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Are *calanco* landforms similar to river basins?

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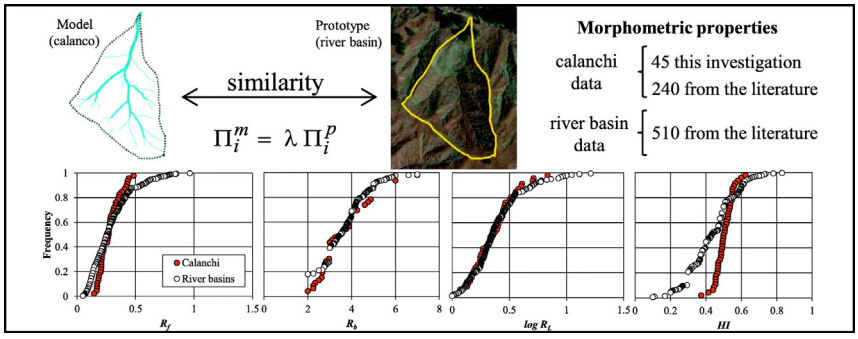
HIGHLIGHTS

- Similarity between *calanchi* and rivers is assessed using dimensionless parameters.
- *Calanchi* shape resembles that of river basins.
- The intrinsic characteristics of *calanchi* generate more branched drainage networks.
- There is higher geomorphic activity on *calanchi* than in river basins.
- *Calanchi* represent a scale model for assessing rapid hydrological processes.

GRAPHICAL ABSTRACT



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ABSTRACT

In the past badlands have been often considered as ideal field laboratories for studying landscape evolution because of their geometrical similarity to larger fluvial systems. For a given hydrological process, no scientific proof exists that badlands can be considered a model of river basin prototypes. In this paper the measurements carried out on 45 Sicilian *calanchi*, a type of badlands that appears as a small-scale hydrographic unit, are used to establish their morphological similarity with river systems whose data are available in the literature. At first the geomorphological similarity is studied by identifying the dimensionless groups, which can assume the same value or a scaled one in a fixed ratio, representing drainage basin shape, stream network and relief properties. Then, for each property, the dimensionless groups are calculated for the investigated *calanchi* and the river basins and their corresponding scale ratio is evaluated. The applicability of Hack's, Horton's and Melton's laws for establishing similarity criteria is also tested. The developed analysis allows to conclude that a quantitative morphological similarity between *calanco* landforms and river basins can be established using commonly applied dimensionless groups. In particular, the analysis showed that i) *calanchi* and river basins have a geometrically similar shape respect to the parameters *Rf* and *Re* with a scale factor close to 1, ii) *calanchi* and river basins are similar respect to the bifurcation and length ratios ($\lambda = 1$), iii) for the investigated *calanchi* the Melton number assumes values less than that (0.694) corresponding to the river case and a scale ratio ranging from 0.52 and 0.78 can be used, iv) *calanchi* and river basins have similar mean relief ratio values ($\lambda = 1.13$) and v) *calanchi* present active geomorphic processes and therefore fall in a more juvenile stage with respect to river basins.

1. Introduction

After the pioneering work of Horton (1945), quantitative landform analysis are normally applied to drainage basins in which water erosion processes and mass gravity movements are the control agents of form

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development. Furthermore quantitative measurements are useful for assessing the age, evolution and dynamics of the landscape (Fryirs and Brierley, 2013; Deng et al., 2015; Lecours et al., 2016). Gravelius (1914), Horton (1932, 1945) and Strahler (1952, 1957) introduced morphometric elements into landform description. More recent studies (Lin and Oguchi, 2004; Oguchi, 1997; Buccolini and Coco, 2010, 2013) demonstrated that the final arrangement of river networks varies with hillslope steepness but also with the area available for their expansion. The morphometric attributes extracted from drainage basins allow their geomorphological characterization and therefore are helpful to describe the occurring fluvial processes and hillslope erosion dynamics (Langbein, 1947; Strahler, 1952, 1957; Avena and Lupia Palmieri, 1969; Bali et al., 2012). Furthermore, basin metrics can be used for integrative hydrological modelling in order to study the interaction between basin area, river total length and the aquifer characteristics at basin scale (Pacheco and Van der Weijden, 2012) or for evaluating the land suitability and the environmental impacts of the actual uses (Valle Junior et al., 2015).

Calanchi (plural of *calanco*) is an Italian term used to characterize typical badlands that appear as small-scale hydrographic units or as groups of minor valleys (Farabegoli and Agostini, 2000; Moretti and Rodolfi, 2000; Pulice et al., 2012; Caraballo-Arias et al., 2014, 2015). In fact it identifies "*a rather small hydrographic unit, horse-shoe shaped, with a tributary system in which each channel is separated from the adjacent ones by means of more or less sharp ridges with slope angles depending on the physical and mechanical characteristics of the bedrock*" (Moretti and Rodolfi, 2000). In principle *calanchi* allow a direct field observation of the interconnections between hillslope processes and landforms (Alexander et al., 2008; Dickie and Parsons, 2012; Vergari, 2015; Yair et al., 2013; Cappadonia et al., 2016). *Calanchi* exhibit, in small temporal and spatial scales, many of the geomorphic processes and landforms that may by observed in a fluvial landscape, hence, this type of badlands may be considered as micro-basins where geomorphic dynamics can be related to their geometric features (Alexander, 1980; Bryan and Yair, 1982; Howard, 1994; Pulice et al., 2012). According to this circumstance, the *calanchi* are often considered as <<*ideal field laboratory*>> useful for studying landscape evolution because of their geometrical similarity to miniature fluvial systems, nevertheless, there is a lack of scientific analysis that demonstrates this hypothesis from a quantitative point of view. The main interest in recognizing the physical similarity between *calanchi* and river basins is due to the possibility of studying a physical process occurring in a drainage basin (prototype) by measuring the magnitude of the same process in a *calanco* (model). In particular, a *calanco* enables the measurements of erosion rates and allows to evaluate the spatial and temporal evolution of landforms in a short time interval (at annual scale or in a period of few years) (Gallart et al., 2013). Moreover, Smith and Vericat (2015) studied the reliability of different survey methods and processing techniques for measuring and monitoring erosion/deposition processes in experimental plots and badlands areas. This research concluded that oblique ground-based images can provide high quality topography models in small areas, such as the *calanchi*, and these can be used to study in detail the topographic characteristics and geomorphoic changes of the landforms.

Considering that the authors studying *calanchi* landforms in Italy (e.g. Farabegoli and Agostini, 2000; Battaglia et al., 2002, 2011; Farifteh and Soeters, 2006; Piccarreta et al., 2006 and references therein and Caraballo-Arias and Ferro, 2016) have considered these landforms as a part of a larger system, i.e. as a portion of a drainage basin, the main goal of this research is to assess *calanchi* landforms as individual geomorphic units and to determine if a *calanco* can be quantitatively considered a physical model of any drainage basin.

To this aim, the geomorphological similarity between *calanchi* and drainage basins is studied by taking into account the main morphometric properties of the *calanchi* units and assessing the dimensionless groups useful for establishing if *calanchi* can be considered as the model of a drainage basin prototype. In detail, the morphometric attributes of 45 Sicilian *calanchi* units are measured and compared with the available literature data regarding the same morphometric variables of drainage basins. A quantitative characterization of the landforms is provided by using the similarity parameters complying with drainage basin shape, drainage network composition and relief properties.

2. Materials and methods

2.1. Study area

For carrying out the quantitative analysis of *calanchi*, the morphometric characteristics of a *calanchi* area, located middle west of Sicily, Italy (Fig. 1) were investigated. The area is located in the left side of the Belice river basin, in the drainage area of the Bicchinel creek and is characterized by a typical mountainous Mediterranean climate with an average annual rainfall of 750–780 mm mainly concentrated in a mild to cold autumn-winter season, while summer periods are warm and dry. The altitude varies from a minimum of 534 masl and a maximum of 786 masl. The temperatures range from an average maximum of 28 °C during the summer and an average minimum of 3 °C during the winter. The area is characterized by very scarce vegetation cover and mainly used as pasture land.

The *calanchi* landforms mainly occur on both sides of a small ridge, which is located south of the Rocca Busambra relief. The landscape is highly dissected by narrow *calanchi* landforms, separated by knife-edged ridges, while less incised *calanchi* landforms are also recognizable in the north-east facing side of the ridge, which are characterized by slightly more rounded divides and gentler slopes and are affected by shallow landslides (Moretti and Rodolfi, 2000).

The identified erosion landforms are mainly cut into the sediments of the Castellana Sicula Formation and, secondary, on the Geraci Siculo member of the Numidian Flysch Formation (Barreca, 2007). The *calanchi* cover an area of 26 ha and occur on 45 small *calanchi* units. In Fig. 1, the delimited *calanchi* are represented while the main basic parameters of the landforms are summarized in Table 1.

2.2. Literature data

In order to assess the geomorphological similarity between *calanchi* and river basins, a compilation of data from the literature regarding 240 *calanchi* and 510 river basins was prepared. Different data are used according to the similarity criterion, that is, basin shape, river network composition and relief properties. This data were selected from the literature taking into account the need of having all variables useful to develop the morphometric analysis; moreover, the data represent different environmental contexts and therefore the subsequent analysis can be assumed independent of geographical or at-site effects. The investigated areas are characterized by different geological formations which range from sedimentary successions in which formations consisting of clays and sands are typical of *calanchi* to river basins characterized by a wide heterogeneity of the lithological characters (flyshes, carbonate rocks, marine clays, conglomerates, etc.). Further heterogeneous characters can be due to different climate conditions and land use/land cover of the river basins with respect to the *calanchi*. This independence of geographical effects is supported by the circumstance that this analysis is developed using the morphological imprint of *calanchi* and river basins located in different areas. The similarity is established by the morphological characters of the landform (shape, network, relief) without taking into account that the time-dependent processes affecting landscape modelling (geological, climatic, land use, etc.) determine the analyzed *calanchi* and basin imprint.