Tools for Semi-automated Landform Classification: A Comparison in the Basilicata Region (Southern Italy)

Salvatore Ivo Giano[1(✉)], Maria Danese[2], Dario Gioia[2], Eva Pescatore[1], Vincenzo Siervo[1], and Mario Bentivenga[1]

[1] Dipartimento di Scienze, Università della Basilicata, Potenza, Italy
ivo.giano@unibas.it, vsiervo@gmail.com
[2] ISPC-CNR, Tito (Potenza), Italy

Abstract. Recent advances in spatial methods of digital elevation model (DEMs) analysis have addressed many research topics on the assessment of morphometric parameters of the landscape. Development of computer algorithms for calculating the geomorphometric properties of the Earth's surface has allowed for expanding of some methods in the semi-automatic recognition and classification of landscape features. In such a way, several papers have been produced, documenting the applicability of the landform classification based on map algebra. The Topographic Position Index (TPI) is one of the most widely used parameters for semi-automated landform classification using GIS software. The aim was to apply the TPI classes for landform classification in the Basilicata Region (Southern Italy). The Basilicata Region is characterized by an extremely heterogeneous landscape and geological features. The automated landform extraction, starting from two different resolution DEMs at 20 and 5 m-grids, has been carried out by using three different GIS software: Arcview, Arcmap, and SAGA. Comparison of the landform maps resulting from each software at a different scale has been realized, furnishing at the end the best landform map and consequently a discussion over which is the best software implementation of the TPI method.

Keywords: Geomorphology · Morphometry · Topographic Position Index (TPI) · DEMs · GIS software · Southern Italy

1 Introduction

Landforms are geomorphic features of the Earth's landscape generated by the interaction between erosional and depositional processes. Landforms can range from large-scale features, such as plains and mountain ranges to small-scale features such as single hills and valleys [1]. Starting from the last century, the geomorphometric properties of the Earth, which at first were hand-made measured [2, 3], have had an acceleration in their computation from the introduction of computer technology and GIS-based spatial analysis. The use of Digital Elevation Models (DEMs), the development of powerful GIS software with a user-friendly programming environment, and the increase in computer computing capabilities have allowed for an increase in the development of

O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12250, pp. 709–722, 2020.
https://doi.org/10.1007/978-3-030-58802-1_51

computer algorithms in different disciplines. Among them, several geomorphological tools of automatic mapping of landforms based on different classification criteria and indexes [2, 4, 5] have been developed. This computer-based approach has permitted users to reduce computational time and to produce statistically-based information on landscape features [6].

The GIS application for semi-automated landform classification known as topographic position index (TPI) is an algorithm used in topographic and DEM analysis; it allows a classification of the landscape in slope position classes and landform categories [7, 8]. The ability of TPI to subdivide the features of a landscape into landform categories is mainly based on topography, this is the method suitable for recognition of morphometric properties of landforms. In fact, the TPI is widely used by many authors in a variety of landscapes throughout the world, in order to classify their characteristic landforms ([7] in the USA; [1] in Turkey; [9] in Belgium; [10] in Iran; [11] in Italy; [12] in Greece).

The goal of the study was designed to check the best landform map extracted by means of the three GIS software using the same landform classification, considering that: 1) TPI index is scale-depending and its values must change with DEM grid resolution, and 2) the algorithms developing the semi-automatic landform extraction are quite the same running in different GIS application as Arcview 3.x, Arcmap 10.x, and SAGA. The study area of the Basilicata Region, located in the southern Italian Apennines chain. This area was selected because here a variety of sedimentary rocks produced a complex landscape that is characterized by many morphological features varying from mountain shapes, reaching over 2000 m of altitude a.s.l., to hills and coastal landscapes [13]. The comparison of different landform maps was made for two different size resolution DEMs at 20 m and 5 m; the results were discussed to assess which map (and consequently which software) produced the best landform extraction with regard to the real morphological features of the landscape.

2 Method: The TPI-Based Classification

Among the many geomorphological methods classifying the landscape features in morphological units or classes, the approach adopted in this paper follows the relief classification which is based on the concept of the topographic position index (TPI). The method was proposed by Weiss (2001) [7] and implemented by Jenness (2006) [8] in different GIS-based software. The topographic position Index (TPI) is calculated as the difference between the elevation value of a cell and the average elevation of the neighbourhood around that cell [7]. This represents a quantitative relief index. The algorithm is implemented with a combination of map algebra functions and returns a classification of the index into slope position and landform types. The TPI index is expressed by the following equation:

$$TPI_i = M_i - \sum\nolimits_{n-1} \frac{M_n}{n} \quad (1)$$

where i is the i_{th} cell of the analysed raster, M_i is the elevation in the i cell, M_n is the elevation of the n pixels belonging to the neighbourhood of i, n is the total number of cells belonging to the neighbourhood of i. Positive values of TPI indicate that the elevation in the cell i is higher than the average value in the neighbourhood cells, thus it allows recognizing ridges; whereas negative values suggest that the elevation in the cell i is lower than the average value in its surrounding, thus it allows to recognize valleys. TPI values near zero are representative of both flat areas and constant slopes.

The classification of the TPI values provides a fast and powerful means in the extraction of landscape morphological classes [8]. The index is scale-dependent so it varies both with the variation of the cell size in the input DEM and with the size of the neighbourhood selected for the TPI computation. In fact, the calculation of TPI from DEM at different scales and with different thresholds provide an analysis of relief forms of various sizes [14]. Consequently, the choice of the appropriate DEM resolution and the neighbourhood size are important parameters for satisfactory results of classification and are, also, related to the goal of the project. When utilizing the neighbourhood, it is important to define both its shape and its appropriate size. For the shape there are many options: among them, one can choose a circle or an annulus radii of the search window. In both cases, the classification tool requires two values (or search radii) for the calculation: a smaller neighbourhood is useful to identify small and local hills and valleys, while the larger neighbourhood identifies larger features [8]. A different landform classification was obtained by Weiss (2001) [7] using a combination of two TPI grid values, large and small neighbourhood,. In such a way, a point of the landscape with a negative TPI value in a small neighbourhood and a positive value in a large neighbourhood can identify a small valley in a larger hilltop and will reasonably be classified as upland drainage. Conversely, a point with a positive TPI value in a small neighbourhood and a negative value in a large neighbourhood can reasonably indicate a small hill or a ridge in a larger valley [8]. Of course, in the case of the circle shape, there will be only one search radius for the small neighbourhood and one search radius for the large one, while in the case of the annulus shape, an inner and an out radii are required, both for the small and for the large neighbourhood. So for the annulus search window, four thresholds have to be defined.

Based on both the TPI threshold values and the slope distribution at each point, the landscape can be classified into discrete slope position classes [7]. This means that TPI values above an established threshold are classified as ridgetops or hilltops, whereas TPI values below the threshold are classified as valley bottom or depressions. Moreover, TPI values near zero are classified as a flat plain or mid-slope areas [7, 8]. Considering the variability of the elevation values within a neighbourhood of a cell, it is useful to define the threshold TPI values in terms of standard deviations from the elevation. In this sense, grid cells with the same TPI value may be classified in different areas.

The TPI and slope combination leads the generation of 10 landform classes listed as follow: 1) Deep narrow canyons/V-shaped river valleys, 2) Midslope drainage/Local valley in plains, 3) Upland incised drainages/headwaters, 4) U-shaped valleys, 5) Plains, 6) Open slopes, 7) Upper slopes/Flat ridge tops/Mesas, 8) Local ridge/hilltops in broad valleys, 9) Midslope ridges or lateral drainage divides/Local ridge in plains, 10) Mountain top/High ridges.

3 Case Study: The Basilicata Region Landforms

3.1 Geology and Geomorphology of the Study Area

The Basilicata Region, located in southern Italy, is part of the Miocene-Quaternary fold-and-thrust belt of southern Apennines chain (Fig. 1) formed by east-verging tectonic units ([15] and references therein) overlapping on the Apulian Platform to form a large duplex geometry [16]. The average direction of the chain axis is approximately N150°, corresponding to the strike of both the main thrusts and younger coaxial normal faults. Extensional tectonics is still active along the axis of the chain deforming Pleistocene sediments [17–22]. Such a complex structural setting produced a mountain chain over 2000 m high and a regional divide oriented NW-SE that separates the drainage network towards south-west in the Tyrrhenian Sea, northeast in the Adriatic Sea, and east in the Ionian Sea.

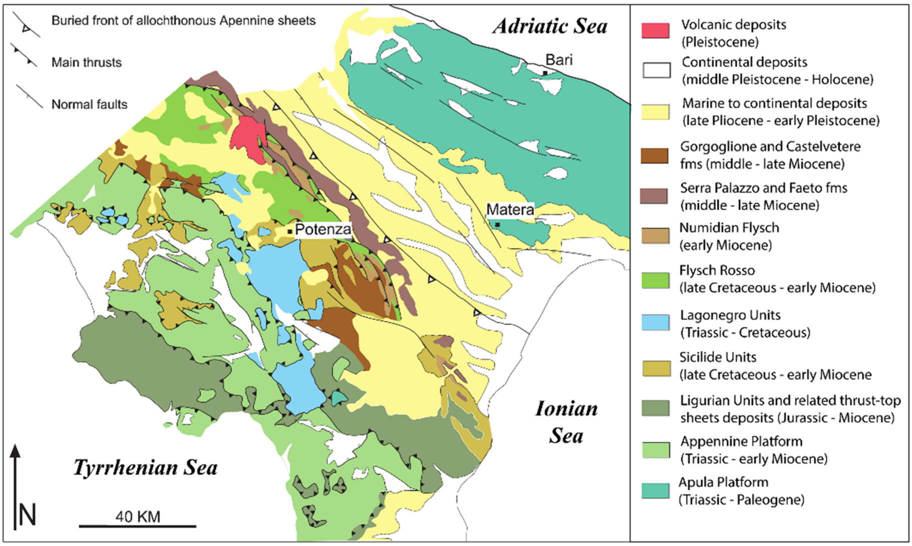

Fig. 1. Geological sketch map of the southern Apennines ([27], mod).

The western and southern sectors of Basilicata are included in the axial zone of the chain, showing high relief with mountains peaks which rise to about 2000 m a.s.l. along the peaks of the Pollino Massif. Faulted-block mountains bounded by high-angle fault scarps are alternated with tectonically-induced basins filled by fluvial to lacustrine deposits that pit the landscape ([19, 23, 24] among others). The uplift rate of the block-faulted mountain front was not constant in time and space because tectonics, in association with climate inputs, generated alluvial fans landforms with different geometry on the side of the basins [24]. The western and southern sectors of the Basilicata represent the geological backbone of the region and are formed by shallow-water carbonate platform units; deep-water siliceous units; siliciclastic arenaceous and clayey units; metamorphic and crystalline units; clastic successions representing the infill of Pliocene and Pleistocene marine to continental syntectonic basins. The central sector of the Basilicata corresponds to the eastern front of the chain and shows hilly reliefs that not exceed 1100 m of altitude. The fluvial valleys are oriented from NE to SW in the northern sector and from E to W in the southeasternmost sector of the study area; here, they transversally cut the Bradano foredeep. The sector is mainly formed by sandstone and clay-rich rocks forming the tectonic units of the embricate frontal thrust unit of the chain. The more external and eastern sector of the Basilicata Region is represented by the Pliocene to Pleistocene Bradano foredeep of the Apennines and is mainly constituted by conglomerates, sands, and clays forming a hilly plan landscape fairly dipping toward the east and transversally incised by the drainage network [13]. It represents the remnant of marine terraced surfaces uplifted in Quaternary times as a consequence of the growth of the Apennines [25, 26].

3.2 Input Parameter Selection for the Case Study

The TPI-based landform classification was implemented in three different tools developed for three different software that computes the same algorithm of landscape classification. The first tool computes the TPI grids in the ArcView 3.x application [8], the second in the ArcGis 10.x [8], and the third, developed by Conrad (2011) [28] employs the calculation of Guisan et al. (1999) [29], in the SAGAgis.

The first step was the parameter choice, corresponding to the cell size of the input DEM. For the purpose of the study, a multiscalar approach was carried out using a 20 m-resolution DEM and a higher resolution (i.e. 5 m) DEM of the Basilicata Region. The DEMs are freely available and downloadable at the following links: http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/dem20/view, and https://rsdi.regione.basilicata.it for the 5 m DEM. In order to calculate attributes for landform analysis using the 20 m and 5 m DEMs, a slope analysis was realized to generate slope maps using the spatial analysis tools of each application.

The second step of the adopted procedures involved the selection of neighborhood size and shape. An annulus shape was used. Moreover, in order to find the best threshold, an iterative process involving many TPI sizes was used to recognizes complex landscape features. After this process, it was highlighted that the best threshold depended on the input raster resolution and that it is also proportional to a factor f, according to the following expression:

$$\text{Threshold} = \text{Cellsize} * \text{f} \tag{2}$$

where f values can be found as scheduled in Table 1.

The f factor for each neighbourhood element is represented by a range of values because it depends also on the landscape mean slope. Usually, with low values of slopes, best results are obtained by using low f in the range, whereas higher values of the mean slope return best results with high f values in the defined range.

In the Basilicata Region, final values were chosen as follows: the TPI value, in the 20 m resolution DEM, was calibrated ranging two annulus neighbourhoods, the small neighborhood with an inner radius of 40 m and an outer radius of 100 m, and the large

Table 1. f values to find the best thresholds for a TPI-based landform classification.

Neighbourhood element	f
Small neighbourhood:	
Inner Radius	2÷3
Outer Radius	5÷6
Large neighbourhood:	
Inner Radius	10÷30
Outer Radius	25÷30

neighborhood with an inner radius of 200 m and an outer radius of 500 m. The TPI value, for the 5 m resolution DEM, was calibrated using in the small neighborhood the inner radius of 15 m and the outer radius of 30 m, and in the large neighborhood the inner radius of 60 m and the outer radius of 120 m. This combination furnished the best landform maps, according to an expert geomorphological inspection of the maps.

4 Results

With the aim to recognize the main morphological features of the study area, the TPI-based automated landform extraction and classification were elaborated from three GIS applications Arcview, Arcmap, and SAGA. Even if the TPI expression is apparently the same, results furnished three landform maps containing different spatial distribution for the ten landform classes. The TPI was calibrated assuming an annulus neighborhood values of 40–100 m (inner radius and outer radius, respectively) for small neighborhood and of 200–500 m for large neighborhood.

The spatial distribution of the automated landforms listed in Table 1 and their correspondence with the morphological features of the landscape was analyzed using both a 20 m- and a 5 m resolution DEM, respectively. With the aims to better discuss the results of the semi-automatic landform classification, the ten landform classes were grouped into main 4 classes which included homogenous features of the landscape affected by similar sculpturing processes. In this way, we have selected the following four landform categories: A) fluvial valley landforms, including deep narrow canyon/V-shaped river valley (n. 1 in Table 1), midslope drainage/local valley in plain (n. 2 in Table 1), upland incised drainage/headwater (n. 3 in Table 1), and U-shaped valley (n. 4 in Table 1) landform classes; B) plain landforms, including the plains class in the automatic extraction (n. 5 in Table 1); C) slope landforms, including open slope (n. 6 in Table 1) and upper slope/flat ridge top/mesa (n. 7 in Table 1) landform classes; D) summit landforms, which include local ridge/hilltops in broad valley (n. 8 in Table 1), midslope ridge or lateral drainage divide/local ridge in plain (n. 9 in Table 1), and mountain top/high ridge (n. 10 in Table 1) landform classes.

Table 2. List of the automated landform classification.

N.	Landform classes	CAT
1	Deep narrow canyons/V-shaped river valleys	A
2	Midslope drainage/Local valley in plains	A
3	Upland incised drainages/headwaters	A
4	U-shaped valleys	A
5	Plains	B
6	Open slopes	C
7	Upper slopes/Flat ridge tops/Mesas	C
8	Local ridge/hilltops in broad valleys	D
9	Midslope ridges or lateral drainage divides/Local ridge in plains	D
10	Mountain top/High ridges	D

4.1 Landform Maps Extracted from a 20 m-Resolution DEM

The fluvial valley landforms (category A, Table 1), include canyons, shallow valleys, U-shaped valleys, and midslope valleys. The first and second landforms, extracted and classified by the Arcview and SAGA Gis applications, perfectly delimitate the floodplains areas (Fig. 2a,b). These landforms, located in both the mountainous and hilly landscapes of the Basilicata, are well-bordered and showing a spatial continuity with the middle-lower floodplains of the Bradano, Basento, Agri, and Sinni rivers. Furthermore, they show a good distribution of the drainage network of the Region with a particular definition of those well-detected by the Arcmap application (Fig. 2c). In this latter application, also the low-order streams are well detected thus to define the spatial distribution of low-order drainage basins (Fig. 2c). It is worth noting that these landforms are detected in the upstream fluvial valleys whereas in the middle to lower reaches they pass to a different landform as a plain.

In the north-eastern side of the Region, the deep-incisions of the fluvial net with steep-slope flanks carved in Cretaceous limestone (i.e. the so-called “Gravine” landforms, which represent a peculiar fluvial landform of the Matera area [30]) - were recognized by all the three applications (Fig. 2).

The plain surface landforms (category B, Table 1) of the Basilicata landscape can be attributed to different several flat landforms categories that can be listed as: the present-day coastal plain of the Ionian Sea; the marine terraces of the Ionian Arc; the floodplains of the middle and lower reaches of the Bradano, Basento, Agri, Sinni, Cavone, and their tributaries; the plain surfaces of the intermontane basins; the terraced fluvial surfaces of the Bradano foredeep (Fig. 2). Plain landforms automatically extracted by Arcview and SAGA Gis software well-surrounded the flat areas corresponding to the Ionian coastal plain, the floodplains, and the flat surfaces of intermontane basins. This well-recognition of landforms was not provided by the Arcmap extraction that discriminates the flat surfaces, and particularly floodplains as well as shallow valleys, thus furnishing a too detailed map which is not corresponding to the landform bounds. In this case the representation is probably influenced by the strongly marked valley landforms (Fig. 2c). The non-optimal automatic recognition of plain

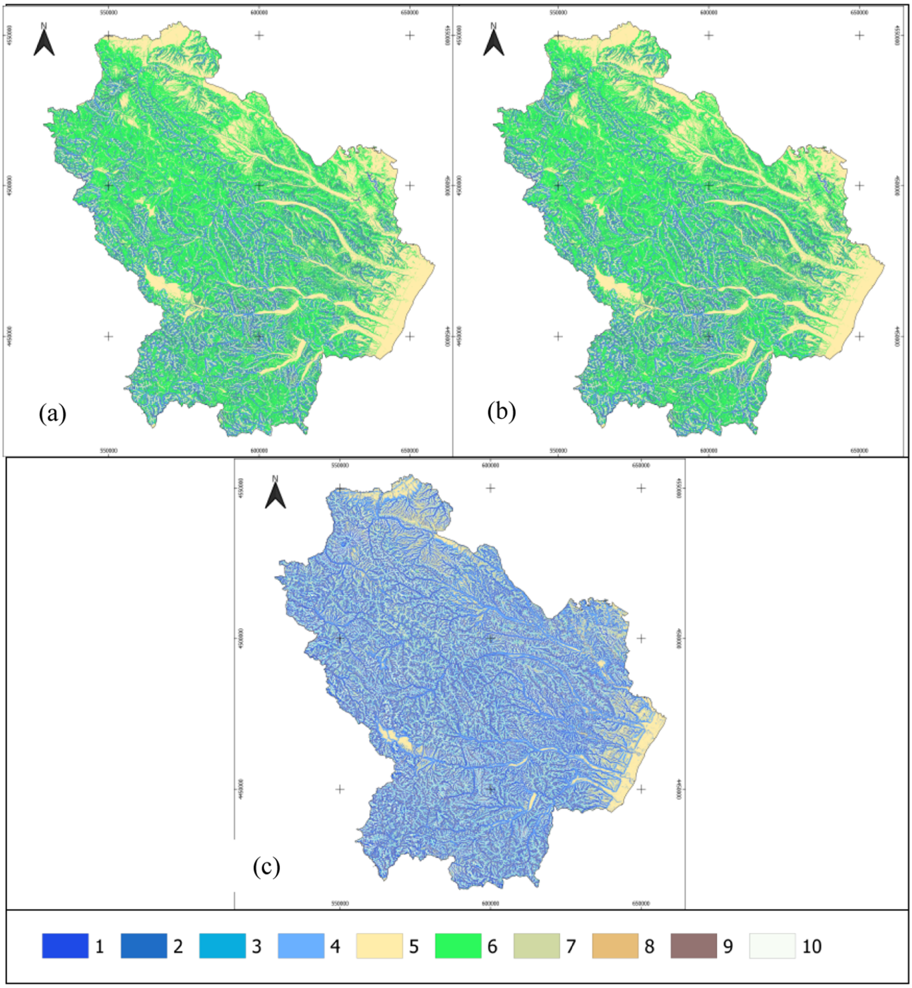

Fig. 2. Maps of semi-automated landform classification extracted from a 20 m resolution DEM and using the tools contained in the Arcview (a), in the SAGA (b), and in the Arcmap (c) GIS applications. Legend: 1) Deep narrow canyons/V-shaped river valleys, 2) Midslope drainage/Local valley in plains, 3) Upland incised drainages/headwaters, 4) U-shaped valleys, 5) Plains, 6) Open slopes, 7) Upper slopes/Flat ridge tops/Mesas, 8) Local ridge/hilltops in broad valleys, 9) Midslope ridges or lateral drainage divides/Local ridge in plains, 10) Mountain top/High ridges.

landforms means that too high TPI values were selected and, therefore, lower values of small and large neighborhoods should provide better results. Among the plain landforms, the high and low terraced surfaces are partially detected by the algorithms of all the three software. They are horizontal surfaces that in geomorphology can be assigned to altiplanes, which in some cases correspond to planation surfaces or mesas. In this sense, the algorithm detected all these high-elevated surfaces as open slopes and mesas.

It is worth noting that only small high-elevated flat surfaces are recognized by the SAGA Gis software that not approaching their real spatial distribution. Finally, a clear recognition of both the flatness surface and the inner edge of Ionian marine terraces was made by the Arcview and SAGAGis tools detecting about 5 surfaces in the area included between the Bradano and Agri rivers (Fig. 2a,b).

In the slope landforms of the category C (Table 1), both open and upper slope or mesas landforms are well-represented thus forming the most landscape of the study area. Slope landforms extracted by Arcview and SAGA Gis represent all the sectors connecting the mountain tops to the fluvial valley features, with a spatial predominance of the open slopes landforms. The upper slopes or mesas are less distributed and are mainly placed under the watersheds or ridges (Fig. 2a,b). In the Arcmap an enlargement of the fluvial valley and mountain top landforms has produced a narrowing of the slope landforms that are few represented in the map of Fig. 2c.

The higher morphostructural features (category D, Table 1) corresponding to several orders of watershed divides/mountain ridges and classified as mountain tops and high ridges by the semi-automatic extraction are quite well represented and reveal a good spatial continuity. It is the case of the ridge alignments oriented NNW-SSE and NW-SE of the central and southern sector of the Basilicata Region (Fig. 2). Conversely, lower ridges and lower watersheds are poorly discriminated because they are included in both open slopes, upper slopes, and mesas.

4.2 Landform Maps Extracted from a 5 m-Resolution DEM

The fluvial valley landforms pertaining to the class (A) extracted from the Arcview and SAGA applications show a similar distribution of the areas (Fig. 3a,b). A small difference is detectable only in the plain view distribution of upland incised drainages and U-shaped valleys landforms that reveal a shifting of the landform boundaries (numbers 3 and 4, Fig. 3, respectively). Conversely, the Arcmap application has emphasized the extraction of U-shaped valley landforms that at the edge of fluvial floodplains and the drainage network is better represented than the previous application (Fig. 3c). The radial drainage network of the Vulture volcano extracted from the Arcview and SAGA applications is clearly reproduced and differ from those of the Arcmap that is too detailed thus to mask the classical radial fluvial pattern of the volcano.

The plain surface landforms included in the class (B) and related to several flat landforms categories as above listed (Table 2) are well recognized by all the applications. The present-day coastal plain of the Ionian Arc and the staircase of marine terrace surfaces are very well extracted; moreover, the inner edge of each marine terrace also appears well outlined. The boundaries of the several hanged marine terraces due to the strong vertical incision produced by the fluvial network are less defined. Both the coastal plain and the marine terrace landforms are transversally cut by the main four eastward rivers of the Basilicata Region, which flow within wide floodplains: in this case, the best extraction is coming from the Arcmap application. The same condition has been observed in the extraction of the larger flat tops of several intermontane basins in which the boundaries of the undissected floodplain and the lower-altitude stair of fluvial terraces are well discriminated. Conversely, local and smaller flat plains of intermontane basins (see for example the fluvial terraces of the

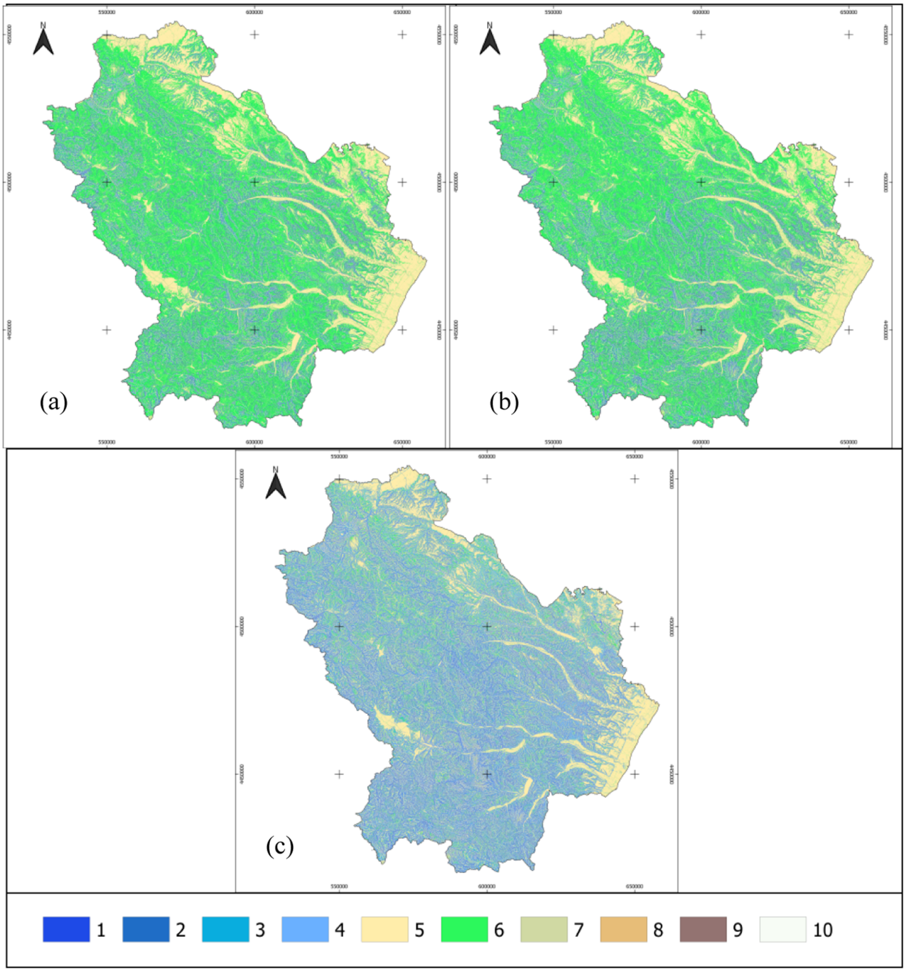

Fig. 3. Maps of semi-automated landform classification extracted from a 5 m resolution DEM and using the tools contained in the Arcview (a), in the SAGA (b), and in the Arcmap (c) GIS applications. Legend: 1) Deep narrow canyons/V-shaped river valleys, 2) Midslope drainage/Local valley in plains, 3) Upland incised drainages/headwaters, 4) U-shaped valleys, 5) Plains, 6) Open slopes, 7) Upper slopes/Flat ridge tops/Mesas, 8) Local ridge/hilltops in broad valleys, 9) Midslope ridges or lateral drainage divides/Local ridge in plains, 10) Mountain top/High ridges.

Pergola-Melandro basin located to north-west of the Agri basin) are classified as flat ridge top or mesas by the Arcmap application.

The slope landforms class (C) formed by open and upper slope or mesas landforms are not well extracted by the Arcview and SAGA applications; in fact, they classified as main landform open slope features (6 in Fig. 3a,b) but did not fully capture flat ridge top or mesas. A completely different extraction has been done by the Arcmap application, that emphasizes the mesas landforms (7 in Fig. 3c) and greatly decreases the representation for open slopes. There is a relevant mistake in the extraction of mesas landforms using the Arcmap application, corresponding to the inner and outer slopes of the terrace edges of fluvial and marine terraces. In this case, the automated extraction has failed the recognition and cannot be applied, in our opinion.

Finally, the higher features of the class (D) are very detailed in the extraction thus to provide a poor identification and delimitation of these landforms. Midslope ridges (9 in Fig. 3) are fragmented and minimized in the Arcview and SAGA extraction while they are a bit more detailed in the Arcmap application. The spatial continuity is very low and there are too many pixels corresponding to different landforms that produced an elevated background noise in the map. Finally, A peculiar feature of the semi-automated extractions is the high noise of the maps and their low degree of readability. This is common to all the three software applications and can be attributed to the high definition of the 5 m DEMs.

The percentages of landform classes obtained by the semi-automated extraction and by using the three applications have provided the differences of landform distribution in the area of Basilicata Region in both the case of 20 m resolution and 5 m resolution DEMs, respectively (Fig. 4). Fluvial valley landform of class (A) shows quite the same percentage of distribution in both the 20 m and 5 m DEMs. A first anomalous high percentage was only obtained by the Arcmap application in both the DEMs that differs from the others applications, as in the case of the deep narrow canyons/V-shaped river valleys (n. 1 in Table 1) that ranging its values from 26.4% to 13% of distribution with regard to the other frequency distributions that are less than 5% of the total values (Fig. 4). The second anomalous high percentage was obtained from the U-shaped valleys (n. 4 in Table 1) values that ranging from 22.9% to 12.7% compared to the values of the other applications that are around 5%.

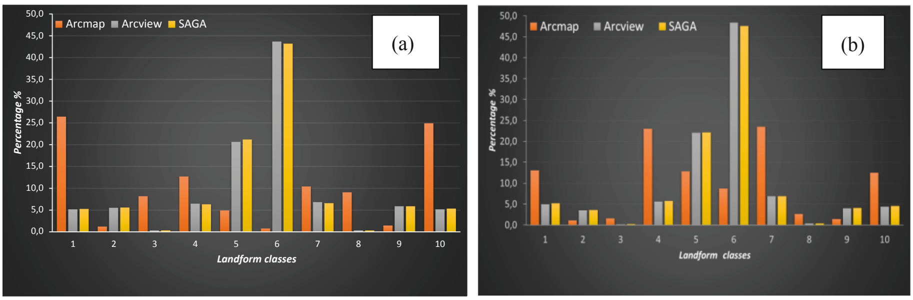

Fig. 4. Percentages of landform classes extracted from the three GIS applications and related to 20 m resolution (a) and 5 m resolution (b) DEMs. Numbers of landform classes are referred to the list of Table 1.

Conversely, in the slope landforms class (C) the percentage values of extracted landform by the Arcmap application is low regarding those obtained from the Arcview and SAGA applications, as reported in the Open slopes (n. 6 in Table 1) reaching a value ranging from 8.7% to 0.8% (Fig. 4). The Upper slopes, flat ridge tops, and mesas landforms (n. 7 in Table 1) show high percentage values in Arcmap suggesting an anomalously high detection and classification of these features by the algorithm. In the final landform class (D) including all the higher-altitude morphological features of the Region the only difference among the three applications and the two DEMs is represented by the Mountain top and High ridges (n. 10 in Table 1). Here, the Arcmap application has detected high percentage values of this landform if compared to other applications, ranging from 24.9% to 12.5% (Fig. 4).

We can conclude that there is a low difference in percentage values between the semi-automated landforms classification obtained by the Arcview and SAGA GIS applications and the only discrepancy is those of the Arcmap. This difference can be observed in both the two 20 m and 5 m resolution DEMs.

4.3 Conclusions

The application of the TPI index, aimed at the semi-automated extraction and classification of landforms in the Basilicata Region, has been carried out. The landform extraction was realized by using three different tools running on the Arcview, Arcmap, and the SAGA GIS software. The study area was selected considering its high variety of outcropping rocks producing a complex landscape and many types of landforms varying from coastal plains to high mountain shapes reaching over 2000 m of altitude. Three landform maps have been extracted from the GIS applications and the same procedure has been applied to 20 m and 5 m resolution DEMs thus to obtain six landform maps. The comparison among the different maps allowed to discuss the best map representation, that is discriminate what map has produced the better and representative landforms. The comparison among the three landform maps classification, extracted from the 20 m grid DEM, showed a general well distribution of fluvial valley (A), plain (B), slope (C), and (D) landforms. These landform categories (see Table 1) are very well extracted by the Arcview and SAGA applications, whilst a less quality representation was furnished by the Arcmap application. The different extraction probably attributed to the radii value will be investigated with more detail in future. The three maps extracted from the 5 m grid DEM showed a better representation of landforms from the Arcmap application, particularly those related to the Ionian coastal plain, with regards to the others. In conclusion, the 20 m DEM furnished the better results using the Arcview and SAGA application, whilst the 5 m DEM shows the good landform extraction by using the Arcmap application.

References

1. Tagil, S., Jenness, J.: GIS-based automated landform classification and topographic, landcover and geologic attributes of landforms around the Yazoren Polje. Turkey. J. Appl. Sci. **8**(6), 910–921 (2008)
2. Horton, R.E.: Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. GSA Bull. **56**(3), 275–370 (1945)

3. Strahler, A.N.: Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union **38**, 913–920 (1957)
4. Hammond, E.H.: Analysis of properties in land form geography: an application to broad-scale land form mapping. Ann Assoc. Am. Geograph. **54**(1), 11–19 (1964)
5. Pike, R.J.: A bibliography of geomorphometry, the quantitative representation of topography; supplement 3.0, Report pp. 99–140 (1999)
6. Evans, I.S., D.U.D.o. Geography: General Geomorphometry, Derivatives of Altitude, and Descriptive Statistics. Defense Technical Information Center, Ft. Belvoir (1972)
7. Weiss, A.: Topographic position and landforms analysis. Poster Presentation. In: ESRI User Conference, San Diego, CA, (2001)
8. Jenness, J.: Topographic Position Index (tpi_jen.avx) extension for ArcView 3.x, Jenness Enterprises (2006). http://www.jennessent.com/arcview/tpi.htm
9. De Reu, J., Bourgeois, J., Bats, M., et al.: Application of the topographic position index to heterogeneous landscapes. Geomorphology **186**, 39–49 (2013)
10. Seif, A.: Using topography position index for landform classification (Case study: Grain Mountain). Bull. Environ. Pharmacol. Life Sci. **3**(11), 33–39 (2015)
11. Gioia, D., Bavusi, M., Di Leo, P., et al.: A geoarchaeological study of the Metaponto coastal belt, southern Italy, based on geomorphological mapping and GIS-supported classification of landforms. Geografia Fisica e Dinamica Quaternaria **39**, 137–148 (2016)
12. Athanasios, S., Anagnostopoulou, O.: Landform Analysis Using Terrain Attributes. A GIS Application on the Island of Ikaria (Aegean Sea, Greece). Ann. Valahia Univ. Targoviste Geograph. Ser. **17**(1), 90–97 (2017)
13. Giano, S.I., Giannandrea, P.: Late Pleistocene differential uplift inferred from the analysis of fluvial terraces (southern Apennines, Italy). Geomorphology **217**, 89–105 (2014)
14. Zwoliński, Z., Stefańska, E.: Relevance of moving window size in landform classification by TPI, Geomorphometry for Geosciences. In: Jasiewicz, J., Zwoliński, Zb., Mitasova, H., Hengl, T. (eds.) Adam Mickiewicz University in Poznań - Institute of Geoecology and Geoinformation, International Society for Geomorphometry, Poznań (2015)
15. Pescatore, T., Renda, P., Schiattarella, M., et al.: Stratigraphic and structural relationships between Meso-Cenozoic Lagonegro basin and coeval carbonate platforms in southern Apennines, Italy. Tectonophysics **315**(1–4), 269–286 (1999)
16. Patacca, E., Scandone, P.: Geology of the Southern Apennines. Bollettino della Societa Geologica Italiana, Supplemento **7**, 75–119 (2007)
17. Di Leo, P., Giano, S.I., Gioia, D., Mattei, M., Pescatore, E., Schiattarella, M.: Evoluzione morfotettonica quaternaria del bacino intermontano di Sanza (Appennino meridionale). Alp. Meditarranean Quat. (Il Quaternario) **22**(2), 189–206 (2009)
18. Giano, S.I., Gioia, D., Schiattarella, M.: Morphotectonic evolution of connected intermontane basins from the southern Apennines, Italy: the legacy of the pre-existing structurally controlled landscape. Rendiconti Lincei **25**(2), 241–252 (2014)
19. Giano, S.I., Schiattarella, M.: Age constraints and denudation rate of a multistage fault line scarp: an example from Southern Italy. Geochronometria **41**(3), 245–255 (2014)
20. Giano, S.I., Pescatore, E., Agosta, F., et al.: Geomorphic evidence of quaternary tectonics within an underlap fault zone of southern Apennines, Italy. Geomorphology **303**, 172–190 (2018)
21. Bavusi, M., Chianese, D., Giano, S.I., et al.: Multidisciplinary investigations on the Roman aqueduct of Grumentum (Basilicata, Southern Italy). Ann. Geophys. **47**(6), 1791–1801 (2004)
22. Giano, S.I., Lapenna, V., Piscitelli, S., et al.: New geological and geophysical data on the structural pattern of the quaternary slope deposits in the Agri high valley, southern Apennines. Alpine Mediterranean Quaternary **10**(2), 589–594 (1997)

23. Aucelli, P.P.C., D'Argenio, B., Della Seta, M., et al.: Intermontane basins: quaternary morphoevolution of Central-Southern Italy. Rendiconti Lincei **25**(2), 107–110 (2014)
24. Giano, S.: Quaternary alluvial fan systems of the agri intermontane basin (southern Italy): tectonic and climatic controls. Geol. Carpath. **62**(1), 65–76 (2011)
25. Bentivenga, M., Coltorti, M., Prosser, G., et al.: A new interpretation of terraces in the Taranto Gulf: the role of extensional faulting. Geomorphology **60**(3), 383–402 (2004)
26. Bentivenga, M., Coltorti, M., Prosser, G., et al.: Recent extensional faulting in the Gulf of Taranto area: Implications for nuclear waste storage in the vicinity of Scanzano Ionico (Basilicata). Bollettino della Societa Geologica Italiana **123**(3), 391–404 (2004)
27. Piedilato, S., Prosser, G.: Thrust sequences and evolution of the external sector of a fold and thrust belt: an example from the Southern Apennines (Italy). J. Geodyn. **39**(4), 386–402 (2005)
28. Conrad, O.: SAGA-GIS Tool Library Documentation (v4.0.1), Tool Topographic Position Index (TPI) (2011). http://www.saga-gis.org/saga_tool_doc/4.0.1/ta_morphometry_18.html. LNCS
29. Guisan, A., Weiss, S.B., Weiss, A.D.: GLM versus CCA spatial modeling of plant species distribution. Plant Ecol. **143**(1), 107–122 (1999)
30. Beneduce, P., Festa, V., Francioso, R., et al.: Conflicting drainage patterns in the Matera Horst Area, southern Italy. Phys. Chem. Earth **29**(10), 717–724 (2004)