in literature for Mediterranean areas. Then, using the initiation area map as the dependent variable with combinations of several predictor variables (elevation, profile and planform curvature, topographic wetness index, stream power index, length-slope factor, lithology, etc.) we produced several LR models. It provided relevant results in terms of statistical reliability (sensitivity analysis), prediction performance (areas under the ROC curve = 0.85) and geomorphology. The models show that gully erosion initiates on steep slopes developed in marls where runoff water concentrates. The susceptibility maps allow a better understanding of the gully process and the development of gully systems in that area.

This approach combining A-S thresholds with multivariate statistical models like LR proves to be efficient when applied to common spatial data and establishes a methodology that will allow similar studies to be undertaken elsewhere.