Flow Connectivity Patterns in Complex Anthropized Landscape: Application in Cinque Terre Terraced Site

Lorenzo Borselli*[§], Devis Bartolini**, Paolo Corradeghini ***, Alessandro Lenzi**, Paolo Petri**
*Universidad Autónoma de San Luis Potosí, Instituto de Geología, San Luis Potosí, México
**Logica del Territorio Soc. Coop. a r.l., La Spezia (Italy)
***3DMetrica, Lerici (La Spezia, Italy)
[§] lborselli@gmail.com

Abstract— **In a study area with a complex dry stone walls terracing system located in the Cinque Terre National Park (Italy), a very high resolution map of the surface connectivity of the flows was generated. A 0.06m resolution DTM produced with aerial photogrammetric techniques by means of UAV allowed to obtain connectivity index (IC) maps that relate the surface flow lines, the IC index and the main instability and collapse processes in the terrace system. The proposed methodology can be integrated with another proposed method for the verification of local stability of dry stone walls. The methodologies are proposed as a new tool for future restoration projects of dry stone wall terraced systems.**

I. INTRODUCTION

In the last 15 years the connectivity paradigm has assumed an increasingly important importance in the scientific literature relating to various processes such as: geomorphological processes of erosion and mass movements; studies relating to geomorphological hazard assessment; evaluation of soil erosion rates; identification of areas most sensitive to soil degradation phenomena, identification of areas with the greatest risk of flow of surface contaminants or nutrients (etc.) [2,3,4,5,7,8,10,13],. The quantitative evaluation of surface connectivity, to be related to other specific indicators of the processes mentioned above, is one of the major developments in geomorphology and environmental science studies in recent years.

The surface connectivity flow, which transport mass and energy through the surface runoff between two specific points located on the surface, has been modeled in the last 15 years by different authors both theoretically and practically [2,4,5].

One of the most used methods is the so-called Connectivity Index (IC) [1]. The IC index was subsequently adopted by several authors [1,6,9,10,11,12] for a large variety of applications. The IC index has also been proposed with a large number of variants.

The IC Index is a parameter that can be calculated in a distributed way across the territory through standard GIS tools once a digital terrain model, with adequate resolution, and a land use map are available. The connectivity index is a geomorphometric parameter that integrates local characteristics of land use or hydraulic impedance produced by the roughness of the ground, depending on which variant is used to calculate it [1].

The results of the study are related to the application of the connectivity theory proposed by [1] in a context of high territorial anthropization such as the drywall systems of the Cinque Terre National Park (Italy). Our study was applied to a digital terrain model (DTM) with high spatial resolution (0.06 m) of a 1 ha area together with a detailed land use classification made on orthorectified Ortho-photo, both obtained by UAV. The study area was chosen given that in the area there are a multiplicity of soil degradation processes linked to the partial abandonment of the drywall system that occurred from the second half of the twentieth century.

The first objective was to test the validity of the calculation methods of the IC index considering the peculiarities of the study area such as: the presence of sub-vertical walls of the dry walls and other characteristics of strong local anthropization. The second objective of the study was to obtain for a highly degraded area, such as the study area, new indications on the design criteria for drywall restoration interventions that consider the dynamics of the degradation processes underway. The tool to reach the second goal was to obtain a map of surface connectivity, a map of the surface drainage lines obtained with very high resolution DTM and a detailed geomorphological map.

II. METHODS

A. Study Area

The selected study area is located within the Cinque Terre national park (La Spezia; Italy) with the coordinates 44 ° 06'34.19 "N, 9 ° 43'49.10" E (Figure 1). The area has an extension of about 1 hectare, between an altitude of 140 m and 180m. The area is characterized by a complex system of terraces that interrupt an average slope of 36 °. The dry-stone walls have an average height of 2m, and are spaced at an average distance of about 6 meters.

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The average slope between one wall and the next is around 8-10 ° (Figure 2). Land use is characterized by bare soil meadows and vineyards. Some of the areas have undergone restoration by the Manarola Foundation with the aim of restoring the portions of the collapsed walls (Figure 3).

Figure 1. Ubication of Study Site, inside Cinque Terre National Park (La Spezia, Italy).

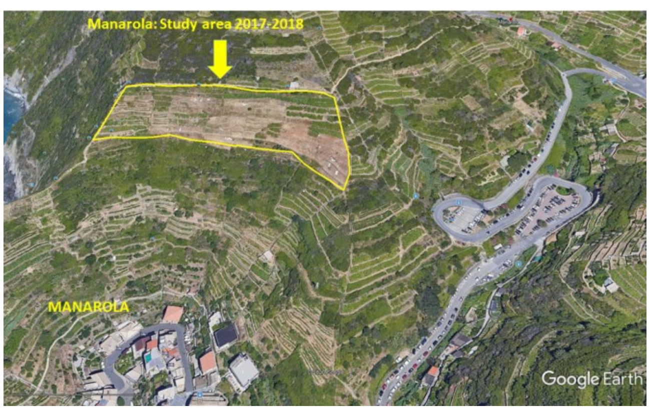

Figure 2. Manarola (Cinque Terre National Parck, La spezia, IT) study site (2017-2018)

B. High Resolution Digital Terrain Model by UAV Aero-photogrammetric Technique.

The high resolution (0.06m) digital terrain model of the entire study area was obtained with aero-photogrammetric technique by UAV. At the time of the investigations, the following cartographic and technical data were available: Regional Technical Map, in scale 1: 5.000, of the Liguria Region; LIDAR data with 1x1m mesh deriving from a survey campaign carried out by the Ministry of the Environment. The UAV vehicle allowed for a complete aero-photogrammetric survey through the acquisition of digital images. Preliminary to the acquisition of the images from the UAV, the high precision measurement of the coordinates of ground control points was carried out by means of a satellite antenna (nRTK survey).

Figure 3. High resolution Ortophoto. Manarola (Cinque Terre National Park, La spezia, IT) study site (2017-2018)

Subsequently, images and measurements were processed within specific software (Agisoft Metashape Professional). Then we proceeded with the elaboration of three-dimensional, oriented and georeferenced points clouds of high information density and their treatment within data processing software (Cloud Compare). At the end the extraction was carried out, from the three-dimensional data returned by ortho-mosaics and digital elevation models with high resolution (0.06 m). The UAV flight was carried out with a flight height of at least 70 m AGL (Above Ground Level). The aerial photographs were taken with the camera in the nadiral position (the optical axis exiting the lens has an inclination of 90 ° with respect to the horizontal) and camera inclined by 45 ° with respect to the horizontal, in consideration of the average slope of the terraced slope. The average overlap between the images was 80%.

C. Index of Connectivity (IC) Map

The connectivity map by means of the IC index was obtained following the original method proposed by [1] through the following equation:

$$\mathrm{IC} = \log_{10}\left(\frac{D_{up}}{D_{dn}}\right) = \log_{10}\left(\frac{\overline{W}\times\overline{S}\times\sqrt{A}}{\sum\frac{d}{W\times S}}\right) \quad (1)$$

where The numerator (D_{up}) represents the feature uphill from a selected benchmark point and evaluates the capacity of water and sediment to descend towards the benchmark point (Borselli et al., 2008). $\overline{W}$ = average value of the weighting coefficient related to land cover/use; $\overline{S}$ = average slope of the area that contributes to the reference point (m/m); A = contribution area (m^2).
The denominator (D_{dn}) measures how the features downhill from the benchmark point allow the water and sediment to reach the sink; the elements of the calculation are similar to the D_{up} element, where the distance (d) to the sink (expressed in m) replaces the contribution area (A) (expressed in m^2).The weight factors W used in the eq. (19 are the same originally implemented by [1] for different land use.The map of IC index was obtained considering a minimum contribution area of 5 m^2 in order to produce basic drainage flow line. The basic algorithm used for determine flow direction has been the D8 algorithm [14] implemented in ArcGIS Module TAUDEM [15].

III. Results and conclusions

The most important results of the study are a series of maps, with an extreme spatial resolution, which represent the distribution of connectivity in relation to the main instability phenomena detected in the drywall system (figure 4). The obtained maps relate the main flow lines that interconnect different terraces through two, or more, points in correspondence with collapsed terraces. The collapse of the terraces and the subsequent deterioration upon the establishment of a continuous flow line associated with accelerated erosion phenomena is a fairly common phenomenon in the Cinque Terre area. The phenomenon can considerably aggravate the degradation of the territory and produce more important threats during extreme hydrological events.

A system of flow lines, with high connectivity, which connects two or more terraces, through the collapse areas (figure 5), represents an extremely risky condition which can produce an acceleration of instability and a high production of sediments towards the urbanized downstream areas. In figure 4 the higher IC index value pixels are related to sites with flow lines interconnecting more than one terraces. Instead the lower IC values, that in some case are present in between two contiguous dry-stone walls, are related to recent human artifact as the temporary accumulation of stones and soil due to restoration work in progress.

In general, a rapid local Increase of IC values are always related to a sharp increase of sediment mobility and thus soil degradation associated to dry-stone walls collapse.

Figure 6 shows how even a high-resolution digital terrain model, such as a DTM lidar (1x1m), is unable to effectively reproduce the complex morphology of a terraced system. Instead, a high-resolution DEM, such as that obtained on the study site, is required to correctly represent the distribution of the actual slopes that are used for a multiplicity of applications. In particular, it is effective for studying the stability of single or multiple dry-stone walls using advanced calculation methods [16]. Lower resolution DTMs (for example 1X1m) are not suitable in this terraced system to reproduce sufficiently reliable connectivity maps.

The methodology developed with the application of the connectivity theory [1] to terraced systems together with the new method of verification of local stability of dry walls [16] is proposed here as a new and fundamental tool for the design of restoration interventions in terraced system of the Cinque Terre, with the aim of also mitigating the adverse effects during extreme hydrological events.

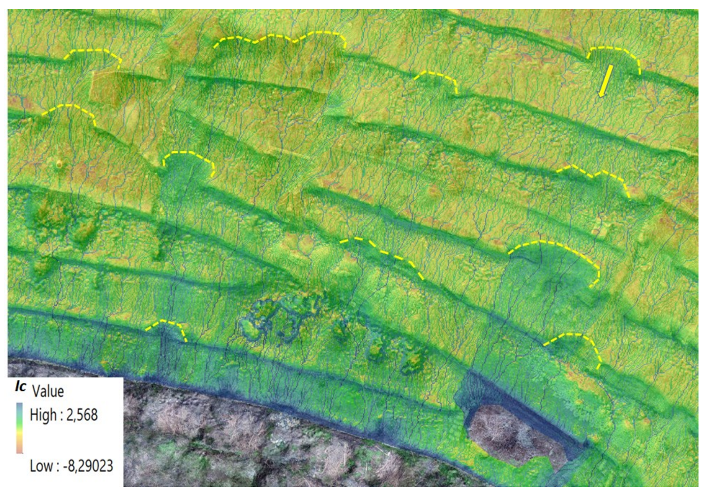

Figure 4..flow Connectivity map by IC index distribution in apportion of study site 30X30m. The grey zone is characterized by dense mediterranean shrub vegetation that do not allow the obtainment of reliable DTM. The yellow lines represent the upper limit of main phenomenon of collapsed dry stone walls. The yellow arrow is positioned in correspondence of site depicted in figure 5

Figure 5 Collapsed Dry stone wall with concentrated runoff pathway across a terraced vineyard in the study site. (Photo P. Petri 2017)

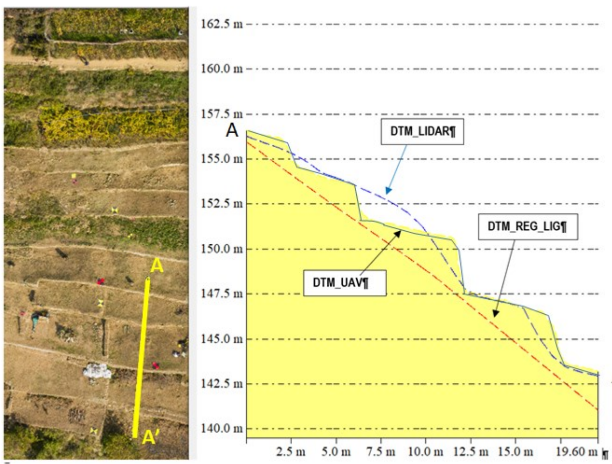

Figure 6 Comparison of three type of topographic profiles obtained from DTM region Liguria (scale 1:5.000 resolution 5x5); DTM form Lidar 1x1m (Ministero Ambiente), DTM obtained by aero-photogrammetric survey by UAV at resolution 0.06x0.06 m.

REFERENCES

[1] Borselli, L., Cassi, P., Torri, D., 2008. Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. CATENA 75, 268–277. https://doi.org/10.1016/j.catena.2008.07.006

[2] Barneveld, R.J., van der Zee, S.E.A.T.M., Greipsland, I., Kværnø, S.H., Stolte, J., 2019. Prioritising areas for soil conservation measures in small agricultural catchments in Norway, using a connectivity index. Geoderma 340, 325–336. https://doi.org/10.1016/j.geoderma.2019.01.017

[3] Bracken, L.J., Croke, J., 2007. The concept of hydrological connectivity and its contribution to understanding runoff-dominated geomorphic systems. Hydrol. Process. 21, 1749–1763. https://doi.org/10.1002/hyp.6313

[4] Bracken, L.J., Turnbull, L., Wainwright, J., Bogaart, P., 2015. Sediment connectivity: a framework for understanding sediment transfer at multiple scales. Earth Surf. Process. Landforms 40, 177–188. https://doi.org/10.1002/esp.3635

[5] Bracken, L.J., Wainwright, J., Ali, G.A., Tetzlaff, D., Smith, M.W., Reaney, S.M., Roy, A.G., 2013. Concepts of hydrological connectivity: Research approaches, pathways and future agendas. Earth-Science Rev. 119, 17–34. https://doi.org/10.1016/j.earscirev.2013.02.001

[6] Cavalli, M., Trevisani, S., Comiti, F., Marchi, L., 2013. Geomorphometric assessment of spatial sediment connectivity in small Alpine catchments. Geomorphology 188, 31–41. https://doi.org/10.1016/j.geomorph.2012.05.007

[7] Chartin, C., Evrard, O., Onda, Y., Patin, J., Lefèvre, I., Ottlé, C., Ayrault, S., Lepage, H., Bonté, P., 2013. Tracking the early dispersion of contaminated sediment along rivers draining the Fukushima radioactive pollution plume. Anthropocene 1, 23–34. https://doi.org/10.1016/j.ancene.2013.07.001

[8] 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-Science Rev. 187, 77–108. https://doi.org/10.1016/j.earscirev.2018.08.004

[9] López-Vicente, M., Álvarez, S., 2018. Influence of DEM resolution on modelling hydrological connectivity in a complex agricultural catchment with woody crops. Earth Surf. Process. Landforms 43, 1403–1415. https://doi.org/10.1002/esp.4321

[10] López-Vicente, M., Ben-Salem, N., 2019. Computing structural and functional flow and sediment connectivity with a new aggregated index: A case study in a large Mediterranean catchment. Sci. Total Environ. 651, 179–191. https://doi.org/10.1016/J.SCITOTENV.2018.09.170

[11] Ortíz-Rodríguez, A.J., Borselli, L., Sarocchi, D., 2017. Flow connectivity in active volcanic areas: Use of index of connectivity in the assessment of lateral flow contribution to main streams. Catena 157, 90–111. https://doi.org/10.1016/j.catena.2017.05.009

[12] Ortíz-Rodríguez, A.J., Muñoz-Robles, C., Borselli, L., 2019. Changes in connectivity and hydrological efficiency following wildland fires in Sierra Madre Oriental, Mexico. Sci. Total Environ. 655, 112–128. https://doi.org/10.1016/j.scitotenv.2018.11.236

[13] Turnbull, L., Hütt, M.-T., Loannides, A.A., Kininmonth, S., Poeppl, R., Tockner, K., Bracken, L.J., Keesstra, S., Liu, L., Masselink, R., Parson, A.J., Ioannides, A.A., Kininmonth, S., Poeppl, R., Tockner, K., Bracken, L.J., Keesstra, S., Liu, L., Masselink, R., Parsons, A.J., Loannides, A.A., Kininmonth, S., Poeppl, R., Tockner, K., Bracken, L.J., Keesstra, S., Liu, L., Masselink, R., Parson, A.J., Ioannides, A.A., Kininmonth, S., Poeppl, R., Tockner, K., Bracken, L.J., Keesstra, S., Liu, L., Masselink, R., Parsons, A.J., Loannides, A.A., Kininmonth, S., Poeppl, R., Tockner, K., Bracken, L.J., Keesstra, S., Liu, L., Masselink, R., Parson, A.J., Ioannides, A.A., Kininmonth, S., Poeppl, R., Tockner, K., Bracken, L.J., Keesstra, S., Liu, L., Masselink, R., Parsons, A.J., 2018. Connectivity and complex systems: learning from a multi-disciplinary perspective. Appl. Netw. Sci. 3, 11. https://doi.org/10.1007/s41109-018-0067-2

[14] Tarboton, D. G. (1997). A new method for the determination of flow directions and upslope areas in grid digital elevation models. Water resources research, 33(2), 309-319.

[15] Tarboton, D. G., & Mohammed, I. N. (2013). TauDEM 5.1 quick start guide to using the TauDEM ArcGIS toolbox. Utah State University (USU), United State.

[16] Borselli L, Petri P. (2020). Muri a secco: verifiche di stabilità con software SSAP 5.0 e criterio GHB(GSI) per le strutture in roccia. Researchgate. https://doi.org/10.13140/RG.2.2.21048.90886/1