Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 441-443, 5 figs., 1 tab.

Identifying gullies in the Mediterranean environment by coupling a complex threshold model and a GIS

D. TORRI (1), L. BORSELLI (2), S.L. GARIANO (3), R. GRECO (3), P. IAQUINTA (3), G. IOVINE (3), J. POESEN (4), O.G. TERRANOVA (3)

Key words: *gully, threshold model, GIS*

INTRODUCTION

Soil erosion by water is an important physical process that leads to land degradation. In particular, gully erosion may contribute, in some cases, to 70% of the total soil loss. Water erosion occurs, forming a channel, when the erosive forces of overland flow exceed the strength of the soil particles to detachment and displacement. A relationship between local slope, *S*, and contributing area, *A*, is supposed to exists as runoff is proportional to the local catchment area. Therefore, an approach to interpret the physical process of gully initiation can be based on the concept of "geomorphologic threshold".

Already in the seventies, PATTON & SCHUMM (1975) and BEGIN & SCHUMM (1979) began modeling gully erosion as a threshold process. They suggested that an equation could be derived by considering that, to excavate a gully channel, the overland flow should produce shear stresses in excess of a critical value. This approach was further organized and systematized by MONTGOMERY & DIETRICH (1994). Similarly, a gully can be assumed to end when there is a reduction of slope, or the concentrated flow meets more resistant soil-vegetation complexes.

METHOD

This study aims to predict the location of the beginning of gullies, on the base of evaluation of *S* and *A*, by means of a mathematical model. To identify the areas prone to gully erosion, the model employs two empirical thresholds relevant to the head (T_{head}) and to the end (T_{end}) of the gullies (of the type $SA^b > T_{head}$, $SA^b < T_{end}$). Such thresholds represent the resistance of the environment to gully erosion, depending on: stoniness, vegetation cover, propensity to tunnelling erosion due to soil dispersibility in water, and the intrinsic characteristics of the eroded material and of the erosivity of the rainfall event.

Such thresholds must be weighed with the local steepness *S*, and applied to all the points of the spatial domain. The mathematical model works in steps as follows: (i) the territory is partitioned into elementary cells; (ii) a pre-processing allows for the identification and removal of sinks in the DTM; (iii) through analyses of hydraulic connectivity, the hierarchical relationships between the various cells are determined.

Literature data on the problem of topological threshold T_{head} was critically analysed. More in detail, data relevant to a) rangeland, b) renaturation situations (usually after abandonment), and c) databases for cropland have been merged. Selected data (see Tab. 1 in which "transitional" refers to abandoned land moving towards re-naturalization) have been examined and interpreted mathematically to assess a value to be taken as a constant for the exponent "*b*" of the above equation.

Tab. 1 – Literature data.

	rangeland		cropland		transitional	
	Coefficient (k)	**Exponent (b)**	**Coefficient (k)**	**Exponent (b)**	**Coefficient (k)**	**Exponent (b)**
average	0.36	0.27	0.07	0.28	0.19	0.21
st dev	0.35	0.14	0.07	0.16	0.17	0.11
median	0.31	0.26	0.06	0.30	0.14	0.20

Literature data on the problem of topological thresholds T_{end} are quite few. The basin area loses its relevance in the considered relationship between *A* and *S*; therefore, a constant value of *S* can be chosen as a threshold, as the trend with the basin area can present a very small exponent.

From Tab. 1: i) the explanatory paper by MONTGOMERY & DIETRICH (1994) seems to be falsified; ii) the exponent *b* may be a constant in the 3 situations; iii) the coefficient *k* shows a net change (i.e., it increases with increasing and more stable vegetation cover). This is in agreement with several erosion models, even if not specifically built to predict gullies (e.g. USLE, RUSLE, EUROSEM, KINEROS, WEPP). Regarding item i), it can be expected that the assumption of steady state is almost never verified. It is well known that runoff time-to-concentration increases with increasing size of the catchment, and that longer rainfall durations imply longer return periods. In other words, if the area of the catchment is used as

(1) CNR-IRPI - Perugia, Italia – e-mail: torri@cnr.it
(2) Instituto de Geologia / Fac. de Ingegneria, Universitad Autonoma de San Luis Potosì (UASLP) – MEXICO.
(3) CNR-IRPI – U.O.S. di Cosenza, Italia.
(4) GEO-INSTITUTE, Heverlee, Belgium.

"catchment area", areas larger than the real ones may be selected, and *A* may not be representative of the discharge anymore. A set of these types of data can artificially lower the exponent. Even trying to get the highest possible exponent out of the area-slope data, this caused a raising in the exponent which, in all cases, remained well below the 0.5-value proposed by MONTGOMERY & DIETRICH (1994) for laminar flow conditions, with a mean value of b=0.38±0.21, n=18 (5 of which from datasets by Montgomery and Dietrich; dataset derived from DTM and maps were ignored).

RESULTS

A threshold line for deposition to occur and for gullies to disappear was selected. This produced a line of "improbable gully observation" (i.e. sedimentation is certain if a gully is observed upslope) cutting through the line of gully Slope-Area threshold, as depicted in Fig. 1 (red line). The chosen trend for the lower end was taken from NACHTERGAELE *et al*. (2001). The composed threshold line (gully initiation and gully end) is also shown in Fig. 1, in which the blue line is still one possible threshold for gully head positioning - i.e. gully initiation (INI) - and the green line represents the effective threshold (ET).

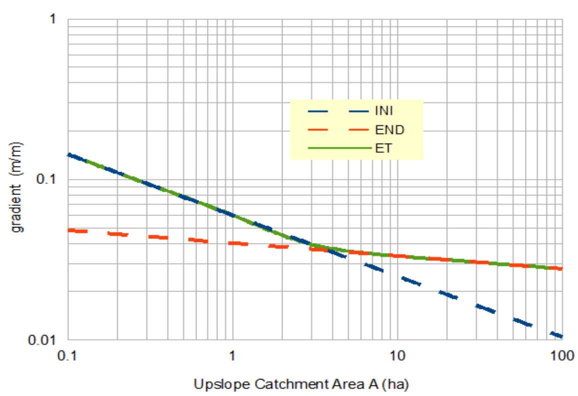

Fig. 1 – Composed threshold line. Blue line: possible threshold line for gully head positioning - i.e. initiation (INI); green line: effective threshold line (ET).

The model was applied to the "Esaro of Crotone" basin (Fig. 2), in Calabria, characterised by a Mediterranean climate. To calibrate the model, the following layers have been employed: (i) a 5-m DTM, (ii) a soil map at 1:25.000 scale, (iii) a land use map (CORINE-level IV).

Fig. 2 – Localization of the "Esaro of Crotone" basin.

A sample check of the data has been conducted by means of direct surveys. Validation of the model and evaluation of its performances have been performed through photo-interpretation of low-altitude flights (Fig. 3).

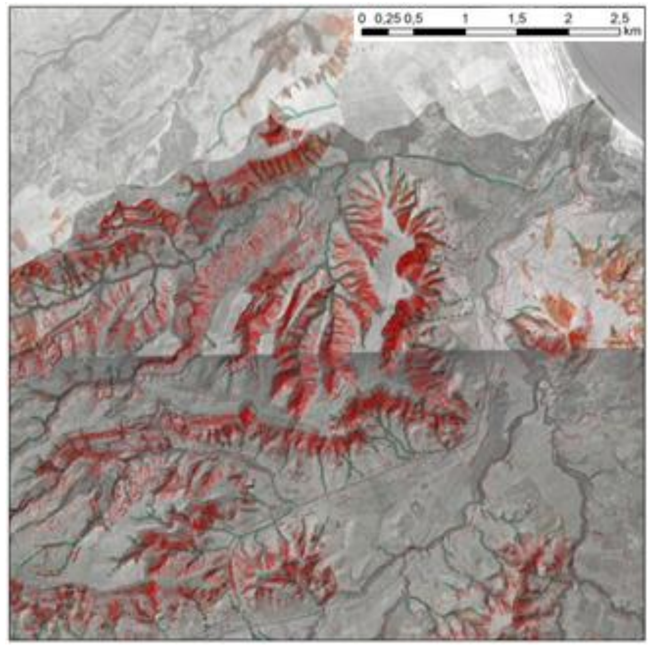

Fig. 3 – Gully-prone areas: sectors mapped through interpretation of air-photos are shown in pink; results of the model are in red.

As a result, a susceptibility map to gully erosion is presented (Fig. 4), related to the different combination among *A*, *S*, land use, and soil characteristics of the examined basin. Finally, an analysis is proposed (Fig. 5), based on the comparison between the current land use and a scenario characterized by insertion of sown grass strips for a number of land uses and for a set of slope classes.

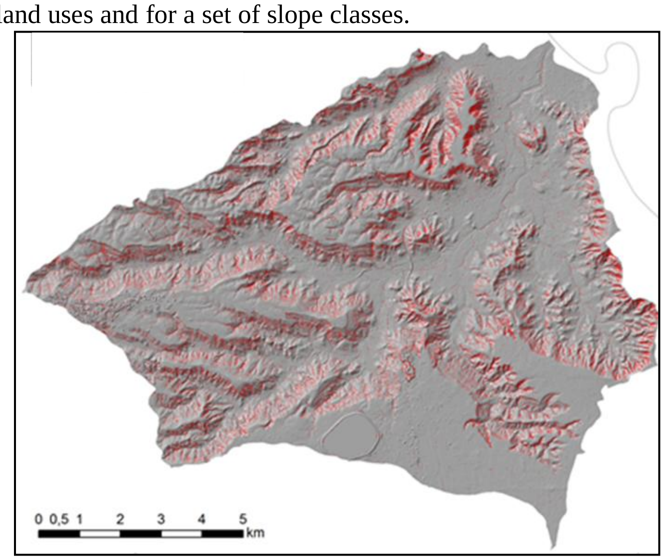

Fig. 4 – Susceptibility map to gully erosion. Actual combination among *A*, *S*, land use, and soil characteristics.

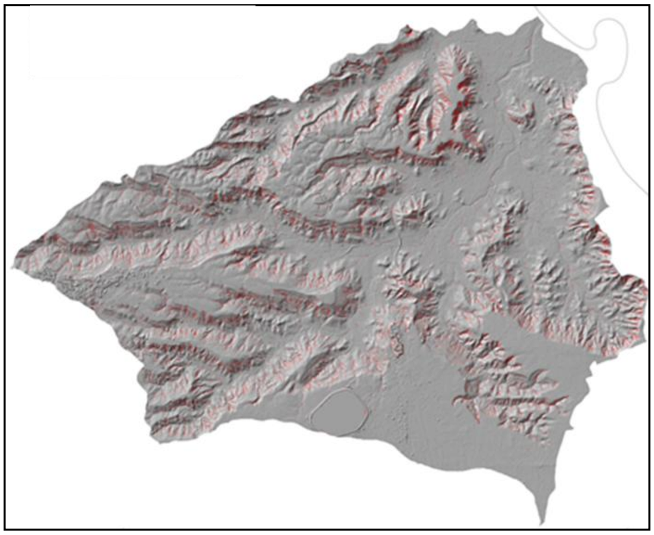

Fig. 5 – Susceptibility map to gully erosion relative to the insertion of sown grass strips for certain land uses and slope classes.

DISCUSSION

The model, as developed so far, is not definitive yet. The relationships have to be re-examined all together, to tune them and avoid over- or under-estimation of existing data. This phase, still in progress, is necessary before applications can be attempted, as – up to date – all the sub-factors have been determined by using only a subset of available data. Nevertheless, the methodological attempt of model application, described above, confirms that the adopted mathematical structure is able to properly capture real situations.

The review of published data on gully area-slope thresholds suggested a lower catchment area exponent with respect to the one proposed by Montgomery and Dietrich, which may be kept constant. In this case, differences in the position of the threshold curve in the Area-Slope diagram will be reflected entirely by the coefficient (slope of the line in the double log representation). This latter can be subdivided into a series of sub-factors, related to rock fragment content, vegetation, and dispersibility of the soil. The relationships here presented are only a first, rough approximation, and need further investigation. Their consistence with a real situation (i.e. the Esaro catchment) suggested that the adopted approach may allow for a better understanding of gully headcut locations and dynamics.

REFERENCES

BEGIN Z.B. & SCHUMM S.A. (1979) - *Instability of alluvial valley floors: a method for its assessment.* Transactions of the ASAE, 347-350.

MONTGOMERY D.R. & DIETRICH W.E. (1994) - *Landscape dissection and drainage area-slope thresholds*. Chapter 11. In: Kirkby M.J. (Ed.), Process models and theoretical geomorphology, John Wiley & Sons Ltd., 221-246.

NACHTERGAELE J., POESEN, J., STEEGEN, A., TAKKEN, I., BEUSELINCK, L., VANDEKERCKHOVE, L. & GOVERS, G. (2001) - *The value of a physically based model versus an empirical approach in the prediction of ephemeral gully erosion for loess-derived soils.* Geomorphology, **40**, 237–252.

PATTON P.C. & SCHUMM S.A. (1975) - *Gully Erosion, Northwestern Colorado: a threshold phenomenon.* Geology, **3**, 88-90.

POESEN J.W.A., TORRI D.B. & VANWALLEGHEM T. (2011) - *Gully erosion: procedures to adopt when modelling soil erosion in landscapes affected by gullying.* Chapter 19, In: Morgan, RPC & M.A. Nearing (Eds.), Handboook of Erosion Modelling, pp.360-386.