GEOMORPHOMETRY 2020 PERUGIA, ITALY JUNE 22 - 26 2020

# GIS-based geomorphometric analysis of stream networks in mountainous catchments: implications for slope stability

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*Abstract*—**This work presents the application and validation of a GIS-based toolbox called SLiX, devoted to extract Stream Length-gradient (SL) index values along stream networks starting from Digital Elevation Models (DEMs). SL anomalous values are helpful to outline significant deviations from the concave-up shape of river longitudinal profiles of bedrock streams within mountainous catchments. The spatial analysis of SL index may be suitable for detecting along stream knickzones, supporting the investigation of the process responsible for their formation such as active tectonics, landslides interacting with streambeds or variations in bedrock resistance to erosion. The application in a mountainous catchment localized in the central Apennines (Italy) confirmed the proper functionality of the tool and the potentiality of the SL spatial analyses. This analysis has been integrated by the study of the Slope-Area (SA) function, which provided the contributing area threshold value required for the extraction of the stream network. SA analysis also supported the geomorphological interpretation of the knickzones detected through the SLiX application. The combination of SL and SA analyses in the sample area within the central Apennines revealed practical for detecting a major knickzone at a paleo-lake originated by the run-out of a rockslide. The SA function allowed interpreting the knickzone as one of the slope-break typologies, suggesting its occurrence and upstream propagation before the emplacement of the mass movement.**

## I. Introduction

Geomorphometric analysis of stream networks and the quantitative analysis of stream longitudinal profiles are useful for the landscape evolution modelling within mountainous catchments. The identification of anomalous gradients occurring along bedrock stream longitudinal profiles (i.e. knickzones), can be practical for detecting mass movements directly interacting with streambeds at the catchments scale [1]. Many geomorphometric indexes have been demonstrated to be suitable for detecting anomalies along stream long profiles [2 and reference therein]. In particular, the Stream Length-gradient (SL) index allows outlining significant deviations from the concave-up shape of stream long profiles supporting the geomorphological interpretation of the processes responsible for the knickzone formation, such as the presence of a geological structure not necessary active, the occurrence of a landslides or the variations of the bedrock resistance to erosion [3 and reference therein]. The analysis of the along stream distribution of the slope values and the contributing area (i.e. SA function) can be practical for the interpretation of the knickzone typology [4]. This analysis allows discriminating the slope-break category, which encompass upstream propagating knickzones due to major variations of the base level of erosion, from the vertical steps, generated by local disturbances (i.e. lithological changes, meander cut-off, stream damming).

The growing availability of information technologies allows facing the application of geomorphometric indices with new tools and taking advantage from GIS procedure. A GIS-based toolbox, named SLiX, has been proposed by Piacentini et al. (2020) [5] to extract SL index values with a reproducible, standardized and timesaving process. The tool allows avoiding an error-prone procedure consisting of several step-by-step phases for converting the DEM dataset in SL index values. In this work, the SLiX toolbox has been used in order to detect the knickzones correlated with the main slope instability occurring within a mountainous catchment located in the central Apennines (Italy) (Fig. 1). The study has been supported by the analyses of the SA function with the double aim of selecting the appropriate contributing area value

*Daniela Piacentini, Francesco Troiani, Mattia Marini, Marco Menichetti and Olivia Nesci (2020)*
*GIS-based geomorphometric analysis of stream networks in mountainous catchments: implications for slope stability:*
*in Massimiliano Alvioli, Ivan Marchesini, Laura Melelli & Peter Guth, eds., Proceedings of the Geomorphometry 2020 Conference, doi:10.30437/GEOMORPHOMETRY2020_68.*

for the channel initiation threshold [6, 7] and for supporting the interpretation of the process responsible for the formation of the along stream anomalous zones [4].

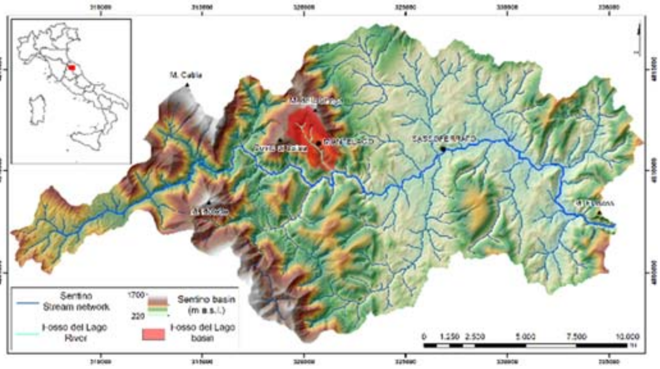


**Figure 1.** Location and altimetry of the study area coinciding with the Sentino catchment (Central Apennines, Italy). The location of the Fosso del Lago tributary has been also reported.

## II. Methods

The interactions between stream network and slope morphodynamics within the Sentino River basin has been investigated by means of a coupled geomorphometric analysis based on the computation of the Stream Length-gradient (SL) index and the study of the Slope-Area (SA) function. The analysis has been based on a 10 m cell-sized DEM, derived from altimetric dataset included in the topographic map, available in vector format at the scale of 1:10.000.

### *A. Computation and spatial analysis of the SL index*

The SL index, according to Hack (1973) [8], is a suitable parameter to detect the deviations of a bedrock stream long profile from the steady-state conditions. In particular, SL may be to be a valid tool for identifying anomalous gradients along bedrock stream channels in mountainous catchments.

The SL Index is defined by the equation 1:

$$SL = \frac{dH}{dL} \times L \qquad (1)$$

where dH is the variation of elevation between two points of the stream channel, dL is the distance between the two points, and L is the total channel length from the channel initiation (Fig. 2).

The SL index values have been extracted taking advantage of the SLiX Toolbox [5] (Fig. 3). The toolbox allows, by means of a codified and timesaving process, to identify landscape portions where anomalous high values of SL Index occur and, consequently, where stream channels show peaks in the erosional dynamic (i.e. knickzones).

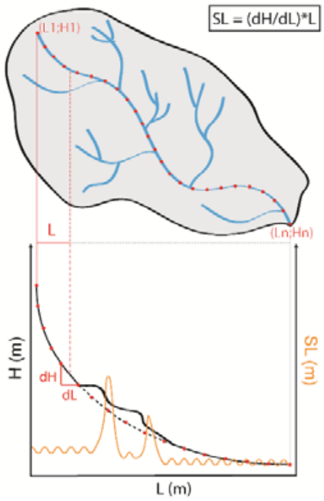


**Figure 2.** Parameters considered for the along stream calculation of SL index values following the Hack's equation (from [5]).

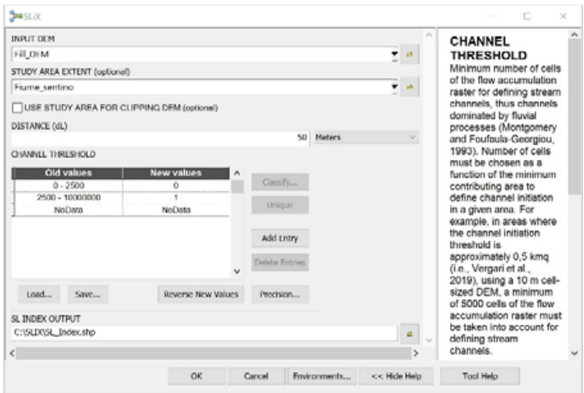


**Figure 3.** SLiX Toolbox mask [5].

### *B. Calculation and interpretation of the SA function*

The SA approach is valid to explore the morphevolution of drainage basins in mountainous landscapes. In particular, the SA function demonstrated to be a valid way for detecting critical thresholds separating slope and channel process domains [6] and for supporting the interpretation of the different knickzone typologies that can characterize stream long profiles [4]. The SA function is pointed out by SA plots [9] where the slope, in m/m, is empirically expressed in function of the drainage area, in $m^2$.

The log form of this relationship is:

$$\log(S) = \log(k_s) + \theta \log(A) \qquad (2)$$

where $k_s$ is the channel steepness index, and θ is the channel concavity index. Hence, the $k_s$ and θ can be readily obtained from the log–log plots [10], computed adopting the method proposed by Tarolli and Della Fontana (2009) [11]. In particular, computing the SA plot for the main channel, within a given catchment, can provide information on the typology of a knickzone. The slope-break typology will appear as a break on the SA scaling and, generally, is indicative of an upstream propagating knickzone generated as the response of the fluvial system to a major variation of the base-level of erosion [4 and reference therein].

## III. Results

The application of the SA analysis using the "total basin" method provided the value of contributing area to be used as threshold for the channel initiation (Fig. 4).

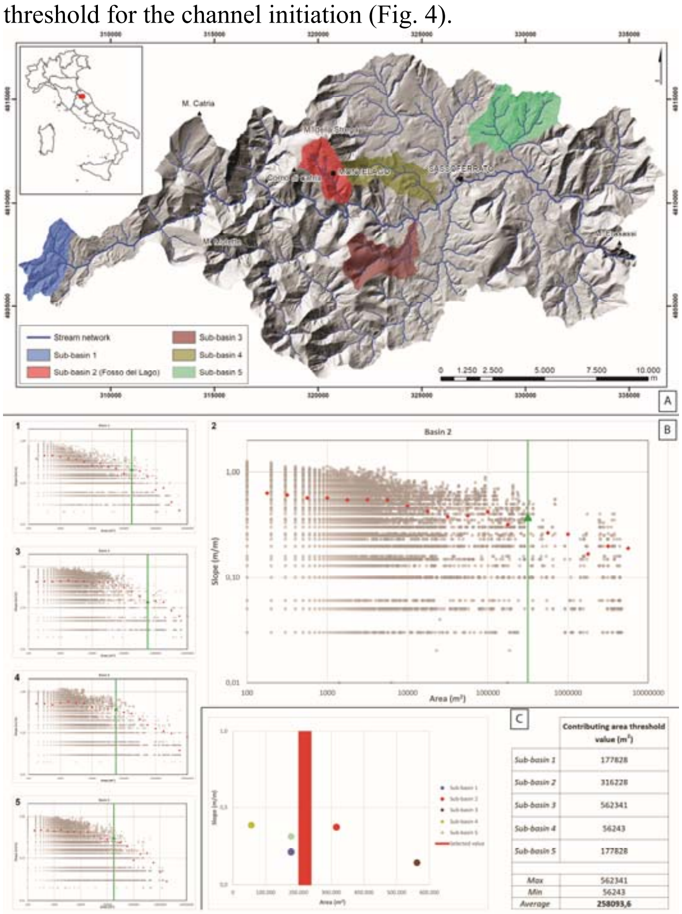


**Figure 4.** SA total basin analysis within five-selected tributary basins (A). The trends and forms of the SA function provided the contributing area threshold value for the extraction of the stream network (B). The selection of the contributing area value equal to 0.25 km$^2$ for the channel initiation (C) allows for extracting only those streams, which are actual dominated by the fluvial process.

The value of 0.25 km$^2$ resulted as mean value of the SA plots computed within five selected tributary catchments, representative of the complex lithological and geomorphological settings of the Sentino River basin. This channel threshold allows the extraction of the stream network including only those channels where the fluvial process is dominant.

Along the extracted stream network, using the procedure included in the SLiX toolbox, the raster map of the location of the major SL anomalous zones has been produced [5]. This map outlines the main knickzones occurring within the Sentino River basin (i.e. SL-HCA map according to [3]) (Fig. 5).

One of the major anomalies occurs within the Fosso del Lago tributary catchment, in the western portion of the study area, along the western flank of the Mount Strega morphostructure.The left valley-side of the Fosso del Lago is characterized by the presence of a rockslide well known in literature [12]. In particular, the mass movement caused the formation of a landslide-dammed lake. This landslide-dam emplaced at the end of the Upper Pleistocene and the resulting lake existed during the Holocene until historical time [13].

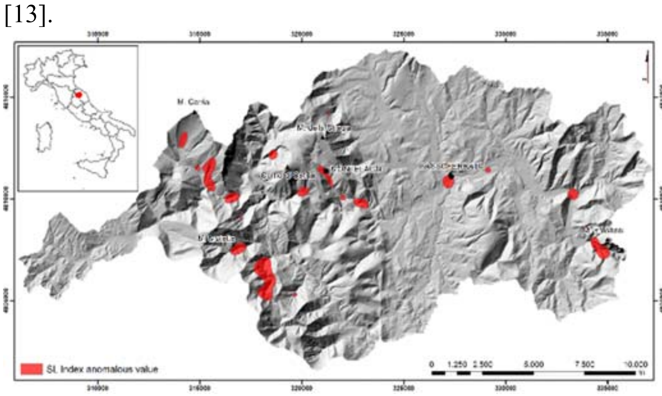


**Figure 5.** Distribution of the anomalous values of SL index detected by the application of the SLiX toolbox [5] within the Sentino River basin. In particular, in red are reported the knickzones identified in agreement with the Hotspot and Cluster Analysis (HCA) approach [3].

Along the main channel flowing within the Fosso del Lago tributary catchment, the SA plot has also been computed (Fig. 6). A break in the SA scaling suggests interpreting the knickzone as one of the slope-break typologies. Therefore, the present-day geometry of the Fosso del Lago long profile is the result of an upstream migrating knickzone that reached the middle portion of the catchment. Here, the augmented relief energy due to the strong stream entrenchment likely produced the morphoevolutionary context during which the slope collapsed, probably favored by the local morphostructural conditions and an intense rock mass fracturing.

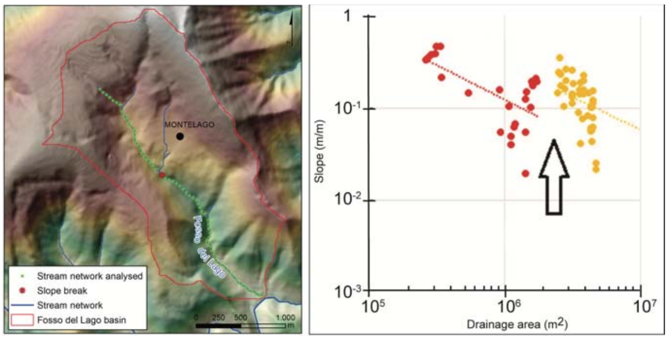


**Figure 6.** Location of the knickzone occurring along the Fosso del Lago tributary catchment. The break on the SA scaling along the main channel allows interpreting the knickzone as one of the slope-break typologies in agreement with Boulton et al. (2014) [4].

## IV. CONCLUSIONS

In this work, we applied a coupled geomorphometric analysis of the stream network, flowing within a mountainous catchment in the central Apennines (Italy) that allowed identifying the major knickzones occurring along the stream long profiles. The results confirmed the validity of the use of the SLiX Toolbox for the computation and the spatial analysis of the SL anomalous values. Within mountainous catchments, many SL anomalies have been demonstrated to occur in correspondence of knickzones well correlated with the presence of mass movements directly interacting with the streambeds. The application to the sample area in the central Apennines confirmed this finding. Furthermore, the integration of the SL results with the analysis of the SA function allows distinguishing the possible cause-effect relationships between a major knickzone and a large landslide occurring in the sample area. The geomorphometric analysis here applied can be useful for the slope instability analysis in mountainous catchments where the slope-channel system is well-connected and the erosional behavior is dominant.

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