Geomorphometric assessment of sediment connectivity: a new tool for sediment management

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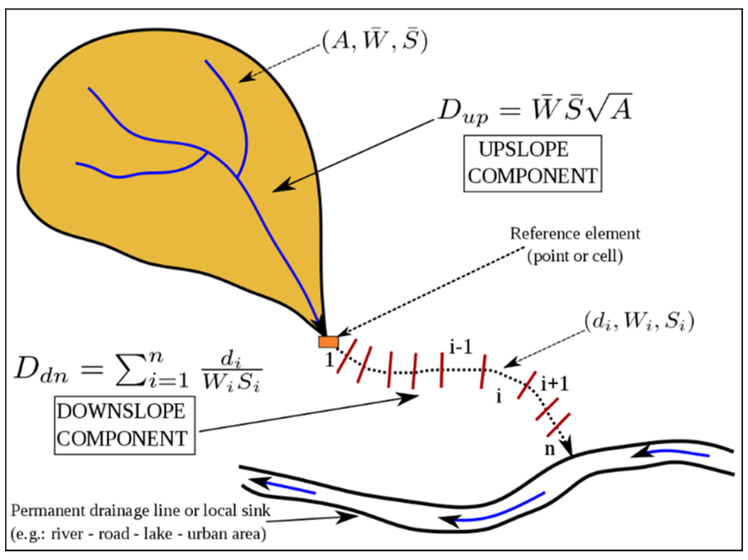
Introduction

Sediment connectivity, which can be defined as the degree to which a system facilitates the transfer of sediment through itself, by means of coupling relationships between its components (Heckmann et al., 2018), has important implications for the behavior of geomorphic systems. In recent years, sediment connectivity has become a key issue in sediment transfer processes analysis and one of the building blocks of modern geomorphology. Geomorphic coupling and connectivity play a relevant role in the assessment of sediment budget in watersheds since they reflect the contribution of different processes that can have a large spatio-temporal variability.

Connectivity model

The growing availability of high-resolution Digital Elevation Models (DEMs) offers new opportunities for the characterization of spatial patterns of sediment connectivity by enabling the quantitative modeling of sediment fluxes through geomorphometric approaches. Recently, a geomorphometric index of sediment connectivity has been developed (Cavalli et al., 2013) .

The connectivity index (*IC*) is aimed at evaluating the potential connection between hillslopes and features acting as targets (e.g. catchment outlet, roads) or storage areas (sinks, retention basin) for transported sediment. IC consists of two components:



IC is defined as:

$$IC = log_{10}\frac{D_{up}}{D_{dn}}$$

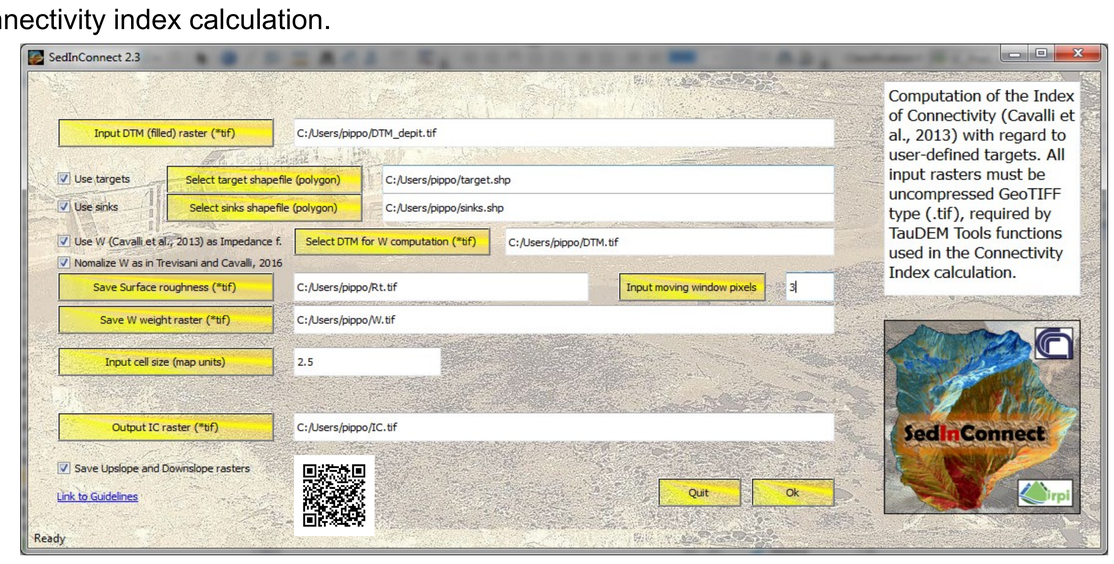
Downslope component D_{dn}: is the sinking potential due to the path length *d*, impedance factor *W* and slope *S* along the downslope path.

Upslope component D_{up}: is the potential for downward routing due to upslope catchment area *A*, mean slope *S* and an impedance factor *W*.

SedInConnect application

SedInConnect 2.3 (Crema and Cavalli, 2018) is a freeware software tool that implements the approach proposed by Cavalli et al. (2013) with further refinements.

The possibility to use the surface roughness as the default weighting factor is included; a novel feature is represented by the optional use of sinks. By using sinks (e.g. lakes, sediment traps behind check dams, karstic areas), the model decouples sink-draining areas from the Connectivity index calculation.



The tool has an intuitive interface in which all the options can be selected.

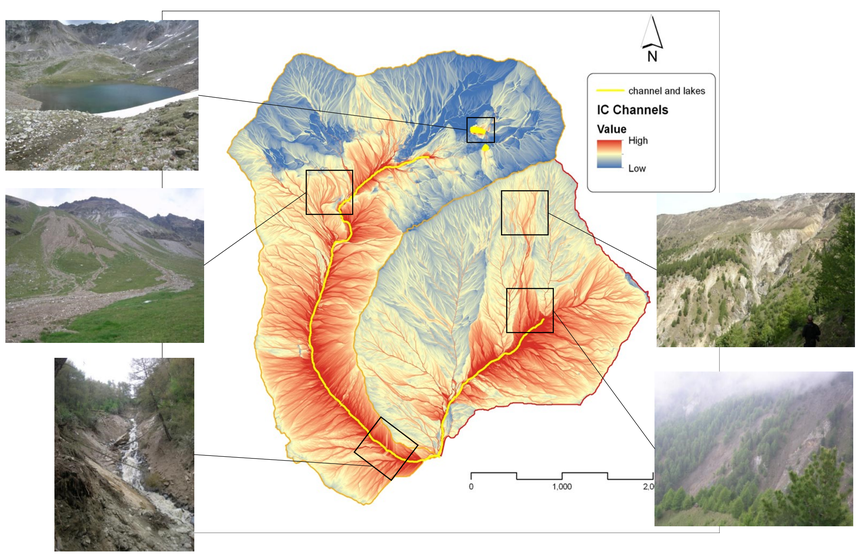
The development of the tool benefits from the use of several features:

- being **free** and **open-source**, it can be directly improved by the scientific community;
- being **stand-alone**, the tool can be used by stakeholders who use different GIS (e.g. ArcGIS, QGIS, etc.);
- the tool, which makes wide use of **TauDEM Tools** routines (Tarboton, 1997), is efficient from a computational point of view.

Link to the software release*:* *https://github.com/HydrogeomorphologyTools/SedInConnect_2.3*

Application at the catchment scale

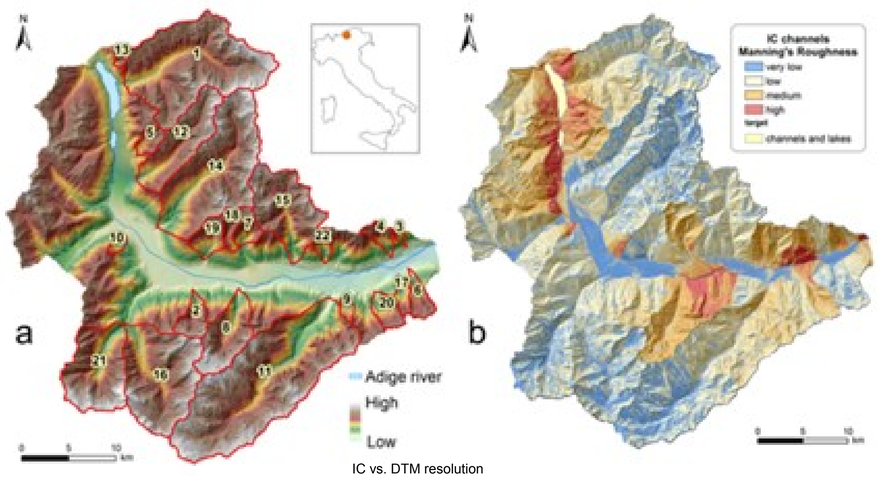
Development and first application at the catchment scale in two adjacent basins (14.8 km^2, Strimm and Gadria, Eastern Italian Alps) featuring different sediment transport processes (bedload vs. debris flow).



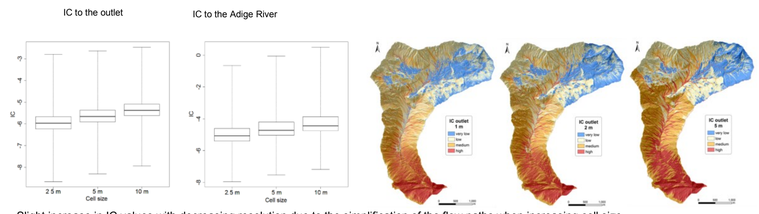
Application at the river basin scale

IC was applied to the middle and upper sector of the Venosta Valley (1096 km^2, Eastern Italian Alps) to test its applicability to a regional context which encompasses areas with a large variability in topography and land use (Cavalli et al, 2014).

The aim was also to investigate the effect of DTM resolution on index results, and the comparability in terms of connectivity values between catchments of different size.

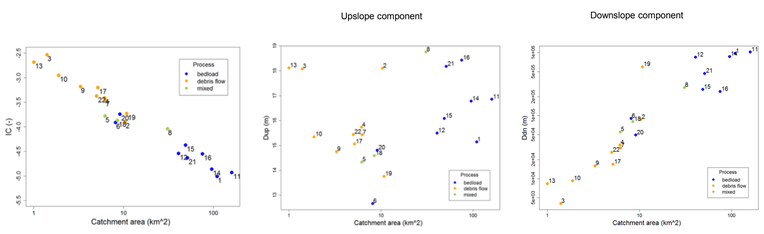


IC vs. DTM resolution



Slight increase in IC values with decreasing resolution due to the simplification of the flow paths when increasing cell size.

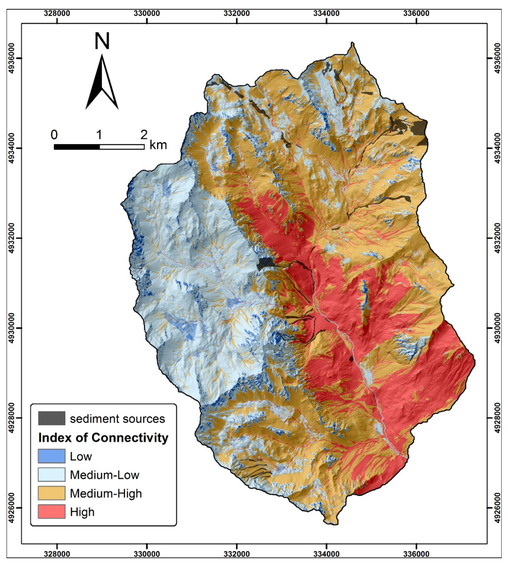
IC vs. catchment size



A strong dependency on catchment size is evident when plotting the mean value of IC against catchment area for the 22 selected catchments. Nevertheless, it can provide useful confirmation on the dominant processes affecting the catchment.

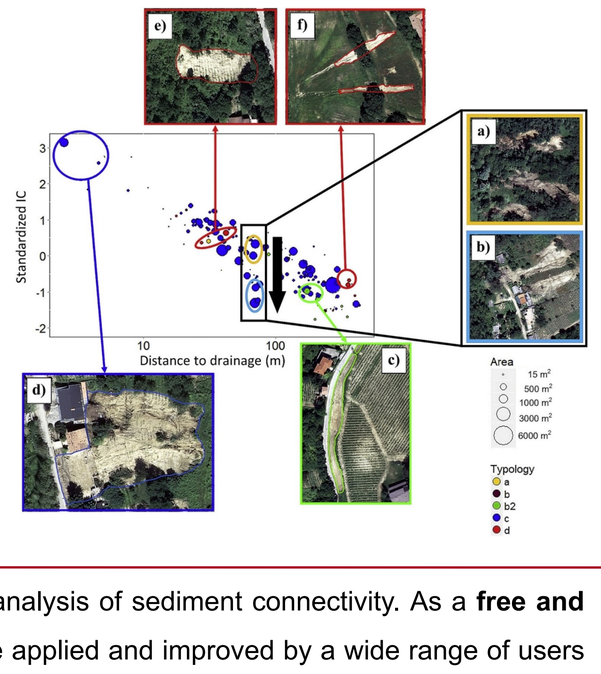
IC and sediment sources

IC has been successfully used in combination with sediment sources and/or landslide inventories in order to characterize such areas and optimize sediment management, to estimate effective contribution at catchment scale and to focus on the most critical hotspots.



In the work by Tiranti et al. (2016), *IC* was integrated with a sediment source database. This way it was possible to rank sediment sources and to assess which areas were effectively contributing to sediment transport at catchment scale. Results were checked against data on sediment deposition from hydropower reservoirs.

In Persichillo et al. (2018), *IC* analysis with channel network or roads as target, integrated with a landslide database, permitted the assessment of the coupling/decoupling degree of each landslide pointing out also the buffering/exposure role of roads and buildings.



Concluding remarks

- The goal of SedInConnect is to support the analysis of sediment connectivity. As a **free and open-source** software, SedInConnect can be applied and improved by a wide range of users (**scientists and stakeholders**);
- the application of the index over large areas gives a **realistic spatial characterization of sediment connectivity** and highlights the role particular **geomorphic features**; it was observed that the use of different impedance factors leads to different IC patterns;
- the proposed sediment connectivity appears slightly dependent from DTM resolution, whereas a strong dependency on catchment size is observed, thus suggesting to compare quantitatively only catchments of similar size;
- the applications demonstrate that a reliable assessment of sediment connectivity via geomorphometric approach, especially when integrated with a sediment sources inventory, is useful for giving **management priorities**. This is a key issue when dealing with sediment management and has important linkages with **hazard assessment** and in relation to priorities of intervention at the catchment scale.

References

- Cavalli M., Trevisani S., Comiti F., Marchi L., 2013. Geomorphometric assessment of spatial sediment connectivity in small alpine catchments. Geomorphology, 188,31-41
- Cavalli M., Goldin B., Crema S., Marchi L., 2014. Application and testing of a GIS-based sediment connectivity model in the Venosta valley (Eastern Italian Alps). European Geosciences Union – General Assembly 2014. Vienna (Austria)
- Crema, S., Cavalli, M., 2018. SedInConnect: a stand-alone, free and open source tool for the assessment of sediment connectivity. Comput. Geosci. 111, 39–45. https://doi.org/10.1016/j.cageo.2017.10.009
- Heckmann, T., Cavalli, M., Cerdan, O., Foerster, S., Javaux, M., Lode, E., Smetanová, A., Vericat, D., Brardinoni, F., 2018. Indices of sediment connectivity: opportunities, challenges and limitations. Earth-Sci. Rev.
- Persichillo, M.G., Bordoni, M., Cavalli, M., Crema, S., Meisina, C., 2018. The role of human activities on sediment connectivity of shallow landslides. CATENA 160, 261–274
- Tarboton, D. G., 1997. A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models. Water Resources Research, 33(2): 309-319
- Tiranti, D., Cavalli, M., Crema, S., Zerbato, M., Graziadei, M., Barbero, S., Cremonini, R., Silvestro, C., Bodrato, G., Tresso, F., 2016. Semi-quantitative method for the assessment of debris supply from slopes to river in ungauged catchments. Sci. Total Environ. 554–555, 337–348.