Automatic Delineation of Slope Units and Terrain Classification of Italy

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ABSTRACT Quantitative geomorphological and environmental analysis requires the adoption of **mapping units**, well-defined **spatial domains** providing local boundaries to aggregate environmental and morphometric variables and to perform calculations. Grid cells, typically aligned with a digital elevation model, are the standard mapping unit choice [1, 2].

Slope Units (SU) represent a wiser choice than grid cells. SU are irregular terrain partitions delimited by drainage and divide lines, also maximizing geomorphological homogeneity within each unit and heterogeneity between neighbouring units. SU bear a stronger **relation with the underlying topography**, absent in grid cells [3]. We developed a **software** for the automatic delineation of SU, given a digital elevation model [4]. Delineation is adaptive, in that SU of different shape and, most importantly, different size, are delineated according to local terrain characteristics.

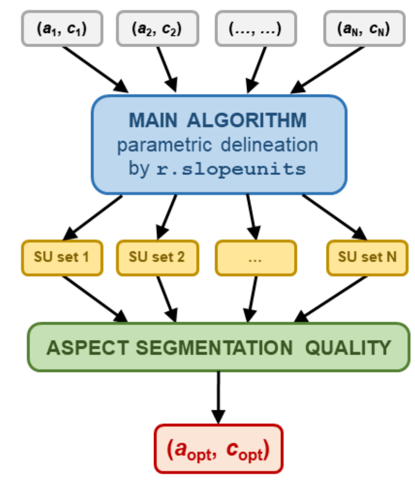
Moreover, **we devised an optimisation procedure** for the size of SU, suitable for study areas of arbitrarily large size and with varying degrees of heterogeneity. Our research group applied SU delineation in many scientific papers studying different areas of the world and for different purposes, including landslide susceptibility zonation [4, 5, 6, 7], aggregation of results of cell–based slope stability models [8, 9], earthquake–induced landslide prediction [10, 11], and optimization of landslide mapping from satellite images [12]. Many other groups used the software for similar applications.

The method, **applied to the whole of Italy**, resulted in a map containing about **330,000 SU polygons** of different sizes and shapes, and with varying local granularity [13, 14]. Fitness of the map was assessed through **a cluster analysis for terrain classification of Italy**. We show that the clusters, selected by a k-means algorithm, provide a non-trivial classification of the territory in terms of morphometric and lithological quantities.

We suggest the use of the SU map for different terrain zonations, including landslide susceptibility modeling, hydrological and erosion modelling, geo-environmental, ecological, forestry, agriculture and land use/land cover **studies requiring the identification of homogeneous** terrain **domains facing distinct directions**.

PARAMETER-FREE delineation of Slope Units

Many combinations of input parameters ...



... *Optimal* combination of parameters

NATION-WIDE SLOPE UNIT MAP

We performed a slope unit delineation for the whole of Italy. Delineation is **parameter-free**, in that the numerical values of the software's input parameters were optimized by maximization of an aspect segmentation function [4]. A subdivision into 539 basins, of size up to 4,300 km^2, provided elementary optimization domains (**Fig. 1**). The optimization algorithm considers, for each basin, its own topographic characteristics and those of the neighboring basins, further constrained within topographic units (**Fig. 2**). Results: **Fig. 3** shows number of SU/km^2; **Fig. 4** shows sample maps.

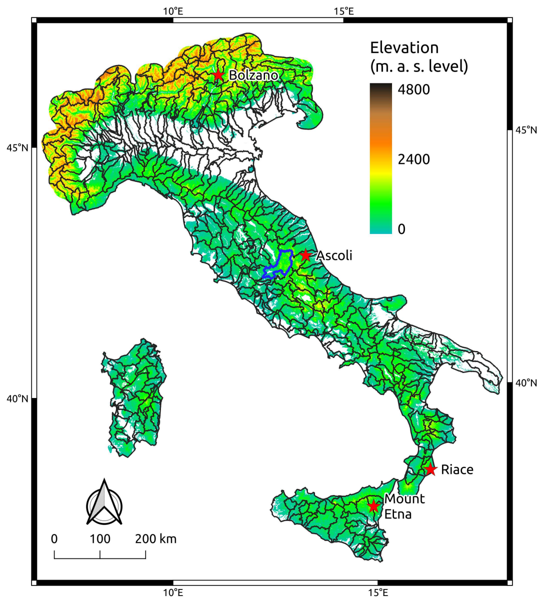


Fig. 1. Basic Optimization Domains

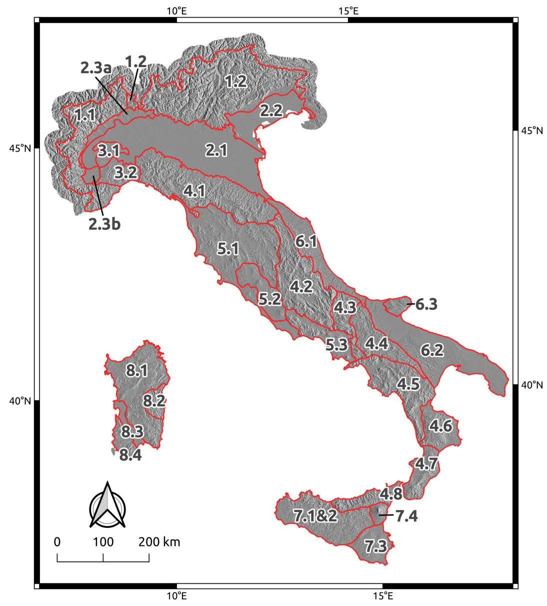


Fig. 2. Topographic Units [15]

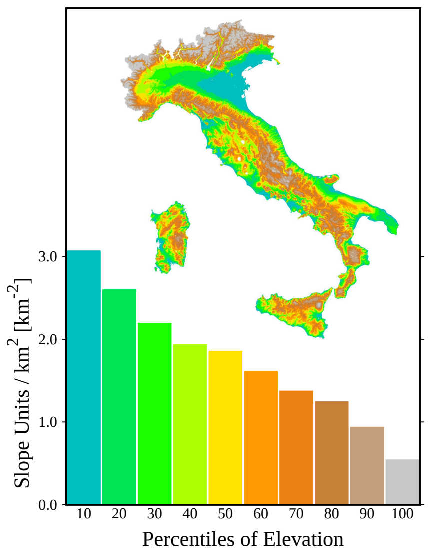


Fig. 3. Number of SU/km^2 decreases with elevation ⟹ SU size increases

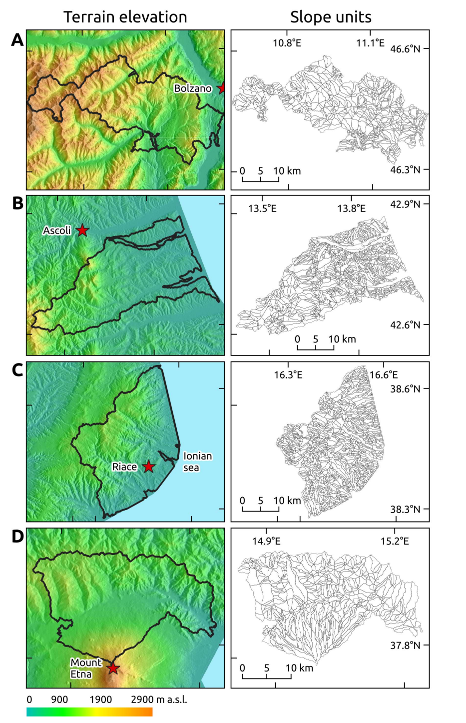


Fig. 4. SU in sample basins (Fig. 1)

TERRAIN CLASSIFICATION OF ITALY

To assess the fitness of the optimal SU map, and the performance of our parameter-free SU delineation algorithm, we **classified Italy using k-means clustering**. The **variables used for classification** (using percentiles of distributions for both) were:

- slope units sizes (9 percentiles for each basin)
- average aspect within slope units (9 percentiles per basin)

were **totally unrelated** to the variables considered to validate the clustering results (**Fig. 5**).

Figures 6, 7 and **8** show that **SU have different properties** in inherently **different geographic areas of Italy**. We investigated slope, elevation, lithological distributions (**Fig. 8**) and SU/km^2 (a proxy for drainage density, **Fig. 6**) within the 7 different clusters singled out by k-means. **Figure 7** further shows the relation between clusters and topographic units of Figs. 2 and 5, in terms of area.

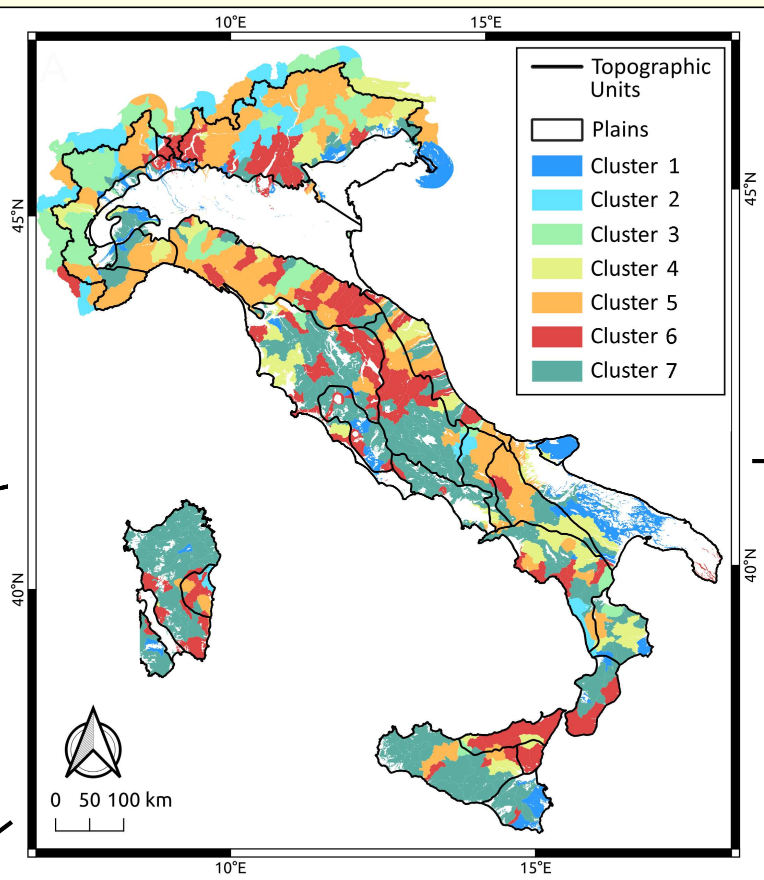


Fig. 5. Terrain classification **based only on SU attributes**

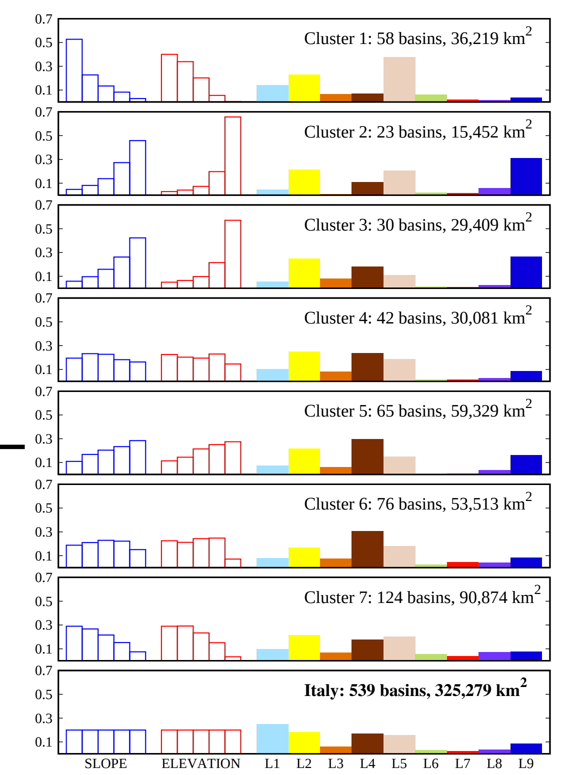


Fig. 8. Clusters have **distinct slope, elevation and lithological content.** L1: Alluvial; L2: Unconsolidated clastic; L3: Consolidated clastic; L4: Turbidite, marl, sandstone; L5: Pyroclastic; L6: Carbonatic; L7: Basalt; L8: Intrusive; L9: Metamorphic.

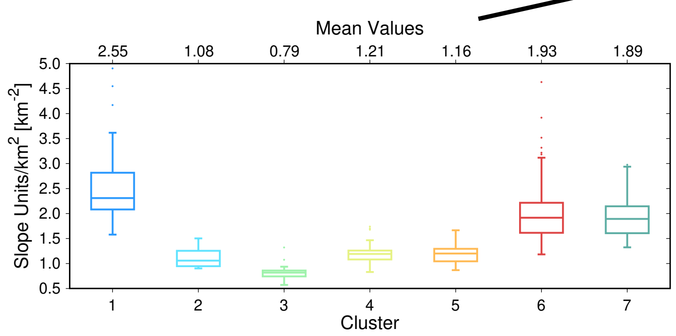


Fig. 6. SU/km^2 are **different in each cluster**

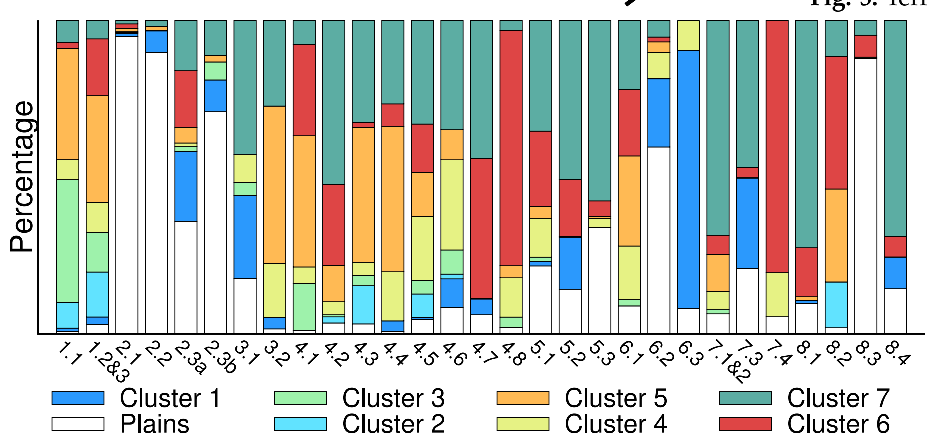


Fig. 7. Percentage of each cluster in topographic units (Figs. 2 and 5)

CONCLUSIONS

- We devised an SU delineation procedure suitable for heterogeneous areas of arbitrarily large size
- The new approach applied to the whole of Italy resulted in a map of 330,000 SU polygons of different sizes and shapes
- Classification of Italy based on SU proprerties returned a sound partition, with respect to different metrics
- The SU map is of potential interest for researchers in geomorphology, geomorphometry, natural hazards and environmental studies

REFERENCES

[1] Guzzetti et al., 1999. Geomorphology 31, 181–216.
[2] Reichenbach et al., 2018. Earth-Science Rev. 180, 60–91.
[3] Carrara et al, 1991. Earth Surf. Proc. Land. 16 427–445.
[4] Alvioli et al., 2016. Geosci. Model Dev. 9, 3975–3991.
[5] Schlögel et al., 2018. Geomorphology 301, 10–20.
[6] Bornaetxea et al., 2018. NHESS 18, 2455–2469.
[7] Jacobs et al., 2019. *Under Review*
[8] Alvioli et al., 2014. Geomorphology, 213, 38–47.
[9] Domènech et al., 2019. Landslides, *in press.*
[10] Tanyas et al., 2019a. Geomorphology 327, 126–146.
[11] Tanyas et al., 2019b. Landslides 16, 661–676.
[12] Alvioli et al., 2018a. Geomatics, Nat. Haz. and Risk 9, 544–567.
[13] Alvioli et al., 2018b. Geomorphometry 2018. PeerJ 6:e27066v1
[14] Alvioli et al., 2019. *Under review*
[15] Guzzetti & Reichenbach, 1994. Geomorphology 11, 57–74.

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Software and maps available at:

http://geomorphology.irpi.cnr.it/tools/slope-units

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